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SCIENTIFIC OPINION

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Welfare of beef cattle

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The declarations of interest of all scientific experts active in EFSA's work are available at https://open.efsa.europa.eu/experts

Abstract

This Scientific Opinion provides an assessment of beef cattle welfare focusing on risks related to flooring, water access, nutrition and feeding, high environmental temperatures, lack of environmental enrichment, lack of outdoor access, minimum space allowance and mixing practices. In addition, risks related to pasture and feedlots, weaning of suckler calves, mutilations (castration, disbudding, dehorning and tail docking), and to breeding practices (hypermuscularity, dystocia and caesarean sections, polledness, maternal ability and temperament) are assessed. Decision-making criteria for the euthanasia of cull cows are also addressed. A selection of animal-based measures (ABMs) suitable for collection at slaughterhouses is proposed to monitor on-farm welfare of fattening cattle. Recommendations to improve the welfare of housed fattening cattle include increasing space allowance and feeding more roughage in relation to current practice, and promoting the use of well-managed bedded solid floors. Provision of enrichment such as brushes and roughage and an outdoor loafing area for housed cattle are recommended. Cattle kept outdoors should have access to a dry lying area and sufficient shade. Water should be provided *ad libitum* via large open water surfaces, and the use of nipple drinkers should be avoided. Mixing of unfamiliar cattle should be avoided and groups should be kept stable. Mutilations should be abstained from, but if carried out, a combination of analgesia and anaesthesia should be applied regardless of the calf's age. Early weaning of suckler calves should be avoided (< 6 months). Homozygous double-muscled animals should be excluded from breeding. Selected ABMs for collection at slaughterhouses to monitor some of the highly relevant welfare consequences experienced by fattening cattle on farm are body condition, carcass fat levels, carcass condemnation, lung lesions and skin lesions. Key data gaps identified are thresholds for dietary fibre, ABM thresholds for fitness for transport and potential long-term effects of mutilations on pain sensitisation.

KEYWORDS

animal-based measures, beef cattle, indoor, mutilations, welfare

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SUMMARY

Background and European Commission's request

The European Commission (EC) requested the European Food Safety Authority (EFSA) to provide a scientific opinion on the welfare of beef cattle (including fattening cattle, suckler cows, heifers and calves, breeding bulls, and 'end of career' (cull) dairy and suckler cows), reflecting the most recent scientific knowledge on the topic. The first Term of Reference (ToR) requested a description of the most common husbandry systems and current practices for keeping beef cattle in the European Union (EU). This ToR was addressed in a separate publication, 'Technical report on the most common husbandry systems and practices for keeping beef cattle' (EFSA, 2025).

The second ToR requested (a) a welfare assessment of housing conditions for beef cattle in relation to flooring, minimum space allowance, water access, nutrition and feeding, high environmental temperatures, lack of environmental enrichment, and lack of outdoor access, (b) a welfare assessment of fattening cattle kept at grass considering outwintering, nutrition and feeding, and water access, (c) an assessment of the risk to the welfare of suckler cows and calves associated with the weaning of suckler calves, (d) the risk to welfare associated with the mutilation of cattle including castration, disbudding, dehorning, and tail docking, (e) the risk to welfare associated with breeding strategies and genetics in relation to hypermuscularity, dystocia and caesarean sections, polledness, maternal ability, and temperament, and (f) decision-making criteria for the euthanasia of cull dairy and suckler cows being kept for the production of beef. Finally, the third ToR requested an assessment of Animal-based measures (ABMs) collected in slaughterhouses to monitor the level of welfare on farm for fattening cattle.

Data and methodologies

The assessment was based primarily on peer-reviewed scientific literature, complemented by expert opinion and information gathered through an EFSA Public call for evidence, which ran from December 2023 to January 2024.

For clarity and conciseness, all welfare consequences deemed highly relevant based on expert opinion are hereafter in this Section referred to simply as 'welfare consequences' (WCs).

Assessment

Water access

Water is provided to housed beef cattle using water troughs, water bowls or nipple drinkers.

The WCs of restricted access to water are prolonged thirst, heat stress and group stress due to competition for access to water. Drinking water free from faecal and microbial contamination must be available at all times. Therefore, daily inspection, regular cleaning of water facilities and periodic microbial and physico-chemical analyses of water are necessary.

From a welfare point of view, large volume troughs allowing a drinking rate of up to 15–20 L/min are the preferred drinker system. Nipple drinkers restrict natural drinking behaviour and should be avoided. Water troughs are preferred to bowls, with a minimum of 6 cm of trough space per animal. However, if water bowls are used, at least one water bowl should be provided for each 10 animals. Each group of animals should have two drinkers to prevent thirst in case of drinker malfunctioning or dirtiness.

Flooring

The most common flooring systems for beef cattle are bare concrete slatted floors (CSFs), concrete slatted floors overlaid with rubber mats (RMs) and, less commonly, solid floors bedded with straw. The WCs of hard flooring are resting problems, restriction of movement, soft tissue lesions and integument damage, locomotory disorders (including lameness) and respiratory disorders. In particular CSFs increase the risk of resting problems, lameness, skin lesions, slipping and injury. Overlaying CSFs with RMs mitigates the risk of restriction of movement due to slippery floors, and improves traction and the resting of beef cattle. However, the risk of resting problems and lameness is still higher in CSFs overlaid with RMs than on bedded solid floors, and CSFs do not provide as comfortable a lying area as straw bedded solid floors. For this reason, where possible, bedded solid floors should be provided in the lying area in preference to CSFs or RMs.

Nutrition and feeding

Under intensive rearing conditions, diets for fattening beef cattle have a high-concentrate content to promote maximum daily gain. Excess of dietary concentrate and insufficient structured fibre can lead to subacute rumen acidosis (SARA), which is the most prevalent metabolic and gastro-enteric disorder in beef cattle. The main recommendation to prevent or reduce SARA is to feed less concentrate and more structured fibre. This will also reduce locomotory disorders associated with SARA and abnormal oral behaviour. However, to date, there is insufficient scientific evidence to establish thresholds for concentrates and roughage in fattening cattle diets to prevent these welfare consequences. When feed additives are used to reduce SARA, mineral buffers should be preferred over yeast products and phytogenic compounds, however, it

should be noted that they have just a modulatory effect on the fermentation process, and they cannot compensate for a suboptimal feeding management. A further recommendation is to ensure a gradual transition from forage-based diets to the more concentrate-based fattening diet in the first 4 weeks after arrival at the fattening farm to prevent digestive disorders. Additionally, when providing *ad libitum* feeding, it is recommended to give enough space at the manger to allow simultaneous access to feed to all the group mates. Feed contaminated with mould or mycotoxins should be excluded from beef cattle rations to prevent immune suppression and secondary locomotory disorders.

Lack of outdoor access

Most beef cattle are fattened under intensive conditions in closed or partially open barns without outdoor access for the entire fattening period. When outdoor access is provided, it can be an outdoor loafing area with free passage between indoor and outdoor areas, or access to pastures of different sizes and qualities and for different times of the year and day.

Lack of outdoor access can result in WCs including restriction of movement and inability to perform play behaviour, sensory understimulation, group stress and inability to avoid unwanted sexual behaviour, inability to perform exploratory or foraging behaviour and heat stress. The extent of restriction of movement depends on the indoor conditions. However, freely accessible outdoor areas adjacent to indoor systems with well-managed underfoot conditions provide enlarged space and opportunities for locomotion-related behaviours such as play behaviour. Outdoor conditions provide more environmental complexity and changing sensory stimulation (e.g. sunlight, wind, rain or olfactory stimuli) than indoor conditions. Although research on beef cattle is limited, available evidence suggests that providing free choice between environmental conditions can reduce the risk of sensory under-stimulation and associated negative affective states.

Freely and easily accessible outdoor area adjacent to the barn furthermore allow lower ranking individuals to withdraw and avoid unwanted interactions with dominant individuals or unwanted sexual behaviour, thereby helping to reduce group stress. Outdoor access that includes pasture promotes exploration and foraging behaviour. A shaded outdoor loafing area adjacent to a barn provides the opportunity to move outside if it is hot or humid inside the housing, mitigating heat stress.

Lack of environmental enrichment

The extent and diversity of enrichment structures and resources that facilitate the expression of highly motivated species-specific behaviour vary in beef cattle husbandry, from little or none in barren housing with monotonous feed conditions of intensively kept beef cattle, to great in extensive pasture systems with high forage diversity. Environmental enrichment is less common in beef cattle than in dairy cattle.

The lack of stimulation and opportunities to perform a wide repertoire of natural behaviours leads to several WCs such as inability to perform exploratory or foraging behaviour with reduced chewing and/or ruminating, inability to perform comfort behaviour, sensory under-stimulation and inability to perform play behaviour. Due to the close relationship between environmental enrichment and nutrition and feeding in cattle, the lack of edible enrichment can also be related to metabolic disorders. Furthermore, sensory understimulation may promote group stress and the inability to avoid unwanted sexual behaviour, although these associations are not well investigated. Environmental enrichment in general reduces sensory understimulation and leads to increased activity.

Environmental enrichment can be provided in the form of (i) manipulable material that can be ingested, e.g. roughage or salt blocks, (ii) inedible material for exploration, including olfactory exploration and manipulation, (iii) equipment allowing comfort behaviour, i.e. brushes or rubbing objects and (iv) pasture access for cattle housed indoors. The simultaneous provision of different enrichments that promote different behaviours will likely have a greater overall effect than single enrichments, but to date this has not been addressed in research. If inedible material is used for enrichment, it should be changed frequently to provide a sufficient degree of novelty. Further research is needed on welfare effects of free-choice feeding in intensive systems, as well as on minimum numbers of enrichment devices in relation to the number of animals in order to limit social competition for these resources.

Mixing of cattle

Mixing cattle to form uniform groups based on criteria such as age, weight, sex or health status is a widely adopted practice in beef cattle herd management. However, this process can disrupt the established social hierarchy within a group, leading to a number of WCs during the re-establishment period. Mixing of cattle leads to increased group stress involving agonistic interactions and unwanted sexual behaviour, less group cohesiveness, separation stress, disturbance of lying behaviour, disruption of feeding and drinking behaviour due to impaired access to resources particularly for subordinate individuals and handling stress. Severe agonistic interactions increase the risk of soft tissue injuries and integument damage, and sometimes bone lesions. Mixing may also result in respiratory disorders due to the mixing of different microbiomes and the higher disease susceptibility caused by stress.

Groups of fattening cattle should remain stable as much as possible and mixing should be avoided. The WCs related to mixing are reduced when mixing occurs at a young age, involves previously acquainted animals, includes at least two familiar individuals, or when animals have prior mixing experience. In addition, increasing space allowance, providing additional feeders and ensuring adequate access to feed and water during the initial mixing period can help mitigate the WCs of mixing. There is currently no evidence that weight-homogeneous groups offer welfare benefits.

High environmental temperatures

The experience of heat stress in cattle is influenced by external factors such as ambient temperature, relative humidity (RH), thermal and solar radiation, presence of ventilation systems, drinking water temperature and barn characteristics, as well as internal factors such as cattle genotype, coat colour and type, body size and condition, health status and degree of adaptation. Heat stress is likely to start when temperatures exceed the upper boundary of the thermal comfort zone (TCZ) but there are no precise estimates of such threshold for cattle. The risk of heat stress increases when temperatures reach the upper critical temperature (UCT) threshold (~ 24–26°C).

Short-term actions to mitigate the effects of heat stress include *ad libitum* water provision, use of fans and sprinklers, and diet management. If possible, cattle should be progressively (within 2–7 weeks) exposed to heat so acclimatisation takes place. Handling stress should be minimised by reducing handling frequency and applying gentle handling techniques. Long term strategies include design and constructions of barns optimised to minimise indoor heat load.

Minimum space allowance

Current practices for space allowances in commercial beef farms vary depending on the EU Member State (MS) and tend to range from 2.4 to 5.5 m^2 per animal in bedded pens and from 1.8 to 3.2 m^2 per animal in slatted pens. The WCs of restricted space allowances are resting problems, restriction of movement, group stress, soft tissue lesions and integument damage, bone lesions (including fractures and dislocations), locomotory disorders (including lameness), inability to perform exploratory or foraging behaviour and inability to perform play behaviour. Providing larger space allowances will increase lying time and allow animals to keep larger inter-individual distances, as well as provide more opportunities for movement and general activity. However, there is a need for more research on the effects of space allowance > 6 m^2/animal on beef cattle behaviour and welfare.

Based on results from the literature, it was estimated that providing 60 cm of feed trough length per animal is sufficient when animals are fed *ad libitum* irrespective of animal weight. Based on allometric calculations, it was estimated that animals of 400 and 700 kg need 1.14 and 1.66 m^2, respectively, to stand while feeding.

Estimates for lying area requirements assumed that lying space should allow synchronicity of lying behaviour, and that group stress will be reduced if animals can keep a certain inter-individual distance. Based on expert judgement, it was estimated that beef cattle over 400 kg kept in groups of 8–20 animals are motivated to keep an average inter-individual distance of ~5 m when lying (90% certainty interval: 2–10 m). For groups of eight, this corresponds to a lying area of ~11 m^2/animal (90% certainty interval: 3–48 m^2). Including space for standing and feeding, the estimated total indoor space allowance is ~13 m^2/animal (90% certainty interval: 5–50 m^2).

Regardless of type of flooring, it is recommended that space allowance per animal be increased in relation to current practice to reduce resting problems, restriction of movement, group stress and locomotory disorders (including lameness).

Risks associated with keeping fattening cattle outside

Cattle kept at pasture

Grass-based husbandry systems involve keeping cattle at pasture from spring to autumn, and some cattle will also be kept at pasture over winter.

Cattle at pasture can experience WCs including prolonged hunger, gastro-enteric disorders, prolonged thirst, heat stress, group stress, handling stress, predation stress, metabolic disorders and sensory under- and/or overstimulation. For cattle at pasture, health and welfare planning should include nutritional schemes and ensure that the risk of problems associated with mineral deficiencies, toxicities and metabolic or parasitic disease is minimised. Grazing cattle should be provided with readily available clean, palatable water at all times, but particular attention should be paid when cattle are at risk of heat stress. In addition, at times of high risk of heat stress, cattle at grass should have easy access to shade and additional exertional stressors such as handling should be avoided.

Also for cattle kept at grass it is relevant to habituate them to humans, and calm, effective handling methods should be employed to minimise stress. Methods to reduce the risk of predation of cattle at pasture should be employed according to local experience of successful initiatives, for example guardian livestock dogs, temporary fencing or including cattle that behave defensively towards predators within the herd. All cattle at pasture should be provided with natural or artificial grooming opportunities, such as trees or brushes.

Outwintered cattle can experience WCs including cold stress, resting problems and inability to perform comfort behaviour. For adult cattle in inclement weather, cold stress may occur at temperatures below 0°C, but in still, dry conditions, cold stress will likely not occur until temperatures are lower. Cattle will use shelters to prevent cold stress and appear to prefer natural over artificial shelters when available. Outwintered beef cattle should always have access to a dry lying area, and shelter from wind and rain (natural shelter, such as trees, is preferred) and ready access to food (e.g. supplementary feed) and water. It should be ensured that fat coverage, coat length and degree of acclimatisation are kept at a level that minimises the risk of cold stress in outwintered beef cattle. The obligation to regularly monitor cattle for signs of illness or other welfare risks should also apply to cattle at pasture, even if outwintered or extensively kept.

Cattle kept in outdoor feedlots

Feedlots are outdoor confinement facilities designed to keep large numbers of animals. Feedlots have compacted soil flooring and basic infrastructure, typically consisting of water and feed troughs sometimes covered by a roof.

The conclusions and recommendations described for housed cattle related to water access, nutrition and feeding, high temperatures, enrichment and mixing are also applicable to feedlot cattle. When there is a risk of heat stress, feedlot cattle should have access to well-aerated, effective shade large enough to accommodate all animals simultaneously. Handling should be kept to a minimum when there is risk of heat stress. High temperatures can also increase dust levels and the risk of respiratory disorders. Dust exposure can be reduced by harrowing and moistening the soil using sprinklers or water trucks, with a target moisture content of 25%–30%.

Mud in outdoor feedlot pens is associated with restriction of movement, resting problems or inability to perform sexual or play behaviours. Additionally, muddy pens increase the risk of lameness. Exposure to mud can be reduced by building a mound, installing drainage systems, providing bedding material, harrowing the soil surface and ensuring a slope to naturally remove excess water from the enclosure.

Risks related to weaning of suckler calves

Natural weaning is a gradual process that occurs when calves are between 7 and 14 months old. In European suckler herds, weaning commonly takes place more or less abruptly between 5 and 11 months of age in order to maintain high productivity and an adequate body condition of the suckler cows. The WCs resulting from weaning are separation stress, handling stress, group stress if weaning and separation are combined with regrouping, as well as inability to express maternal behaviour in cows and inability to perform sucking behaviour and prolonged hunger in calves. In weaned calves, these are expressed by increased vocalisation, pacing and seeking, along with reduced feeding and lying.

While abrupt weaning remains the most common approach, gradual weaning and two-step weaning strategies using nose flaps and fence-line separation offer potential benefits in reducing behavioural and physiological stress responses in both cows and calves. To improve calf welfare, weaning should be delayed as long as the body condition of the cow allows, ideally taking place once calves are ingesting solid feed that can cover their nutritional requirements and are familiar with post-weaning feeds. Calves weaned at an older age are generally better equipped to handle nutritional and social transitions and tend to exhibit fewer stress signs compared to early weaning (e.g. before 90 days). In general, weaning before 6 months should be avoided. Regardless of age, two-stage weaning is preferred over abrupt weaning, but the effects of nose flaps on nasal lesions should be monitored and non-harmful flap models should be explored. Recommended strategies to reduce stress around weaning are creep weaning, habituation to human presence, gentle handling and keeping calves with familiar calves and in a similar environment. However, certain welfare impacts – such as the disruption of maternal and sucking behaviours and restricted nursing opportunities – cannot be fully eliminated.

Risks associated with mutilations

Castration

Castration of bulls can be performed using various methods, including surgical castration, rubber ring or band castration, and Burdizzo castration, all of which involve tissue damage and cause pain. The WCs associated with these methods include soft tissue lesions and integument damage, handling stress, resting problems, restriction of movement and separation stress. Immunocastration, which does not involve removal of testicles, and prevents pain resulting from integument damage or soft tissue lesions, is currently not approved in the EU for cattle, but if available would prevent most WCs of castration.

In general, the need for castration should be assessed, and if possible, castration should be avoided. Band castration and rubber ring castration should be avoided due to longer healing times.

While it is often assumed that young calves experience less pain than older animals during castration, available data on physiological and behavioural measures do not conclusively demonstrate age-related differences in pain perception. However, conducting castration at an early age (between 1 and 8 weeks) is recommended due to smaller wound size and faster healing. Due to limited data on castration in calves under 1 week of age, no specific recommendations can be provided for this age group.

Calves should not be castrated without pain mitigation. Combining local anaesthesia with non-steroidal anti-inflammatory drugs (NSAIDs) is more effective in reducing pain than using a single agent, but no combination of pain mitigation drugs is likely to be fully effective, particularly under field conditions.

Furthermore, best practices on pain mitigation include to consider the time for the medication to take effect when planning the castration procedures, and workflow being optimised in order to reduce handling and restraint times. Pain mitigation should be properly applied and continued as long as pain is likely to be experienced. Standardised protocols for the use of efficient local anaesthesia and analgesia should be promoted, and facilities should be adapted to minimise handling stress and pain. Castration should be performed by a veterinary surgeon or trained operator who can recognise signs of pain and complications.

Disbudding and dehorning

Disbudding is a common practice in beef cattle and consists of the destruction or removal of the free-floating horn buds in the skin above the skull of calves. In contrast, dehorning – the surgical removal of grown horns in calves over 2 months of age and in adult cattle – is a less frequent practice and routine dehorning is banned in some EU MSs. Both techniques aim to reduce animal injuries and damage to hides, reduce damage to facilities, ease cattle handling and promote human safety. Disbudding and dehorning lead to WCs like soft tissue lesions and integument damage, bone lesions (including fractures and dislocations), handling stress, eye disorders, separation stress and inability to perform sucking behaviour. Regardless of the method, both disbudding and dehorning are painful practices.

If possible, disbudding and dehorning should be avoided. The need for disbudding should be prevented by adapting housing, handling practices and transport conditions for horned animals or by rearing genetically hornless (polled) cattle. Dehorning should not be conducted unless justified by veterinary indication on an individual animal. When carried out, standardised protocols should be promoted that include the mandatory use of efficient local anaesthesia and analgesia, considering the time of the medication to take effect when planning the procedures.

Surgical disbudding and caustic paste disbudding should be avoided. Guidelines on the correct use of the numerous different brands of disbudding irons on the market should be made available and followed due to their impact on induced pain and ease of healing. Disbudding a few days after birth (e.g. at 3 days of age) should also be avoided because of the potential increase of long-term pain sensitivity, although more research should be carried out on this issue. For any method of horn removal, and particularly for extensively raised cattle, a safe and low-stress restraint should be applied to alleviate handling stress and improve the safety of the personnel.

Sedation prior to mutilations should be carried out when calves are unused to handling, but further research should be carried out on possible negative welfare effects of sedation.

Tail docking

Tail docking, i.e. the removal of part of the tail, is a rare practice which aims to reduce tail injuries and tail tip necrosis that may arise from constrained housing and inappropriate floor conditions; the practice has been banned in almost all EU MSs. If carried out, surgical removal of the tendinous part of the tail tip is currently the most common method, but other methods exist such as hot docking and elastic banding. The WCs related to tail docking are handling stress, soft tissue lesions and integument damage, and resting problems.

Tail docking is a painful procedure that increases restlessness (e.g. head movements directed towards the tail, increased number of standing bouts) with more pronounced effects following banding compared to hot-iron docking. Tail-tip injuries and necrosis can be mitigated by management measures such as adequate space allowance and floor conditions. Therefore, tail docking should not be carried out routinely and the need for tail docking can and should be prevented by the provision of sufficient space and appropriate floor conditions.

Risks associated with breeding practices

Hypermuscularity

Hypermuscularity in beef cattle results from mutations in the myostatin gene which induce increased numbers of muscle fibres (hyperplasia) and lead to substantially higher meat yields and leaner mass. The double-muscled (DM) phenotype is expressed when animals are homozygous for the mutated allele(s). Breeds commonly known for double-muscling are Belgian Blue, Piedmontese, Marchigiana and Asturiana de los Valles. In much of the Belgian Blue and Piedmontese populations, the mutated alleles have reached fixation, meaning that almost all animals exhibit the mutated allele in homozygosity.

The WCs of double-muscling include reproductive disorders (e.g. dystocia due to a mismatch between calf size and the pelvic conformation of dams, increasing perinatal mortality), handling stress (e.g. in the course of caesarean sections, assisted births, subsequent delayed colostrum intake and onset of maternal behaviours), heat stress (mismatch between heat production and heat dissipation possibilities), respiratory disorders, locomotory disorders (including lameness) and bone lesions (e.g. due to increased load together with reduced bone mass), muscle disorders (e.g. white muscle disease) and metabolic disorders (e.g. reduced feed intake capacity, higher risk of mineral deficiencies). In addition, DM animals may also show an increased risk of fatigue and increased stress susceptibility.

For welfare reasons, homozygous double-muscled animals should not be used, and heterozygous hypermuscular genotypes that show intermediate phenotypes should be preferred. Breeding bulls not carrying the myostatin gene mutations responsible for double-muscling should be used. Selection strategies should also include traits for improved anatomical features, e.g. pelvic conformation for calving ease. The implications of low calf weight as part of the 'birthing ease' trait are unknown.

Dystocia and caesarean sections (C-sections)

Dystocia, or difficult calving, may have serious consequences on cow welfare (e.g. soft tissue lesions and integument damage, handling stress, prolonged hunger, prolonged thirst, muscle disorders and reproductive disorders) and calf welfare (e.g. increased mortality, gastro-enteric disorders, respiratory disorders). Planned C-section can be used to avoid dystocia in DM animals but it has other negative WCs for cows.

The incidence of dystocia and C-sections varies across beef cattle breeds. In hypermuscular DM cattle, dystocia is primarily due to the larger birth weight and muscular hypertrophy of the calves, which exceed the pelvic capacity of the dam. Furthermore, skeletal underdevelopment of hypermuscular DM dams relative to the muscle mass may complicate calf passage through the birth canal. To minimise the risk of dystocia, elective C-sections are highly prevalent in DM cows (in ~90% of calvings in DM Belgian Blue cows) but, inferring from literature available on humans, repeated C-sections increase the likelihood of health-related issues such as bleeding, infection, adhesions, problems to the bowel and udder. As dystocia and hypermuscularity are associated in DM breeds, measures to mitigate the general WCs of hypermuscularity can also help reduce dystocia risk and need for (planned) C-sections. Breeding could also be used to reduce dystocia risk in non-hypermuscular beef cattle breeds by selecting for calving and birthing ease, reduced stillbirths and pelvic conformation traits. However, heritability for calving ease and birthing ease is generally low to moderate. Estimation of breeding values in beef cattle sires and dams should be improved by identifying candidate genes and markers associated with calving ease and dam pelvis morphology.

Polledness

Soft tissue lesions and integument damage resulting from disbudding and dehorning can further be mitigated through introgression of polledness in horned cattle breeds. In some breeds, introgression of the polled variant has already been achieved with a rather high frequency, whereas in other breeds introgression is limited due to low allele frequency or cultural preference for horns as a breed-specific trait. Since polledness is a dominant trait, intensive selection for polledness can lead to the complete loss of the horn trait.

When deciding between polled and horned cattle, it is recommended to consider the functional role of horns (e.g. establishing and maintaining stable social dominance relationships, self-grooming, defence against predators, thermal regulation). The choice between polled or horned beef cattle should depend on the specific housing and management conditions. In environments with low group stress and low number of physical agonistic interactions and related injuries, it is less indicated to keep or select for polled cattle. If hornless cattle are to be kept, selection for genetic polledness is to be preferred to disbudding/dehorning to avoid pain and stress. However, selecting for polled cattle could reduce genetic diversity and may negatively affect traits like disease resistance and other welfare-related traits. Further research on these risks is recommended.

Maternal ability

Maternal ability is a multifaceted trait that includes temperament, calving ease, maternal behaviours, ability to produce milk and maternal reproductive efficiency. Thus, it is a complex trait influenced by dam genetics but also by other factors, such as age, experience, parity, management practices and other external factors influencing the dam's and calf's general body condition and health. Maternal ability includes several traits with variable heritability, and selection is challenging in case of traits with low heritability. Moreover, while traits like calving ease and calf weaning weight are easily measurable, maternal behaviours are less feasible to record. Therefore, they are currently not incorporated in commercial selection schemes. Although udder and teat morphology are moderately heritable traits associated with calf survival and growth rates, they have not been included in beef cattle selection schemes yet. Genomic selection may help to make selection schemes for maternal ability in beef cattle more efficient. In suckler cows, temperament is closely associated with maternal ability.

Temperament

In beef cattle, temperament can be defined as the animals' consistent behavioural and emotional responses to various stimuli and can be assessed from an early age.

Cattle temperament plays a role in animals' responses to handling and human interventions during routine procedures, but especially in stressful situations. Cattle that are highly excitable, fearful or aggressive in response to human interventions or social interactions are more likely to express fear reactions that can lead to injuries. In contrast, animals that are more docile or calm are likely to exhibit fewer stress responses and remain more cooperative during human interventions.

Current breeding practices for improving beef cattle temperament include the assessment of the candidate sires with behavioural tests, but assessment methods vary widely and partly rely on subjective definitions. The genetic basis of temperament is complex, involving multiple genes and gene–environment interactions. Although heritability estimates for temperament are typically low to moderate, identification of genes and genomic regions could be useful for enhancing selection for docile and calm temperament in beef cattle. In addition to the assessment of sires, it is recommended to assess the daughters of the sire candidates to consider the link between temperament and maternal ability. Behavioural tests used in selection programmes to assess temperament should be harmonised.

Decision-making criteria for cull cows to be kept for fattening

Culling decisions in suckler and dairy cows are most often driven by involuntary factors such as fertility issues and udder health problems, while reasons like low production and lameness are less frequent. The decision for the course of action to take for a cull cow depends on her fitness for human consumption and for transport, the likelihood of successful treatment and the level of welfare impairment. In this context, a decision tree was created to aid decisions. However, there are knowledge gaps. Research is recommended on how cows with various health conditions respond to transport, on their welfare during withdrawal periods if recovery is incomplete, their welfare during fattening and the WCs of delays between different decisions and actions. Where necessary, professional advice (e.g. from a veterinarian) should be sought on the level of welfare impairment, likelihood of successful treatment, fitness for human consumption and for transport.

Currently, lists of criteria for decisions for fitness for transport are available; however, cases of doubt can occur which would benefit from a broader consensus on relevant conditions with clearly defined ABM thresholds. It is recommended to further develop broadly agreed ABM thresholds for deciding on fitness for transport.

Animal-based measures collected in slaughterhouses

The ABMs selected as most suitable and promising for collection at slaughterhouses to monitor the level of welfare on farm for fattening cattle are carcass fat levels, carcass condemnation, *post-mortem* lung lesions and *post-mortem* skin lesions. Currently, these ABMs are not routinely recorded in EU slaughterhouses for animal welfare monitoring of fattening cattle, but some are already collected for food safety or classification purposes. The selected ABMs refer mostly to health-related WCs and only to a limited extent indicate inability to perform species-specific behaviour on the farm, such as resting problems. There are no ABMs to detect inability to perform exploratory or foraging behaviour, or restriction of movement nor ABMs for positive welfare that can be collected in slaughterhouses.

Variation in the assessment methodologies makes it difficult to compare the currently available data. Therefore, harmonisation and standardisation of data collection and recording are needed, including training and reliability testing. For a comprehensive welfare assessment, ABMs collected at slaughter should be complemented with data on behavioural ABMs collected on farm and during transport, and with information on farm mortality.

Animal-based measures by welfare consequence

Lastly, for each welfare consequence identified as highly relevant for indoor fattening cattle, ABMs that could be collected on farm were identified based on their feasibility, sensitivity and specificity.

1 | INTRODUCTION

1.1 | Background and Terms of Reference as provided by the requestor

1.1.1 | Background

In accordance with the Farm to Fork Strategy, published on 20 May 2020, the Commission is working on the revision of the EU animal welfare legislation. This includes the following acts:

1. Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes[1];
2. Council Directive 1999/74/EC of 19 July 1999 laying down minimum standards for the protection of laying hens[2];
3. Council Directive 2008/119/EC of 18 December 2008 laying down minimum standards for the protection of calves[3];
4. Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs[4];
5. Council Directive 2007/43/EC of 28 June 2007 laying down minimum rules for the protection of chickens kept for meat production[5];
6. Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97[6];
7. Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing.[7]

There is currently no specific EU animal welfare legislation covering beef cattle, but beef cattle are covered by Directive 98/58/EC. EFSA adopted opinions on the welfare of beef cattle in 2012 and 2001.

Against this background, the Commission would like to request the EFSA to review the available scientific publications and other sources to provide an updated and sound scientific basis for possible future EU specific legislation on the welfare of beef cattle.

This request is about the protection of beef cattle (un-weaned suckler calves, fattening cattle, suckler cows, heifers, breeding bulls and end of career dairy and suckler cows).

This mandate does not cover the welfare of veal calves, nor the welfare of calves born on dairy farms that are slaughtered for beef (up to 6 months of age) as they have been covered in a dedicated Scientific Opinion.[8]

The above types of cattle are understood as follows:

- **Suckler calves** are reared by their dam (usually a beef breed) and are weaned at approximately 6 months of age.
- **Fattening cattle** are weaned cattle (greater than 6 months old) being farmed for the production of beef. This assessment covers the production of these cattle until they are slaughtered at various ages depending on the production system in question.
- **Suckler cows/heifers** give birth to and rear suckler calves until they are weaned.
- **Breeding bulls** sire calves, naturally or via artificial insemination, that are used for the beef production.
- **End of career dairy cows** are dairy cows who are no longer producing milk and are being kept for meat production.
- **End of career suckler cows** are cows no longer being used to produce and mother suckler calves but are being kept for the production of meat.
- **Dual purpose breeds**: breeds of cattle than can be used for both beef and milk production.

1.1.2 | Terms of Reference

The Commission therefore considers opportune to request EFSA to give an independent view on the protection of beef cattle.

A. The Commission requests EFSA to deliver a **technical report** in accordance with Article 31 of Regulation (EC) No 178/2002on the elements below:

TOR 1. A review of the most common husbandry systems and current practices for keeping suckler calves, fattening cattle, suckler cows, heifers, breeding bulls, end of career dairy cows and end of career suckler cows in the EU.

[1]OJ L 221, 8.8.1998, p. 23.
[2]OJ L 203, 3.8.1999, p. 53.
[3]OJ L 10, 15.1.2009, p. 7.
[4]OJ L 47, 18.2.2009, p. 5.
[5]OJ L 182, 12.7.2007, p. 19.
[6]OJ L 3, 5.1.2005, p. 1.
[7]OJ L 303, 18.11.2009, p. 1.
[8]https://open.efsa.europa.eu/questions/EFSA-Q-2020-00480?search=Calves.

This is to include types of housing, flooring and bedding, access to the outdoors, periods at grass and nutrition and feeding. It also includes a description of calving facilities in use and the practice of tethering.

B. The Commission requests EFSA to deliver a **scientific opinion** in accordance with Article 29 of Regulation (EC) No 178/2002 focusing in particular in the problems identified below (ToR 2 a-f and ToR 3):

TOR 2a. Welfare assessment of housing conditions for beef cattle (including feedlots) in relation to:

- Flooring - types of flooring, including bedding and resting areas;
- Minimum space allowance at different resources (e.g. total space allowance and space needed in bedding and resting areas, feeding trough space requirements);
- Water access - type of drinkers, number of drinking points;
- Nutrition and feeding strategies;
- Extreme environmental heat (housed and outdoors);
- Environmental enrichment;
- Lack of outdoor access;
- Mixing of cattle.

TOR 2b. Welfare of fattening cattle kept at grass considering:

- Outwintering: protection from cold, wind, rain and underfoot conditions;
- Nutrition and feeding;
- Water access.

TOR 2c. The risk to the welfare of suckler cows and calves associated with the weaning of suckler calves.

TOR 2d. The risk to welfare associated with the mutilation of cattle including:

- Castration;
- Disbudding;
- Dehorning;
- Tail docking.

TOR 2e. The risk to welfare associated with breeding strategies and genetics in relation to:

- Hyper-muscularity;
- Dystocia and caesarean sections;
- Polledness;
- Maternal ability;
- Temperament.

TOR 2f. Decision making criteria for the euthanasia of end of career dairy and suckler cows being kept for the production of beef.

TOR 3. The assessment of Animal-Based Measures collected in slaughterhouses to monitor the level of welfare on farm for fattening cattle.

1.1.3 | Interpretation of the Terms of Reference

This mandate refers to the protection of beef cattle (un-weaned suckler calves, fattening cattle, suckler cows, heifers, breeding bulls, cull dairy cows and cull suckler cows). Although the definitions of the animal categories are identical to those included in the mandate for most categories, some considerations are provided to clarify the scope of some of them:

Fattening cattle: These are weaned cattle more than 6 months old being farmed for the production of beef. While steers are not specifically mentioned in the mandate, these are also part of the fattening cattle category. Fattening cattle also includes bulls and heifers, but not dairy replacement heifers.

Breeding bulls: In the mandate it is specified that breeding bulls are cattle that 'sire calves that are used for beef'. It is recognised that calves sired by a breeding bull may also be used for dairy (i.e. in most cases it will depend on the breed, but not always), but in the context of this opinion the focus is only on bulls that are bred to produce calves that will be used to produce beef.

Cull cows: In this document the term 'cull cow' is used rather than 'end-of-career cow' as mentioned in the ToRs. 'Cull cow' is a term commonly used in the literature and has also been used in a previous EFSA opinion to refer to this animal category (EFSA AHAW Panel, 2022b). It refers to dairy and suckler cows for which their primary productivity (milk, calves) is considered insufficient. They may be sent to slaughter, kept for fattening or killed.

'Dairy-beef' calves: These are calves born on dairy farms and subsequently reared and slaughtered for beef (but not for veal) at >8 months of age. Any hazards or practices specific to dairy-beef calves not already addressed in the Scientific Opinion on the Welfare of calves (EFSA AHAW Panel, 2023a) are described and assessed as appropriate in this opinion.

The term 'dual-purpose breeds' was included in the mandate under 'types of cattle' and was listed in the animal categories. Although this term does not refer to an animal category, the interpretation is that the assessment should also cover animals of dual-purpose breeds. In this context, dual purpose breeds were defined as breeds of cattle that are selected for both beef and milk production.

Interpretation of specific requests

This document provides the assessment requested in ToRs 2a–e and ToR 3, while the Section on the housing practices part of ToR 1 is published separately as a technical report.

ToR 2a. Welfare assessment of housing conditions for beef cattle (including feedlots) in relation to: Flooring, minimum space allowance at different resources, water access, nutrition and feeding strategies, extreme environmental heat, environmental enrichment, lack of outdoor access and mixing of cattle.

ToR 2a requests to assess housing conditions (i.e. flooring, water, nutrition and feeding, extreme environmental heat, environmental enrichment, lack of outdoor access and mixing of cattle). The term 'extreme environmental heat' was rephrased as 'high environmental temperatures' to reflect that such climate conditions are not infrequent (as the word 'extreme' could suggest).

Under the housing Section, tie-stalls are not discussed because they are used much less frequently than loose housing systems for keeping suckler cows and fattening cattle. General welfare concerns related to tie-stalls were discussed in the EFSA scientific opinion on the Welfare of dairy cattle (EFSA AHAW Panel, 2023b).

According to the mandate received by EFSA, the factors discussed for cattle kept indoors (flooring, minimum space allowance, water access, nutrition and feeding strategies, high environmental temperatures, environmental enrichment, lack of outdoor access and mixing of cattle) should be also discussed in the context of feedlots. With the exception of the Section 'lack of outdoor access', which does not apply to feedlots and cattle kept on pasture (see ToR 2b below), the principles discussed in the context of indoor housing (i.e. relationships between hazards and welfare consequences (WCs)) equally apply to cattle kept in feedlots. Hence in the feedlot Section these principles are not discussed again and only the results of research specifically taking place in feedlots are mentioned. It is also worth mentioning that the EFSA experts considered that the minimum space allowance recommendations for cattle kept indoors also apply to cattle kept outdoors.

Minimum space recommendations were requested for three aspects: (1) feed trough space requirements (m/animal), including space for standing while feeding (m^2/animal); (2) lying area (m^2/animal); and (3) total space allowance (m^2/animal). As a 'minimum' space allowance recommendation was requested for the space allowance topic, an approach based on a behavioural model was developed to provide quantitative, minimum space allowance recommendations. This is presented as a standalone chapter.

ToR 2b. Welfare of fattening cattle kept on pasture considering: Outwintering, nutrition and feeding and water access

ToR 2b requested an assessment of the welfare of fattening cattle kept on pasture considering outwintering, nutrition and feeding and water access. Because other categories of cattle are also commonly kept on grass, such as suckler cows and suckler calves, the welfare assessment was carried out for these two categories as well.

In addition, the Section on feedlots requested under ToRs 2a–e was included under ToR 2b to focus ToRs 2a-e on housed cattle only

ToR 2c. The risk to the welfare of suckler cows and calves associated with the weaning of suckler calves

The mandate text was straightforward with no further interpretation considered necessary.

ToR 2d. The risk to welfare associated with the mutilation of cattle including castration, disbudding and dehorning

There was a discussion on the importance of animal integrity in the context of mutilations. Beyond the pain resulting from mutilations, the functions of the removed body parts are discussed with regard to relevant WCs but the ethical dimension of integrity of an animal was considered beyond the scope of this scientific opinion.

ToR 2e. The risk to welfare associated with breeding strategies and genetics in relation to: Hypermuscularity, dystocia and C-sections, polledness, maternal ability and temperament

As for ToR 2c and ToR 2d, no interpretation was needed for this ToR.

ToR 2f. Decision-making criteria for the euthanasia of end of career dairy and suckler cows being kept for the production of beef

The mandate requested EFSA to assess the decision-making criteria for the euthanasia of cull cows being kept for the production of beef.

There was a discussion among the EFSA experts on whether strictly speaking this request could be interpreted as falling into a 'risk management' rather than 'risk assessment' and hence be beyond EFSA's mandate. While a 'decision-making' set of criteria could be interpreted as being risk management because it involves direct decisions, it was eventually understood that this ToR was pertaining those decisions that are relevant from a welfare point of view. In parallel, practical considerations for taking decisions around culling of cows should also be considered, such as whether a cow is fit for human consumption. In this context, the final interpretation of this request was that the decision steps relevant to welfare should be identified to aid the decision-making process for cows being removed from the productive herd whilst acknowledging that a full risk assessment of the WCs at stake in each decision step was not within the scope of this ToR.

ToR 3. The assessment of animal-based measures collected in slaughterhouses to monitor the level of welfare on farm for fattening cattle

This ToR requested the identification of animal-based measures (ABMs) collected at the slaughterhouse, both before and after slaughter (*ante-mortem* and *post-mortem*), that could be used to monitor the welfare of fattening cattle on farm. These ABMs should provide information on the overall welfare state of a specific population within a herd, farm or region/country. All fattening beef cattle categories (i.e. fattening bulls, heifers and steers) were considered in the assessment of ABMs collected in slaughterhouses for monitoring fattening cattle welfare on farms. For ABMs collected at slaughter related to calves please refer to EFSA AHAW Panel (2023a).

2 | DATA AND METHODOLOGIES

2.1 | Data

2.1.1 | Scientific literature

Peer-reviewed scientific articles were the main source of data used in the assessment. The literature searches and inclusion and exclusion criteria are presented in Appendix C.

2.1.2 | EFSA Public call for evidence

In line with its policy on openness and transparency, and in order to receive any relevant evidence on the welfare of beef cattle on farm from the scientific community and all interested parties, EFSA launched a Public call for evidence from 7 December 2023 to 31 January 2024. Beef cattle population, husbandry systems and housing, cattle mutilations and breeding strategies were the topics considered by EFSA to be most relevant to gather feedback on. The document presenting the Public call for evidence included different ToRs of the mandate received from the EC and is available at Open EFSA (https://connect.efsa.europa.eu/RM/s/consultations/publicconsultation2/a0lTk0000001qhJ/pc0742).

A total of 226 anonymised comments were received from stakeholders from 10 countries (Belgium, Czech Republic, Denmark, Finland, Germany, Ireland, Italy, Netherlands, Spain, United States), consisting of written comments, scientific papers and grey literature (technical reports, outputs from databases, non-published data). Stakeholders were from the following affiliation categories: "EFSA registered stakeholders", "Non-Governmental Organizations (NGOs)", "Public authorities in EU Member States (MSs)", "Academia/Research institutes", 'International Organizations" and "Other". Out of 226 comments, 39 were classified as meaningless (e.g. 'no info', 'see attachment'), 11 were identical duplicates and 4 were out of the scope of this public call for evidence. Only relevant comments and publications suggested in the EFSA Public call for evidence were considered by the EFSA experts in their assessment and these are cited in this document as appropriate (see Appendix D for instructions on how to retrieve the information submitted by stakeholders). The full list of submissions including their attachments, is available at Open EFSA (https://open.efsa.europa.eu/consultations/a0cTk00000024kHIAQ?search=beef+cattle).

The data provided through the Public call for evidence reflect a variety of reported practices concerning the welfare of beef cattle. The information was considered as received when informative for the assessment and was not verified or validated by EFSA.

2.2 | Methodologies

The overall approach taken in this document for a scientific assessment of welfare was that described in the EFSA guidance on risk assessment for animal welfare (EFSA AHAW Panel, 2012a). This Scientific Opinion also follows the guidance protocol that was developed by the EFSA Panel on Animal Health and Animal Welfare (AHAW) to answer the mandates received in the context of the Farm to Fork strategy (EFSA AHAW Panel, 2022a). Based on these EFSA methodological guidance documents, a protocol describing the problem formulation was developed at the start of the assessment to identify the main questions of relevance and to determine the most appropriate methodological approach for each ToR. This is presented in Appendix A.

2.2.1 | Methodologies used in ToR 1

The assessment relative to ToR 1 (a review of the most common husbandry sustems and current practices for beef cattle) was published separately as a Technical report and the methodology used for that report is there described (EFSA, 2025).

2.2.2 | Methodologies used in ToRs 2a–e

Following the EFSA guidances documents on animal welfare (EFSA AHAW Panel, 2012a, 2022a), EFSA experts (a) identified the most relevant WCs resulting from the husbandry practices and hazards defined in ToRs 2a–e) of the mandate (i.e. flooring, minimum space allowance, water access, nutrition and feeding, high environmental temperatures, lack of outdoor access and mixing), (b) described suitable animal-based measures (ABMs) to detect and monitor the most relevant WCs identified in (a) and (c) provided qualitative or quantitative recommendations to prevent or mitigate those WCs.

The definitions of welfare consequences (WCs) listed in Section 2.3 were those part of the EFSA guidance protocol (EFSA AHAW Panel, 2022a), but only the WCs relevant to beef cattle were considered. In the context of this Scientific Opinion, the WC 'sensory under- and/or overstimulation' was interpreted as referring only to the aspect of 'under-stimulation' because the occurrence of 'over-stimulation' was not identified for any of the factors assessed.

The identification of the highly relevant WCs was executed based on expert opinion. The opinion of the EFSA experts was elicited through an exercise of individual classification of the relevance of WCs (considering severity, prevalence and duration) followed by group discussion to identify the highly relevant WCs by consensus. For a detailed description of the steps involved in this process, see EFSA AHAW Panel (2022a) (see Section 3.1.1.4 of EFSA AHAW (2022a).

Some highly relevant WCs were not a direct consequence of the hazard but were rather associated with one of the WCs initially selected as highly relevant. In those cases, the WCs were still selected but classified as 'linked WCs'. For instance, a WC from feeding fattening cattle a diet with a high content of concentrates is metabolic disorders, and a linked WC from metabolic disorders is locomotory disorders (i.e. laminitis as a consequence of ruminal acidosis).

Interventions or measures to prevent or mitigate the WCs and the ABMs suitable for detecting and monitoring each WC including definition, interpretation, feasibility, sensitivity and specificity were identified using expert knowledge and data from the scientific literature. Literature searches focusing on the topics of interest were carried out and used as a basis for the assessment presented in each Section (for more details on the literature searches, see Appendix C).

ToR 2d focusing on the risks to welfare associated with the castration, disbudding, dehorning and tail docking followed the same methodology to identify the highly relevant welfare consequences of these mutilations. In addition, information collected through the AHAW network (EFSA, 2024) regarding common practices around mutilations in the different MSs was also taken into account by the EFSA experts when discussing current practices.

The assessment related to the identification of 'minimum space allowance' requirements (included in TOR 2a) required further methodological steps; these are described below.

2.2.3 | Methodologies used in ToR 2a – minimum space allowance

2.2.3.1 | *Allometric calculations (space needed for feeding)*

The first step was to follow the process described under Section 2.2.2 to identify highly relevant WCs of restricted space allowance and the second step was to carry out a literature search to describe the relationship between space allowance (feeding space, lying and total pen space) and beef cattle welfare (Appendix C).

The literature search output included publications estimating space requirements based on allometry (i.e. relating floor space and animal body weight). Accordingly, equations to estimate space needed for feeding (i.e. linear trough space per animal (m)), space needed for standing while feeding (m^2) and space needed for lying (m^2) were retrieved, as well as different constant k-values where (see Equations 1 and 2) reported in the literature.

For feed troughs, Petherick and Phillips (2009) proposed the equation

$$L = kW^{\frac{1}{3}}, \tag{1}$$

where L = feed trough length, W = liveweight and k is a constant of value = 0.064.

To estimate the area needed for standing, the same authors proposed

$$A = kW^{\frac{2}{3}}, \tag{2}$$

where A = area for standing, W = liveweight and k is a constant of value = 0.02 (but other k-values have been proposed in the literature (e.g. EFSA AHAW Panel, 2022b; Gallo et al., 2023).

These equations were discussed by the EFSA experts, as well as potential drawbacks of basing space allowance recommendations solely on allometry. It was considered that allometry was suitable to estimate feed trough requirements in a context where feed is provided *ad libitum* (i.e. feed is always available) because having all animals eating at the same time is less necessary. For example, in groups of 16–33 animals, Schneider, Volkmann, Spindler, and Kemper (2020a) observed that even at times of feed delivery not more than 40% of the animals were at the feed trough and that the average percentage of animals eating rarely exceeded 20%. This was considered to allow for animals to keep larger inter-individual distances and reduce group stress while feeding.

In contrast, it was considered that allometric equations for lying equated to very restricted lying areas with a consequent impact on resting problems and group stress, not possible to mitigate other than by effectively increasing space (Volkmann et al., 2021). A 'behavioural model' was then developed to estimate space allowance recommendations for lying based on the assumptions that the available space should allow synchronous lying and inter-individual spacing behaviour. Further details on the methodology followed are provided below.

2.2.3.2 | *Behavioural model (space needed for lying)*

One of the premises of the 'behavioural model' here described was that beef cattle will synchronise their lying behaviour when space (and other resources such as feed) are not restricted. This assumptions were based on a review of studies reporting synchronous behaviour and spacing behaviour in cattle (Section 3.3.3).

The main assumptions of the model were:

1. A group of beef cattle will show synchronous lying behaviour when space (and other resources such as feeding) are not restricted. Schneider, Volkmann, Spindler, and Kemper (2020b) reported that, in 6 groups of 6–8 bulls kept on slatted floors fully or partially covered with rubber mats, there were periods with all but one or two animals lying or animals lying down directly after another individual took a standing position, indicating an attempt of the group's individuals to synchronise lying behaviour.
2. Cattle are motivated to keep a certain inter-individual distance while lying (Gygax, Siegwart, & Wechsler, 2007; Gygax et al., 2010; Kondo, Masato, et al., 1989; Kondo, Sekine, et al., 1989).
3. A proxy to quantify the space perception of cattle is to measure the distance between the heads of neighbouring cattle (eye-to-eye). The space required to allow synchronous lying behaviour in a group of cattle can be quantified by estimating the average inter-individual distance between the heads of adjacent animals:

$$d = \frac{\sum d_i}{n} \tag{3}$$

where d is the average distance between the heads of adjacent animals within a triangularisation, d_i is the distance between the individual heads and n is the number of individual distances. A more precise approach would involve calculating the average area of the 'triangles' formed between the heads of individual animals and deriving the side length d of an equilateral triangle with an equivalent average area. This method is conceptually similar to computing the geometric mean of the inter-individual distances.

The following assumptions were made on the shape of the pen:

4. The available space is represented as a rectangle with a length-to-width ratio denoted by λ. The shorter side of the rectangle is defined as '*a*'.
5. The distance from the midpoint of the animal's head to the side of the rectangle is set to w/2, corresponding to half the body width (w) of the animal (Figure 1).

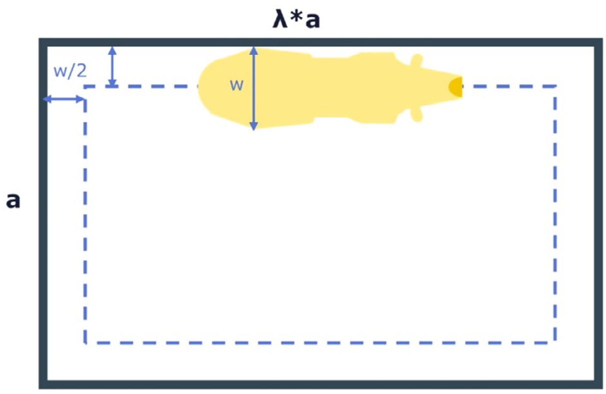

FIGURE 1 Assumptions made on the shape of the pen and on the relationship between cattle size and pen size parameters.

The following assumptions were made on the distribution of cattle in a pen:

6. The necessary space is calculated with an even distribution of cattle having all the same distance between heads to their neighbours.
7. The minimum inter-individual distance (dmin) of cattle allowing synchronicity of lying behaviour is used to calculate the necessary space (Figure 2).

n represents the number of animals present in the pen.
E.g. for eight animals the necessary space is estimated as:

$$\text{Number of animals: } N = 8 \tag{4}$$

$$\text{Short side: } a = 2 \times 0.866 \times d_{\text{min}} + w \tag{5}$$

$$\text{with } 0.866 = \sqrt{3/4} \tag{6}$$

$$\text{Long side: } \lambda \times a = 3 \times d_{\text{min}} + w \tag{7}$$

$$\text{Area of the pen: } A = \lambda \times a^2 \tag{8}$$

$$\text{Area per animal: } Z(N) = A/N \tag{9}$$

$$\text{Length-to-width: } \lambda = (\lambda \times a)/a \tag{10}$$

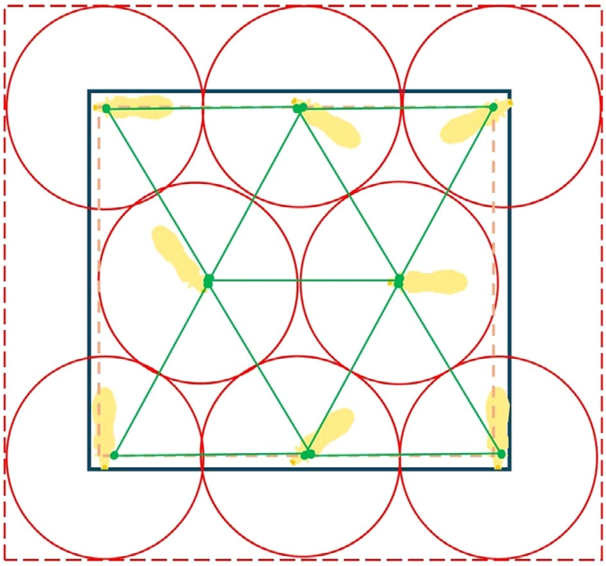

FIGURE 2 Distribution of eight animals in a pen following the model assumptions, i.e. an even distribution of cattle having all the same distance between heads to their neighbours and a head-to-head minimum inter-individual distance.

Distribution of cattle in a pen following the same assumptions was also estimated for other group sizes (e.g. 3, 14 and 20 animals). Group sizes of 8, 14 and 20 animals were ultimately chosen because they reflect group sizes commonly practiced. The corresponding diagrams for groups of 3, 14 and 20 animals are presented in Appendix E.

The developed model was discussed and agreed by the EFSA experts. However, as the behavioural model required the estimation of the parameter dmin (minimum inter-individual distance cattle are motived to keep when lying synchronously) for which there was no specific data available in the literature for beef cattle kept indoors, a 'semi-formal' expert knowledge elicitation was carried out.

2.2.3.3 | *'Semi-formal' Expert knowledge elicitation*

An expert knowledge elicitation (EKE) was carried out to estimate the values that the parameter of interest (minimum inter-individual distance cattle are motived to keep when lying synchronously can take. An EKE protocol, including an evidence dossier, was put together by EFSA staff and EFSA experts and underwent several steps of review to include all available evidence of interest for the EKE question. Table 1 presents the EKE question and other considerations discussed by the EFSA experts to define the context to which recommendations would apply.

The EFSA experts considered available scientific data reported in peer-reviewed scientific studies on lying behaviour; particular emphasis was given to studies reporting social spacing and inter-individual distances in beef cattle. A summary of the studies considered by the EFSA experts is presented in the results section (see literature review of Section 3.3.3). In addition, over 50 photographs of cattle lying in pens of different sizes were collected by the EFSA experts (based on their own photographs, photographs taken by their contact network or photographs available online). The photographs depicted cattle in a lying position across various environments, including indoor and outdoor settings, slatted and bedded floors, and pens with different space allowances. These visual materials were used to gather additional evidence on spacing behaviour in beef cattle. Experts were asked to provide individual estimates for the lower and upper bounds (credible range), as well as the median and interquartile range for the parameter of interest dmin. Each of these estimates was discussed by the EFSA experts and a consensus was reached for each value. Following an evaluation of goodness-of-fit, a beta distribution was identified as the most appropriate for dmin. The beta-distribution parameters were $\alpha = 0.97751$, $\beta = 2.6953$, $a = 1.95$ and $b = 14.3$ corresponding to shape parameters (α and β) and upper and lower bounds of the distribution (a and b). After fitting the EKE derived values to the selected beta distribution using 10,000 iterations, the behavioural model was run to estimate space allowance requirements.

TABLE 1 Background and assumptions taken in the context of the EKE on the effects of restricted lying space allowance on beef cattle welfare.

EKE components	Definitions and assumptions
Wording of the mandate	'Minimum space allowance at different resources (e.g. total space allowance and space needed in bedding and resting areas, feeding trough space requirements)'
Interpretation of the mandate	Recommendations are requested for three aspects: (1) linear feed trough space requirements (m/animal), including space for standing while feeding (m^2/animal); (2) lying area (m^2/animal); (3) total space allowance (m^2/animal). Feeding area requirements are calculated using allometry. Lying area requirements are calculated through a 'behavioural model' that mimics the distribution of cattle in a pen when lying. A key parameter of this model is the 'inter-individual distance' cattle are motivated to keep while lying. Expert knowledge is used to estimate this parameter due to the limited scientific evidence in the literature for indoor beef cattle. The parameter of interest in the context of the EKE is hence the 'minimum inter-individual head-to-head distance cattle are motivated to keep while lying that does not impact the synchronicity of the lying behaviour' (dmin). Total space allowance requirements are estimated by the area estimated for standing while feeding and the area needed for lying. The area needed for standing while eating already considers the recommendations for linear trough space. It was assumed that the total space allowance estimated would allow for other activities (e.g. walking, brush use) when not all animals are lying.
Animal category	Beef cattle, weighing 400–700 kg, held indoors in groups of 8 to 20
Husbandry system, context and assumptions	Indoor pens. Beef cattle housed indoors in groups of 8, 14, 20 cattle. Beef cattle with a slaughter weight of 400–700 kg. Stable groups assumed (familiar animals). Lying areas were defined as having a rectangular shape, with the rectangle long and short side sides having a ratio of 1 to 1.5. Synchronicity of the lying behaviour defined as 100% of the group lying at the same time.
Question	What is the (average) minimum inter-individual distance to the nearest neighbours kept by cattle in the lying area that does not impact the synchronicity of the lying behaviour (dmin)?
Unit	[m]

2.2.3.4 | *Estimation of total space allowance in a pen*

The results from the assessment on feeding and lying areas were used to estimate total space requirements with the results equally applying to two pen designs common in beef farming: pens with slatted floors and pens with a bedded lying area. In pens with a bedded lying area the separation of functional areas is clearer than in fully slatted pens and the space behind the trough is not used for lying because there is a dedicated lying area. In contrast to bedded pens, in fully slatted pens there is no physical separation between the lying and the feeding area which theoretically allows animals to use the entire space for lying. While in slatted pens the space in front of the feed trough could in theory be used for lying, it is often dirty and the likelihood for displacements of lying animals by animals motivated to feed is high. Hence, it was considered that this space would likely not be selected by the animals to lie down, and for this reason a dedicated lying area was considered necessary in both slatted and bedded floor pens with no differences in estimated space requirements.

2.2.4 | Methodology used in ToR 2f

A literature search was conducted to identify the main reasons for culling cows (see details on the literature search in Appendix C). In addition, available guidance from the Care4Dairy decision tree on 'end of career cows' was reviewed (Care4Dairy, 2024). It was noted that the definitions used by EFSA and by Care4dairy differ:

- In this Scientific Opinion, a cull cow was defined as: 'dairy and suckler cows for which their primary productivity (milk, calves) is considered insufficient. They may be sent to slaughter, kept for fattening or killed'.
- The Care4Dairy (Care4Dairy, 2024) uses the term 'end of career cows' rather than cull cow and defines it as 'cows considered to be at the end of their productive life, either due to natural culling, illness or injury'.

Following a discussion of the Care4Dairy decision tree, the EFSA experts considered that a new tree was necessary to address the specific questions of interest in this mandate.

In this context, the questions of interest were the following:

- In which instances can a cow be kept for fattening?
- What are the animal welfare considerations indicating whether a cull cow should be fattened, transported to a slaughterhouse or killed on farm?

These questions formed the basis for a new diagram to guide actions. This diagram was created by the EFSA experts based on a discussion of likely scenarios and necessary steps to guide the decision of whether a cow leaving the productive herd could be kept for fattening, sent to slaughter or killed. Gaps of knowledge and case examples reflecting different levels of welfare impairment were also selected by the EFSA experts to demonstrate how the tree would be applied in those cases.

The relevance of the outputs of the EURCAW on fitness for transport in this context was also discussed by the EFSA experts.

2.2.5 | Methodology used in ToR 3

In ToR 3 EFSA was asked to provide a list of ABMs to be collected in slaughterhouses that can be indicative of the level of welfare of fattening cattle while on farm. To shortlist the ABMs, EFSA developed a procedure that integrated different aspects such as the relevance of the ABM to animal welfare, the relationship of the ABM with on-farm welfare (and not transport, lairage or slaughter); existing data from the literature, and feasibility of the ABM for large-scale collection. Considering the limited availability of published data on this topic, this assessment was based both on expert knowledge and data from the scientific literature. This methodology was consistent with the methodology used in past EFSA opinions that included a similar request from the EC (EFSA AHAW Panel, 2022c, 2023a, 2023a, 2023d). Additional details on the methodological steps are provided below.

The starting point was a list of 25 ABMs (11 *ante-mortem* and 14 *post-mortem*) that were potentially relevant for measurement at slaughter in fattening beef cattle (i.e. fattening bulls, heifers and steers). This list was prepared by EFSA based on relevant scientific literature (EFSA AHAW Panel, 2012a; Welfare Quality, 2023a) and on expert knowledge. For each ABM, the preferred time of assessment (i.e. *ante-* or *post-mortem*) was identified.

TABLE 2 List of ABMs potentially relevant to collect in slaughterhouses for monitoring the level of on-farm welfare of fattening beef cattle. The list was proposed by EFSA experts, with indication of the preferred time of assessment (*ante-* or *post-mortem*). Description of ABMs is available in EFSA (2023).

ABMs in beef cattle	
Ante-mortem	***Post-mortem***
1. Body condition	1. Lung lesions – pneumonia
2. Lameness	2. Lung lesions – pleuritis
3. Skin lesions – wounds/injuries	3. Liver disorders
4. Skin lesions – abscesses	4. Pericarditis
5. Body cleanliness	5. Claw disorders
6. Coughing/sneezing	6. Skin lesions – bruises
7. Nasal/ocular discharge	7. Skin lesions – abscesses
8. Laboured breathing	8. Bursitis (swollen joints)
9. Rectal prolapse	9. Abomasal lesions
10. Hernia	10. Rumen lesions
11. Diarrhoea	11. Intestinal disorders
	12. Mastitis
	13. Carcass condemnations
	14. Carcass aspect (conformation and fat cover)

To gather information on their use in practice in the different MSs, the current use of the listed 25 ABMs (Table 2) was discussed by the EFSA AHAW (Animal Health and Animal Welfare) Network (Animal Welfare topic) at their annual meeting (EFSA, 2023). Specifically, information on ABMs currently recorded during ante- and *post-mortem* inspections of beef cattle at the slaughterhouses in the different MSs, the existence of a database for the electronic recording of these ABMs, their feasibility and any automated systems for their assessment was discussed (EFSA, 2023). Network members were asked to score the provided *ante-mortem* and *post-mortem* ABMs; this resulted in a list of ABMs deemed useful to be recorded and monitored in slaughterhouses.

Following the input gathered during the 2023 AHAW network meeting, the EFSA experts carried out a semi-quantitative consensus exercise evaluating the ABMs of Table 2. The exercise consisted of two steps: (i) Screening of ABMs and (ii) Selection of ABMs.

Step (i) Screening was carried out through an expert opinion exercise on the initial list of ABMs, on the basis of four screening criteria (i.e. questions with a Yes/No answer):

1. Relevance to animal welfare: Is the ABM relevant to the WCs defined in this opinion (Table 3), and not only to production and meat quality aspects?
2. Relationship with the farm (and not transport or lairage): Is the ABM indicative of WCs taking place on farm and not caused or masked by transport, lairage or slaughter?
3. Existing data in literature: Do scientific publications describe the ABM, detailing methodologies, prevalence or the relation with on-farm WCs?
4. Feasibility for large-scale collection: Is the ABM already routinely collected or is there evidence that it could be collected in a national programme?

As a precautionary principle, if consensus was not reached, the criterion was considered a 'Yes'. Only ABMs that received a 'Yes' for all criteria passed to the second step (Selection).

Step (ii) the Selection step consisted of a ranking of the ABMs based on the four criteria presented below.

The four criteria were:

1. WCs (C1): The EFSA experts identified which WCs (from the list of 33 WCs applicable to beef cattle, Section 2.3) observed on farm could be associated with the selected ABMs (from the list in Table 2). To assign eAach ABM a score, first the percentage of associated ABMs to the WCs was calculated by dividing the number of WCs associated by the total number of WCs ($n=26$). The ABM was scored according to the percentage of WCs selected. The following percentages were associated with the 4 different scores: (1) Score 1: From 1% to 14%; (2) Score 2: from 15% to 29%; (3) Score 3: from 30% to 44%; (4) Score 4: from 45% to 58%.
2. Technology readiness (C2): Each ABM was evaluated for the known level of readiness of an automated system to be adopted by the market, based on the technology readiness scale (Mankins, 1995).
3. Already used at slaughter (C3): The ABMs were scored according to the answers received from the exercises of the AHAW Network (EFSA, 2023).
4. Priority given by the AHAW Network (C4): answers provided by MSs at the 2023 AHAW Network meeting were considered and complemented with the knowledge from the EFSA experts.

For each of these criteria, the EFSA experts agreed on a score from 0 to 4, where '0' means no association between the ABM and the criterion (e.g. no association of the ABM with any WC in C1, no use of the ABM in a slaughterhouse context in C3) and '4' the highest score.

A weight was attributed by expert consensus to each criterion according to its importance in answering the request of the mandate. The allocated weights were C1 = 3; C2 = 2.8; C3 = 2.5; C4 = 1.7. A final score (weighted score) was calculated following the formula below:

$$\text{Weighed score} = \frac{\left(\text{score}_{C1} \times \text{weight}_{C1}\right) + \left(\text{score}_{C2} \times \text{weight}_{C2}\right) + \left(\text{score}_{C3} \times \text{weight}_{C3}\right) + \left(\text{score}_{C4} \times \text{weight}_{C4}\right)}{\sum_{C4}^{C1} \text{weights}}. \quad (11)$$

Based on the calculation of the weights above, a table listing the ABMs ranked by final weighted score was produced. The final selection of ABMs was made by expert consensus aiming at a maximum number of five ABMs, considering the mandate requestor's requirement.

Finally, each selected ABM was described with its definition (as reported in EFSA, 2023) interpretation, means of assessment and arguments for the selection, based on scientific evidence found in the literature (see details on the literature searches in Appendix C) and on expert knowledge.

2.3 | Welfare consequences for beef cattle

Table 3 presents a comprehensive list of WCs potentially experienced by beef cattle that were used as a basis for the welfare assessment presented in this document. This list was initially published in an EFSA methodological guidance document for welfare assessment (EFSA AHAW Panel, 2022a).

TABLE 3 List and definition of welfare consequences used as a basis for the welfare assessment presented in this document. These were initially published in (EFSA AHAW Panel, 2022a).

	Welfare consequence	Definition
1	Bone lesions (including fractures and dislocations)	The animal experiences negative affective states such as pain, discomfort and/or distress due to fractures or dislocations of the bones (excluding those fractures leading to locomotor disorders).
2	Cold stress	The animal experiences stress and/or negative affective states such as discomfort and/or distress when exposed to low effective temperature.
3	Eye disorders	The animal experiences negative affective states such as discomfort, pain and/or distress due to irritation or lesion or lack of function of at least one eye.
4	Group stress	The animal experiences stress and/or negative affective states such as pain, fear and/or frustration resulting from a high incidence of aggressive and other types of negative social interactions, often due to hierarchy formation and competition for resources or mates.
5	Gastro-enteric disorders	The animal experiences negative affective states such as discomfort, pain and/or distress due to impaired function or lesion of the gastro-intestinal tract resulting from for example nutritional deficiency, infectious, parasitic or toxigenic agents.
6	Handling stress	The animal experiences stress and/or negative affective states such as pain and/or fear resulting from human or mechanical handling (e.g. loading/unloading).
7	Heat stress	The animal experiences stress and/or negative affective states such as discomfort and/or distress when exposed to high effective temperature.
8	Inability to avoid unwanted sexual behaviour	The animal experiences stress and/or negative affective states such as pain and/ or fear resulting from inability to avoid forced mating.
9	Inability to perform exploratory or foraging behaviour	The animal experiences stress and/or negative affective states such as frustration and/or boredom resulting from the thwarting of the motivation to investigate the environment or to seek for food (i.e. extrinsically and intrinsically motivated exploration).
10	Inability to express maternal behaviour	The animal experiences stress and/or negative affective states such as frustration resulting from the thwarting of the motivation to care for offspring, including during the pre-partum/pre-laying phase.
11	Inability to perform sucking behaviour	The animal experiences stress and/or negative affective states such as frustration resulting from the thwarting of the motivation to suck from an udder.
12	Inability to chew and/or ruminate	The animal experiences stress and/or negative affective states such as frustration resulting from the thwarting of the motivation to ingest sufficient amounts of fibrous feed or the inhibition of rumination.
13	Inability to perform play behaviour	The animal experiences stress and/or negative affective states such as frustration resulting from the thwarting of the motivation to engage in social/locomotor or object play.
14	Inability to perform sexual behaviour	The animal experiences stress and/or negative affective states such as frustration resulting from the thwarting of the motivation to engage in sexual activities.
15	Inability to perform comfort behaviour	The animal experiences stress and/or negative affective states such as discomfort and/or frustration resulting from the thwarting of the motivation to maintain the function and integrity of the integument (e.g. cannot keep clean, scratch, dust bathe).
16	Isolation stress	The animal experiences stress and/or negative affective states such as frustration and/or fear resulting from the absence of or from limited social contact with conspecifics.
17	Locomotory disorders (including lameness)	The animal experiences negative affective states such as pain, discomfort and/or due to impaired locomotion induced by, e.g. bone, joint, skin or muscle damage.
18	Mastitis	The animal experiences negative affective states such as pain and/or discomfort due to the inflammation of at least one of the mammary glands.
19	Metabolic disorders	The animal experiences negative affective states such as inappetence, weakness, fatigue, discomfort, pain and/or distress due to disturbed metabolism (e.g. acidosis and ketosis), deficiencies in several nutrients (e.g. anaemia) or induced by ectoparasites affecting metabolism or poisoning.
20	Motion stress	The animal experiences motion sickness, stress and/or fatigue due to the forces exerted as a result of acceleration, braking, stopping, cornering, gear changing, vibrations and uneven road surfaces during transport.

TABLE 3 (Continued)

	Welfare consequence	Definition
21	Muscle disorders	The animal experiences negative affective states such as discomfort and/or pain due to a disorder or lack of function of the muscles.
22	Predation stress	The animal experiences stress and/or negative affective states such as fear and/or pain resulting from being attacked or perceiving a high predation risk.
23	Prolonged hunger	The animal experiences craving or urgent need for food or a specific nutrient, accompanied by a negative affective state, and eventually leading to a weakened condition, as metabolic requirements are not met.
24	Prolonged thirst	The animal experiences craving or urgent need for water, accompanied by an uneasy sensation (a negative affective state), and eventually leading to dehydration as metabolic requirements are not met.
25	Restriction of movement	The animal experiences stress and/or negative affective states such as pain, fear, discomfort and/or frustration because it is unable to move freely, or to walk comfortably (e.g. due to overcrowding, unsuitable floors, gates, barriers).
26	Respiratory disorders	The animal experiences negative affective states such as discomfort, pain, air hunger and/or distress due to impaired function or lesion of the lungs or airways.
27	Resting problems	The animal experiences stress and/or negative affective states such as discomfort, and/or frustration due to the inability to lie, rest comfortably or sleep (e.g. due to hard flooring or vibration during transport). This may eventually lead to fatigue.
28	Reproductive disorders	The animal experiences negative affective states such as pain and/or discomfort due to a disorder of the reproductive system resulting from physical injury or infection (including dystocia and metritis).
29	Sensory under- and/or overstimulation	The animal experiences stress and/or negative affective states such as fear, discomfort due to visual, auditory or olfactory under/ overstimulation by the physical environment.
30	Separation stress	The animal experiences stress and/or negative affective states such as fear and/or frustration resulting from separation from conspecifics.
31	Skin disorders (other than soft tissue lesions and integument damage)	The animal experiences negative affective states such as pain, discomfort and/or distress due to e.g. infections (e.g. dermatophytosis/ ringworm, pseudomonosis, staphylococcosis, viral diseases), ectoparasites (e.g. mange), inflammation of the skin or sunburn.
32	Soft tissue lesions and integument damage	The animal experiences negative affective states such as pain, discomfort and/or distress due to physical damage to the integument or underlying tissues, e.g. multiple scratches, open or scabbed wounds, bruises, ulcers, abscesses and hair loss. This welfare consequence may result from negative social interactions (such as aggression), from handling, from damaging environmental features or from mutilation practices (e.g. de-horning).
33	Umbilical disorders and hernias	The animal experiences negative affective states such as discomfort and/or pain due to inflammation of the navel or any type of hernias.

2.4 | Uncertainty assessment

The uncertainty in the assessment performed for this Scientific Opinion was investigated following the procedure detailed in the EFSA guidance on uncertainty analysis in scientific assessments (EFSA Scientific Committee, 2018a, 2018b) and EFSA guidance for the development of animal welfare mandates in the context of the Farm to Fork strategy (EFSA AHAW Panel, 2022a).

The uncertainty relating to key conclusions was assessed through expert opinion. EFSA experts were asked to provide their individual judgement on the certainty for each key conclusion according to three predefined certainty 'ranges' (Table 4) (adapted from EFSA, 2019, Table 4). A 'key' conclusion was defined as any conclusion containing elements that could potentially inform legislation on the welfare of beef cattle. For instance, a listing of WCs associated with lack of water access was not considered a key conclusion, but a conclusion on water availability and amounts to prevent prolonged thirst was. Group discussion took place during which experts had the opportunity to explain the rationale behind their judgement, and a consensus on the category better reflecting the overall certainty was reached.

The uncertainty analysis related to the identification and description of current practices, the selection of the WCs and their related ABMs was limited to the description of the potential sources of uncertainty, the nature or cause of the uncertainty and the potential impact of the uncertainty on the assessment.

TABLE 4 Certainty ranges used to express certainty around conclusions statements.

	Certainty ranges		
Quantitative assessment	**> 50%**	**> 66%**	**> 90%**
Qualitative translation	More likely than not	From likely to almost certain	From very likely to almost certain

The main results of the uncertainty analysis are included in the main body of this document. Additional details are presented in Appendix B, including the reasons for a lower certainty when the certainty categories >50% or >66% were selected.

3 | ASSESSMENT

This Section presents the results of the welfare assessment carried out for ToRs 2a–e and ToR 3. The results related to ToR 1 (current housing practices used to keep beef cattle) were published elsewhere (EFSA, 2025).

3.1 | Beef cattle husbandry systems in Europe

Beef cattle husbandry systems differ widely within the European Union (EU) due to the diversity of geographic and climatic conditions, housing and feeding systems, and genetics, and can be broadly classified into indoor, grass-based and feedlot systems. The largest proportion of beef cattle reared indoors are loose housed in groups. Loose housing refers to a system where animals are housed untethered in a pen, typically in groups, except for breeding bulls, which may be housed individually. A detailed description of husbandry and housing practices is provided in a separate document addressing ToR 1 of the mandate (EFSA, 2025).

3.2 | Housing conditions (indoors)

This Section discusses current practices, main welfare consequences (WCs) and respective prevention and mitigation strategies related to water access, flooring, nutrition and feeding, lack of outdoor access, lack of environmental enrichment, lack of outdoor access, mixing of cattle and high environmental temperatures for housed cattle. The text focuses mostly on fattening cattle as this is the animal category for which most evidence exists. Where data are also available for suckler cows and suckler calves, this is mentioned in the text.

3.2.1 | Water access

3.2.1.1 | *Current Practices*

Water is provided to beef cattle via bowls, water troughs or tanks and nipple drinkers (see EFSA, 2025). Bowls hold a few litres (from 0.5 to 3 L approximately) and are designed to serve one animal at a time. They may be self-filling to maintain constant levels or provide water on demand through a lever mechanism. In contrast, water troughs or open tanks are capable of holding up to hundreds of litres and are usually self-filling. A nipple drinker is a cylindrical-shaped nozzle made of plastic or metal; water is released into the animal's mouth when a valve rod is pushed. For images of bowl drinkers and troughs, see EFSA (2025).

There is no legislation at EU level regarding water quality and contamination levels for livestock drinking water. Studies on water quality and disinfection treatments for cattle (Llonch et al., 2023; Llonch, Verdú, Guivernau, et al., 2024; Llonch, Verdú, Martí, et al., 2024) have been based on the limits for human consumption.[9] The contamination of drinking water with infectious agents can be reduced or eliminated by disinfection, which is becoming more common on farms that do not use tap water. Chlorination is the most common treatment; however, as water pH plays a role on the efficacy of the treatment process, acidification may be needed to achieve an effective disinfection. Chlorination alone or chlorination with acidification reduces the total count of coliforms, *Escherichia coli, Clostridium perfringens* and faecal enterococcus (Llonch et al., 2023). Other water disinfection treatments include the use of hydrogen peroxide or chlorine dioxide. Water chlorination, without acidification or the addition of chlorine dioxide, were more efficient in eliminating coliforms than water disinfection using hydrogen peroxide (Llonch, Verdú, Martí, et al. (2024).

3.2.1.2 | *Welfare consequences*

The WCs selected as highly relevant for housed cattle as a result of inadequate water access are **'prolonged thirst'**, **'group stress'** and **'heat stress'**. **'Metabolic disorders'** were identified as a consequence of prolonged thirst and **'respiratory disorders'** as a consequence of group stress. The definition of each WC is available in Section 2.3 and the ABMs used to identify and assess each WC are defined in Section 3.10.

[9]Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. OJ L 330, 5.12.1998, p. 32–54.

3.2.1.3 | *Preventive and mitigating measures*

3.2.1.3.1 | *Prolonged thirst*

Prolonged thirst occurs when animals cannot fulfil their water needs over extended periods of time due to limited water availability or restricted access. Drinking behaviour can be assessed through drinking frequency, drinking duration and water intake. These parameters will depend on animal-related factors (animal category, age and dominance rank), water quality, environmental conditions (temperature and humidity) and drinker characteristics (type, flow and accessibility). This Section addresses water volume requirements of beef cattle, water quality and drinker type, while recommendations on the number of drinkers are provided under the Section 3.2.1.3.2 on 'group stress'.

3.2.1.3.1.1 | Water requirements

Daily water requirements vary depending on animal size, production stage and age (Wagner & Engle, 2021) with heavier animals having higher water intake requirements (Wagner & Engle, 2021; Winchester & Morris, 1956) and adult animals tolerating longer periods without water than younger animals (Jensen & Vestergaard, 2021). Daily water intake is estimated to be approximately three times the dry matter intake (DMI) (kg) under normal environmental conditions (< 14°C) (Ahlberg et al., 2018; Wagner & Engle, 2021). Table 5 summarises daily water intake that can be expected for different beef animal categories according to their body weight (BW), dry matter feed intake and environmental temperature. For instance at 4°C, heifers and steers of 360 kg are expected to drink 24 L/day, finishing cattle of 450 kg 33 L/day, suckler cows in the first months of lactation 43 L/day, bulls of 635 kg 30 L/day (adapted from Wagner & Engle, 2021).

Water intake is also influenced by environmental conditions. Water intake increases with rising temperatures, from approximately three times the DMI at temperatures below 10°C to about five times the DMI at 26.6°C (Wagner & Engle, 2021) (Table 5). Similar substantial increases have been observed in summer (with an average daily mean ambient temperature of 21.4°C and average daily maximum ambient temperature of 27°C) compared to winter (with an average mean ambient temperature of 4.2°C and average maximum ambient temperatures of −2.0°C) corresponding to up to 87% of the water intake in winter (Arias & Mader, 2011). Moreover, water intake rises with decreasing humidity and increasing solar radiation (Ali et al., 1994; Wagner & Engle, 2021).

For suckler cows, water intake also varies during lactation, with higher requirements during lactation compared to the dry period (Appuhamy et al., 2016). Water intake also increases with milk yield, with each additional litre of milk produced per day leading to an estimated increase of 1.3 L of water intake per day, as reported for dairy cows (Appuhamy et al., 2016; Jensen & Vestergaard, 2021).

TABLE 5 Total daily water intake of different beef categories as a function of body weight (BW), dry matter intake (DMI) and temperature (adapted from Wagner and Engle (2021) based on data from National Academies of Sciences Engineering Medicine (2016) and Winchester and Morris (1956)).

			Water intake, L/day	
Animal category	**BW, kg**	**Projected daily DMI, kg**	**At 4.4°C**	**At 26.6°C**
Heifers and steers	180–450	4.9–8.6	15.1–26.5	25.4–44.3
Finishing cattle	270–540	7.4–11.8	22.7–36.7	37.9–61.3
Cows nursing calves, first 3–4 months of lactation	410–500	11.3	43.2	67.8
Bulls	270–820	6.5–10.6	20.1–32.9	33.7–54.9

3.2.1.3.1.2 | Water quality

Indicators of water quality include faecal and microbial contamination, nitrates, salts and sulfate concentrations (Llonch, Verdú, Guivernau, et al., 2024; Wright, 2007). Cattle have been found to avoid water sources contaminated with 0.005% faecal matter when clean water was available (Willms et al., 2002) and to drink less water when contaminated water is the only source (0.5 and 1 mg faecal matter/g water) (Schütz, 2012). However, some studies have found that ruminants tolerate a high bacterial load in drinking water (Beede & Myers, 2000; Jemison & Jones, 2002) but with a consequent decrease in growth rates (Lardner et al., 2005; Llonch et al., 2023; Willms et al., 2002).

Cattle appear to show an aversion to sulfate salts in their drinking water. A high concentration of sulfates likely affects the palatability of the water, leading to altered drinking behaviour and reduced consumption when cattle are exposed to concentrations exceeding 4000 ppm SO_4 over an extended period (Zimmerman, 2003). Sodium sulfate (Na_2SO_4) seems to reduce water intake at high concentrations (López et al., 2021; Patterson, Johnson, Epperson, & Haigh, 2004) with a reported reduction of water intake of 35% with an addition of 5000 mg/L for heifers (Weeth & Hunter, 1971) and of 9% for 4500 mg/L for yearling steers (Johnson et al., 2004). However, other studies showed no difference in water intake when increasing sodium sulfate concentration up to 5000 mg/L (Digesti and Weeth (1976) for 2500 mg/L for heifers, Patterson, Johnson, Ward, and Gates (2004) for 2608 mg/L for lactating suckler cows, Evans et al. (2024) of 5000 mg/L for beef heifers). High concentrations of magnesium sulfate also reduce water intake (> 4000 mg/L, Grout et al. (2006)).

The source of water can influence water intake volumes. A preference study looking at water consumption and drinking behaviour of cattle of eight different types of water (direct entry water, unaerated water, aerated water, coagulated/chlorinated water, coagulated/ozonated water and three types of well water) in 2 groups of 12 yearling beef steers of ~300 kg in Canada concluded that the most consumed water type tended to be not chemically treated, and have sulfates and total dissolved solid levels < 2000 and 3000 mg/L, respectively, but this preference was not observed across all four trials (Lardner et al., 2013).

3.2.1.3.1.3 | Drinker type

Cattle drink by suction at a rate of up to 24 L/min and prefer to drink from open water surfaces (reviewed by Jensen & Vestergaard, 2021). Nipple drinkers do not allow natural drinking behaviour and have a very low flow rate. Bowls with low water flow and volumes restrict normal drinking behaviour and can extend drinking time (Jensen & Vestergaard, 2021), which in turn increases the risk of animals being displaced before they meet their water needs. According to Welfare Quality assessment protocol for dairy cows, bowl water flow rates lower than 10 L/min are considered insufficient (Welfare Quality, 2023b). In dairy cows, a review of evidence from different studies suggests that the water intake per bout and the number of visits to the drinker are lower when cattle are offered water in troughs compared to bowls (reviewed by Jensen & Vestergaard, 2021). A study investigating drinking behaviour in two groups of heifer calves after their arrival to feedlots (with each group being of composed of 85 heifers weighing on average 250 kg and 235 kg) observed that each heifer spent on average 7.9 min/day drinking over the 57-day study period split into a mean of 5.7 visits to the drinker (Buhman et al., 2000).

Periodic water samples allowing to verify the quality of water regarding bacterial load and composition are especially recommended for ground or surface water. The preferred drinker type from a welfare point of view are large volume troughs allowing a drinking rate of up to 15–20 L/min. Bowls are not recommended because they have a small volume and do not allow such a drinking rate. Considerations of the number, placement and accessibility of drinkers are important for preventing prolonged thirst; these are discussed below.

3.2.1.3.2 | *Group stress*

There are a few studies on the drinking behaviour of group-housed cattle but very limited data on the relationship between water availability and group stress in beef cattle, with most evidence resulting from studies on dairy cows. It is known that competition and social dynamics play a role in water access in cattle, with higher drinking activity and water intake reported in dominant cows compared to subordinate ones (Andersson et al., 1984). A recent study concluded that higher ranking dairy cows had fewer visits to the drinker, higher average daily water intake and higher number of visits to the drinkers during peak competition time compared to cows ranked lower in the social hierarchy (Foris et al., 2024).

3.2.1.3.2.1 | Water flow and drinker accessibility

A review on drinking behaviour and free water intake of dairy cattle (Jensen & Vestergaard, 2021) observed that dairy cattle housed indoors tend to visit the drinker 5–20 times a day, but this is highly dependent on drinker type (Jensen & Vestergaard, 2021). Cattle with restricted water access tend to drink more at each drinking opportunity, however, this increased intake per drinking bout may still be insufficient to meet their water needs (Payne, 1965; Schmidt et al., 1980; Mulenga, 1994; Hatendi et al., 1996; Sibanda et al., 1997; as cited in Williams et al., 2016, p. 1088) because the rumen volume limits how much water can be consumed at each drinking opportunity (Nicholson, 1989). When cattle are housed, peaks of water intake are seen in association with feeding events (reviewed by Jensen & Vestergaard, 2021). Social hierarchy dynamics also impact drinking behaviour and having additional drinking points could be a strategy to reduce group stress. According to the Welfare Quality (2023b) protocol, one water bowl per 10 dairy cows or 6 cm of trough length per cow is sufficient to meet their behavioural and physiological needs. In a study comparing the effects of a lower drinker density (1 bowl per 10 cows) with a higher one (3 bowls per 10 cows) on the drinking behaviour and number of displacements of dairy cows, it was concluded that dominant cows monopolised access to the drinkers and drank on average 5 L more water when the drinker density was lower compared to when more drinkers were available (Nizzi et al., 2023). Based on these results, the authors argued that such drinker densities (1 drinker per 10 cows) are insufficient for dairy cows (Nizzi et al., 2023), but it is unknown whether this would apply to beef cattle as well. When evaluating water intake depending on number of troughs provided, Marti et al. (2020) did not find an increase in water intake in fattening bulls housed in partially open barns with 18 bulls/pen when provided with one water trough per pen compared to two water troughs. These different findings may be due to the fact that water availability is higher when it is provided via a trough than via a bowl.

For group sizes commonly observed in beef farming (8–14 animals per pen) the presence of more than one drinker per pen reduces the risk of prolonged thirst in case of drinker malfunctioning or drinker dirtiness. Placing drinkers outside the lying area (e.g. on one of the edges of the pen) facilitates access to them. It is recommended to provide at least 6 cm of trough length per animal or a minimum of one water bowl per 10 animals.

3.2.1.3.3 | *Heat stress*

For a discussion on the relationship between heat stress and welfare in housed cattle, see Section 3.2.7 on high environmental temperatures. For a discussion on water requirements depending on temperature, see the Section 3.2.1.3.1 on 'prolonged thirst'.

3.2.1.3.4 | *Linked welfare consequences*

'Metabolic disorders' are linked with 'prolonged thirst' because feed intake is reduced when water is restricted. Water is involved in the ingestion, chewing, swallowing, digestion, absorption and transport of nutrients (Silanikove, 1992; Utley et al., 1970) and it has been estimated that restricting the volume of water ingested can reduce feed intake between 9% and 16% (Williams et al., 2016). '**Respiratory disorders'** are linked with 'group stress'. This is particularly relevant in the assembly centre before cattle are transferred to the fattening unit or upon arrival at the farm when animals are mixed with individuals from other farms in the same pen. Shared access to water points across pens markedly increased the risk of bovine respiratory disease (BRD) (odds ratio (OR) 4.3, 95% credible interval: 1.4–10.3) in a longitudinal study with 35,131 animals clustered within 14 feedlots in Australia (Hay et al., 2016). Another hazard identified was adding animals to pens over multiple days compared to placing all animals in a pen in a single day, but with a lower OR (1.9, 95% credible interval 1.2–2.8) (Hay et al., 2016). The results of this study indicate that water troughs should be positioned in the middle of the pen to avoid transmission of pathogens through water sharing across pens. This is especially relevant when cattle are sourced from different origins or arrive from outdoor systems and are placed in pens (Hay et al., 2016). However, having drinkers in the middle of the pens is not practical for cleaning, and may cause lower water intake as the drinker would be far from the feeder. It may also cause more aggressive interactions due to the transit in the resting area.

3.2.1.3.5 | *Welfare consequences relevant to suckler cows and suckler calves*

'**Prolonged thirst'**, **'heat stress'** and **'group stress'** were selected as highly relevant welfare consequences experienced by suckler cows and suckler calves exposed to water restriction. The higher water requirements of a suckler cow are discussed above. The water requirements of suckler cows nursing calves will likely be higher than that of fattening bulls in normal environmental conditions (45 and 54 L for bulls and nursing cows at 3–4 months of lactation, respectively, when ambient temperature is 14°C) (Wagner & Engle, 2021). It is estimated that on days warmer than 27°C), a suckler cow can drink up to 68 L a day (Wagner & Engle, 2021).

3.2.1.4 | *Conclusions on water access*

1. Water is an essential nutrient for cattle, with water requirements varying depending on age, size of cattle, production stage, diet, feed intake and environmental conditions including temperature, humidity and solar radiation.
2. Cattle drink water by suction at a rate of up to 24 L/min. Water troughs allow natural drinking behaviour, while water bowls have limited surface area, depth, volume and water flow. Volume and water flow are critical factors in ensuring water availability.
3. Nipple drinkers typically have low flow rates and do not allow natural drinking behaviour (certainty > 90%).
4. Highly relevant welfare consequences of restricted access to water are 'prolonged thirst', 'group stress' and 'heat stress'.
5. Prolonged thirst occurs when cattle are unable to meet their water requirements due to excessive competition or restricted access to water.
6. Competition for water increases, leading to group stress particularly for subordinate cattle, when availability is restricted due to limited water flow, drinker size or number of drinkers. This can reduce water intake and increase the risk of injuries (certainty > 90%).
7. For dairy cows, a minimal drinking places:animals ratio of one drinker per 10 cows or 6 cm of water trough space per cow is required to meet both their behavioural and physiological needs throughout summer and winter (certainty > 66%). Although specific data for beef cattle are lacking, this ratio is expected to suffice, given that dairy cows at the peak of lactation have higher water demands than beef cattle.
8. Providing drinkers away from the lying area improves accessibility of drinkers (certainty > 66%).
9. Reduced growth performance is associated with the ingestion of water contaminated with faeces, containing elevated levels of pathogenic bacteria (certainty > 90%).
10. Water quality is reduced by the presence of nitrates, sulfates and salinity.

3.2.1.5 | *Recommendations on water access*

1. Drinking water free from faecal and microbial contamination must be available at all times. Therefore, daily inspection and regular cleaning of water facilities are necessary.
2. Water troughs are preferable, and at least 6 cm of trough space per animal should be provided. Nipple drinkers are not recommended.

3. A minimum of two water sources per pen should be available to reduce the risk of prolonged thirst in case of malfunctioning or dirtiness.
4. In case water bowls are used, sufficient water flow should be maintained and at least one water bowl should be provided for each 10 animals.
5. Positioning drinkers near service aisles and in proximity to feeders enhances animals' access, ease of maintenance and inspection.
6. To ensure water quality, water should be periodically analysed, particularly when the water sources are wells, rivers, lakes or reservoirs. If water quality is compromised due to microbial contamination, elevated concentrations of nitrates, sulfates or high salinity, appropriate water treatments should be carried out.

3.2.2 | Flooring

3.2.2.1 | *Current Practices*

Floor types used in beef cattle loose housing can be broadly classified into three main types: concrete slatted floors, concrete slatted floors covered with rubber mats and bedded floors. Hard and dirty floors are the main hazards identified in this context.

3.2.2.1.1 | *Solid floors, concrete slatted floors (CSFs) and CSFs covered with rubber mats (RMs)*

Solid floors are typically made of concrete and are usually bedded with loose material such as straw, sawdust, wood chips or, more rarely, sand (Lensink et al., 2013). Straw is the most common bedding material (Lensink et al., 2013; Schulze Westerath et al., 2009). The use of litter requires its regular renewal to not impair the cleanliness of the animals. In sloped floor systems, the bedded resting area may have a slope of between 8% and 10% and the mixture of manure and bedding material is gradually pushed downwards by the trampling of cattle. The manure is then removed from the lowest point while clean straw is added to the highest areas (Schneider, 2020).

CSFs consist of concrete sections separated by gaps, which can be either narrow and long, or consist of broader panels with shorter sections (sometimes also called 'waffle slats'). CSFs are suspended above slurry pits or channels to facilitate the drainage of liquids and faecal material. Housing beef cattle in CSFs is a common system in the European Union. However, in recent years there has been a tendency to cover or replace CSFs with specially constructed slatted RMs designed to match the gap profile of the concrete slats to improve animal comfort and facilitate locomotion (Figure 3).

In most beef cattle housing systems, the type of flooring does not differ between feeding and resting areas. However, there are also systems with a differentiated lying area that feature straw-bedded areas alongside solid or slatted sections in the feeding area.

There is considerable evidence on cubicle housing of dairy cows (EFSA AHAW Panel, 2023b), but there is limited knowledge on the number of beef cattle housed in cubicle systems, and whether bedding materials or RMs are used in these cases (Lawrence et al., 2022). Some suckler cows and their autumn-born calves are housed in cubicles with a straw-bedded cubicle base and a calf creep feed area. When male fattening cattle are housed in cubicles, RMs are the most common cubicle base.

FIGURE 3 Beef cattle housed in a pen with concrete slatted floor covered with rubber mats (© Giulio Cozzi).

3.2.2.2 | *Welfare consequences*

The WCs selected as highly relevant for housed cattle as a result of hard and slippery flooring are **'resting problems'**, **'restriction of movement'**, **'soft tissue lesions and integument damage'**, **'locomotory disorders (including lameness)'** and **'respiratory disorders'**. Restriction of movement is linked with the **'inability to perform comfort behaviour'**, **'inability to perform sexual behaviour'** and **'inability to perform play behaviour'**. Resting problems are linked with welfare consequence **'inability to chew and/or ruminate'**. The presence of anti mounting devices in beef indoor pens is associated with the welfare consequence 'inability to perform sexual behaviour'. The definition of each WC is available in Section 2.3 and the ABMs used to identify and assess each WC are defined in Section 3.10.

3.2.2.3 | *Preventive and mitigating measures*

3.2.2.3.1 | *Resting problems, restriction of movement and inability to chew and/or ruminate*.

This section discusses resting problems and restriction of movement resulting from flooring characteristics. For a discussion of the impact of restricted space allowances on resting problems see Section 3.3 on minimum space allowance.

3.2.2.3.1.1 | Floor hardness and slipperiness

Hard flooring has been associated with poor lying comfort including changes in the lying down and standing up movements, and slippery underfoot conditions increase the risk of slipping, injury and abnormal transitions between postures. Some of the most important ABMs to evaluate these aspects are the duration of standing and lying behaviour, the number of lying bouts, and deviations from the normal movements involved in getting up and lying down (Absmanner et al., 2009; Elmore et al., 2015; Haley et al., 2000; Lidfors, 1989). Studies evaluating resting problems and restriction of movement have focused mostly on a comparison of the behaviour of animals kept on CSFs, CSFs covered with RMs and bedded floors. These are discussed below.

There is evidence from experimental studies that CSFs can cause beef cattle to change their normal lying down and standing up movements compared to CSFs covered with RMs or bedded floors. Compared to CSFs, RMs flooring facilitates natural standing up and lying down movements of fattening cattle by providing more grip during those movements and reducing pressure on carpal joints (Platz et al., 2007). It has also been shown that compared to CSFs, RMs improve bulls' confidence to stand and move (Cozzi et al., 2013). The frequency of atypical transitions, lying down interruptions or variables showing discomfort were observed to be more frequent in bulls housed on CSFs compared to RMs pens (Absmanner et al., 2009; Brscic et al., 2015; Gygax, Mayer, et al., 2007). Bulls housed on CSFs performed transitions more cautiously as the fattening cycle progressed (Magrin, Gottardo, Brscic, et al., 2019), and got up less frequently after reaching 15 months of age (Platz et al., 2007). Similar observations were reported in further studies (Absmanner et al., 2009; Andreae, 1979; Andreae & Smidt, 1982; Magrin, Gottardo, Brscic, et al., 2019; Platz et al., 2007). Bulls housed in pens with CSFs had more lying down interruptions (Absmanner et al., 2009; Brscic et al., 2015; Gygax, Mayer, et al., 2007). Fewer lying down interruptions and a higher frequency of lying bouts are interpreted as an indication of less hesitancy and more confidence in changing positions. Other effects reported in bulls housed in RMs compared to CSF pens include less inactivity and resting time, increased social interactions and a lower proportion of animals treated for locomotory problems (Brscic et al., 2015). However, an association between RMs flooring and dirtiness of coats has also been reported, likely due to the smaller draining gaps of RMs flooring compared to CSFs (Brscic et al., 2015).

The effects of bedded flooring on beef cattle lying behaviour have also been researched. Steers kept on straw displayed less abnormal movements during these transitions and tended to lie down and stand up more frequently than when kept on CSFs (Graf, 1984). Similarly, finishing bulls on straw bedded solid flooring had a higher number of lying bouts and a lower proportion of interrupted lying down and standing-up movements (Gygax, Mayer, et al., 2007a) compared to both CSFs and RMs. Straw flooring was associated with a higher number of short standing bouts compared to RMs, and these were higher in RMs than in CSFs. However, no differences in total lying time were observed across the three floor types (Gygax, Mayer, et al., 2007a; Keane et al., 2018a). The fact that straw was associated with a higher number of lying bouts and short standing bouts compared to rubber-coated slats was interpreted as indicating that the quality of the straw lying surface was higher than RMs. No differences in lying time across different types of floor were also reported in a more recent meta-analysis on the relationship between floor properties and beef cattle lying behaviour.

In summary, these studies indicate that compared to CSFs, RMs mitigate some of the resting problems and restriction of movement observed in CSFs, but RMs increase animal dirtiness compared to CSFs. Additionally, while overlaying CSFs with RMs improves traction, RMs do not provide as comfortable a lying area as straw bedding, which is associated with the highest comfort and less resting issues. RMs therefore cannot be considered equivalent to straw bedding. Hence, straw bedded floors are the preferred option to avoid restriction of movement and allow comfortable resting.

3.2.2.3.1.2 | Cubicle floor slope

The effect of the lying area slope on the behaviour and dirtiness of fattening bulls using cubicles with three different mat types (a RM with nubs on the underside; a waterproof textile mattress, with tubes filled with granulate on the underside; a foamed mat) was examined in a cross-over study (Schulze Westerath et al., 2006). The slope of the lying area was 3, 5, 8 and 10%. The authors concluded that a 5% slope of the lying area was optimal in cubicles for fattening bulls as a compromise between lying area dryness and lying comfort. The daily lying time decreased with steeper lying area slope on two of the mat types studied (RM and mattress), indicating a decrease in lying comfort. A study on dairy cows showed a preference for a flooring with a slope of 3% over one with 10% (Van Hoof, 2018), while in the study from Wilson et al. (2022) cows did not show a clear preference between a free-stall area with a slope of 4.5% and one of 9.3%. However, when using the steepest stalls, cow spent less time lying down and ruminating (Wilson et al., 2022). Therefore, a lying area with a slope between 3 and 5% seems to better suit the behavioural needs of cattle.

3.2.2.3.2 | *Soft tissue lesions and integument damage and locomotory disorders (including lameness)*

Another issue of CSFs is that this type of flooring is often associated with injuries (Brscic et al., 2015; Platz et al., 2007) such as tail tip lesions, and carpal and tarsal joint lesions.

3.2.2.3.2.1 | Floor type and tail tip lesions.

Tail tip necrosis was reported in farms with bulls housed in slatted floors (Madsen & Nielsen, 1985). Tail trampling due to close confinement most likely causes the initial lesion, but hard flooring such as CSFs, hot season and BW above 200 kg contribute to its development and severity (Madsen & Nielsen, 1985). Schrader et al. (2001) also reported that the frequency of severe tail tip lesions in fattening bulls was highest on slatted floors and lowest in straw floors. CSFs have also been identified as a risk factor in a USA survey, where 'producers with slatted floor barns were 19.8 times more likely to have animals treated or slaughtered for tail tip necrosis than were those with solid floor' (Drolia et al., 1991).

Space allowance also plays a role on the tail tip lesions formation (Ingvartsen & Andersen, 1993). More tail tip lesions were observed in smaller pens compared to larger pens (i.e. from 1.77 m^2/animal to 3.73 m^2/animal) and the number of lesions increased with a higher live weight of bulls (from 150 to > 500 kg) (Schrader et al., 2001). Other studies reported that lower space allowances (from 1.4 to 3.1 m^2/animal) led to more serious tail lesions (Andersen et al., 1997), and that the incidence of severe tail lesions was higher in animals housed on CSFs or animals first housed on straw bedding followed by CSFs, compared to rubber-coated slatted floors or straw-bedded floors (Rouha-Muelleder et al., 2012). In sum, the development of tail-tip injuries in beef cattle is more likely if animals are kept in CSFs and the risk increases if these are combined with a reduced space allowance and with a high live weight of the animals.

3.2.2.3.2.2 | Floor type and carpal and tarsal joint lesions

The carpal joints of fattening bulls that had been housed either on concrete or rubber-coated CSFs from 6 to 16 months of age were examined at slaughter (Wierenga, 1990). The mean damage score of the carpal joints of bulls housed on concrete was 2.7 compared with 2.1 for bulls on rubber-coated slats. However, this result is difficult to interpret as the scoring system ranged from 0 to 3, and the difference was not tested statistically. The quality of different lying surfaces on lesions and swellings at the carpal and tarsal joints on 623 bulls was examined in a further study (Schulze Westerath et al., 2007); bulls housed on straw had the smallest lesion scores at the joints, while CSFs had the highest lesion scores at the carpal joints, with intermediate values on RMs and in cubicles (provided with five different types of soft lying mats). At the tarsal joints, lesion scores were similar on CSFs and RMs and in the same range or worse on most mats in the cubicles (Schulze Westerath et al., 2007). A similar observation was reported in a study where bulls housed on CSFs had most carpal joint lesions compared to those housed on RMs, on straw, or on a combination of straw and CSFs (Rouha-Muelleder et al., 2012).

According to Magrin, Gottardo, et al. (2020), a small difference in the dimension of slot openings and slat width on fully RMs pens (Control: 30 × 100 mm vs. Test: 35 × 90 mm) led to a slight tendency to develop more swellings on bulls' hock and carpus (0.55% Control vs. 3.18% Test). The authors suggested that 'the slight reduction in slat width of test floors could have decreased the contact area between joints and the ground, increasing the pressure and friction at the hock level' (Magrin, Gottardo, et al., 2020).

3.2.2.3.2.3 | Floor type and lameness

One of the key factors contributing to the development of lameness in beef cattle is the type of flooring. However, as there is often an interaction between flooring types and space allowance, this can lead to confounding effects in some studies. Nutrition may also play a role on lameness development; this is discussed in Section 3.2.3.

A survey study in 18 farms (nine with slatted floors and nine with straw bedding) from 1983 reported that the incidence of lameness was 4.75% among steers housed on slatted floors and 2.43% among steers in straw yards. Septic traumatic pododermatitis following hoof penetration and cellulitis of the limb were more prevalent among cattle kept on slatted floors, whereas general necrotic lesions were more common in cattle kept in straw-bedded pens (Hannan & Murphy, 1983). A further cross-sectional study on fattening bulls kept in bedded housing systems in a total of 63 farms in Austria, Germany and Italy (housing from 41 to 700 animals) revealed similar average lameness prevalences (1.8%–2.3%, range 0%–23%; Kirchner et al., 2014). The prevalence of locomotor apparatus diseases in one large farm (data collected from about 18.000 animals over a one-year period) in Italy with straw bedded pens was 3.97% for intact bulls (Compiani et al., 2014). A more recent study published in 2019 reported that the prevalence of mild lameness in bulls on eight Italian finishing farms was not affected by flooring type (1.23% overall), however severe lameness (requiring the early culling of the animal) was more prevalent in CSF pens (1.86%) than deep litter pens (0.56%) (Magrin, Gottardo, Brscic, et al., 2019). Regardless of the type of flooring system, it has been reported that the claw condition of fattening bulls deteriorates with increasing BW (Stanek et al., 2004) and age (Fjeldaas et al., 2007).

Oehme et al. (2018) showed that claws bore lower pressure loads on RMs compared with concrete, which may lead to a reduction of mechanically induced claw lesions. Conversely, in dairy cattle the low abrasiveness of RMs was shown to increase the occurrence of overgrown claws at the toe level resulting in longer dorsal walls and diagonal lengths compared to concrete flooring (Telezhenko et al., 2009). Wechsler (2011) has reiterated this fact suggesting that soft floors cause insufficient claw wear resulting in impaired claw health.

However, on RMs with incorporated corundum and radial profile in dairy cow cubicle houses, skid resistance and step length were increased and the length of slides decreased in comparison to plain RMs (Pöllinger & Zentner, 2016). It can be presumed that increased roughness of the floor also leads to increased hoof wear, although it must be kept in mind that floor abrasiveness may be reduced under long-term use (Steiner et al., 2011). These authors recommend equipping about 20% of the floor area in dairy cattle barns with abrasive materials to ensure sufficient claw wear. However, it must be considered that loose housed dairy cows walk longer distances than beef cattle that are usually kept in smaller groups and at lower space allowances. Floor abrasiveness is relevant also because functional claw trimming is not a routine practice in beef cattle (due to the short fattening cycle and the high risk of injury to the trimmers) (Tunstall et al., 2021).

3.2.2.3.2.4 | Slats design and lameness

Kirchner et al. (1987) investigated the loading on the claws in relation to different types of slatted floors. If the foot is placed partially over a space between the slats, the loading on the parts of the soles that are in contact with the slats is increased. Fattening bulls of 450 kg BW were measured to have a mean footing contact area of 53 cm^2, and by increasing the width of the slots in a slatted floor from 15 to 25 mm, the mean pressure on the soles of the claws rose from 2.36 to 3.02 Pa. Kirchner et al. (1987) observed that, at a pressure below 2.5 Pa, claw health was apparently not affected.

Magrin, Gottardo, et al. (2020) compared two rubber covered concrete slatted floors, different dimensions of slot openings and slat width (Control: 30 and 100 mm vs. Test: 35 and 90 mm) regarding claw disorders in fattening bulls. Interdigital hyperplasia and white line fissure were detected only in Control pens (2.6%). Overall, a higher prevalence of asymmetric claws was observed in Control pens, even though corkscrew (6.67%) and scissor claws (10.0%) were only found in Test bulls. Overall differences in slat design and slot width did not seem to affect claw health and disorders given their low prevalence (Magrin, Gottardo, et al., 2020). These results do not provide sufficient basis for specific recommendations on slat opening dimensions and slat width when rubber covered slatted floors are used.

3.2.2.3.2.5 | Floor cleanliness and lameness

The cleanliness of flooring is an important factor for claw health in terms of infectious diseases and slipperiness of flooring surfaces because the friction of a surface does not only depend on the type of surface but also on its self-cleaning properties, e.g. size of slots or the cleaning frequency. Although no specific studies on the relationship between floor hygienic conditions and lameness in fattening beef kept indoors were found, studies in feedlots indicated that when the floor became muddy or very humid, the skin of the claws softened and this increased the risk of claw lesions and infections (Currin et al., 2005; Stokka et al., 2001). Dirtiness of the floor has also an effect on integument cleanliness (see also Section 3.2.2.3.4 on 'inability to perform comfort behaviour').

3.2.2.3.3 | *Respiratory disorders*

The type of flooring plays an important role in air quality. Particulate matter (dust) can be released from bedding materials, but this will ultimately depend on the straw quality and litter management (e.g. they ways in which straw is placed in the pen). In turn, noxious gases can be released from urine, faeces, hair and skin residues that accumulate on solid floors or on the surface below the slatted floors (Cambra-López et al., 2010).

To the authors' knowledge the only studies focusing on the relationship between concentrations of particulate matter and indicators of respiratory disorders were carried out on calves. The endotoxin concentration in 47 calf-rearing farms with solid concrete floors bedded with straw (with the exception of one farm which had slatted floor combined with a straw bedded floor) ranged widely (range: 2.32–901.0 Endotoxin Units (EU)/m^3 and 0.03–30.3 EU/µg). A cut-off of 8.5 EU/µg in the dust mass was suggested to predict the presence of mild lung lesions (≥ 1 cm consolidation assessed by thoracic ultrasonography) in calves (van Leenen et al., 2021). An earlier study based on cross-sectional data from 60 farms by the same authors reported a relationship between a prolonged exposure to > 4 ppm of ammonia with an increased risk of such mild lung lesions in calves (van Leenen et al., 2020). This cut-off value is just under the one proposed by Lundborg et al. (2005) who suggested that exposure of calves to ammonia concentrations > 6 ppm increases the risk of respiratory diseases. No studies on appropriate levels of ventilation to avoid poor air quality are known to the authors.

3.2.2.3.4 | *Linked welfare consequences*

Restriction of movement is linked with the **'inability to perform sexual behaviour'**. The inability to perform sexual behaviour is mainly related to inappropriate flooring, with bulls and cows being unwilling to mount when housed on slippery surfaces. A higher flooring traction improves bulls' confidence to exhibit a greater number of mounting events compared to CSFs (Cozzi et al., 2013). While several studies reported a greater number of mountings in bulls housed on RMs than in bulls housed on CSFs (Elmore et al., 2015; Magrin, Brscic, et al., 2020; Ruis-Heutinck et al., 2000), this was not observed by Platz et al. (2007) who observed similar number of mountings across both types of flooring. Mounting frequency was higher in beef cattle housed on straw compared in CSFs (Absmanner et al., 2009).

3.2.2.3.4.1 | Anti-mounting devices

Although not strictly linked to flooring, it was considered important to also discuss other housing aspects that result in the inability to perform sexual behaviour as it is the case of 'anti-mounting devices (Figure 4). Such anti-mounting devices consist of three or four horizontal bars running across the pen and placed at a height circa 30–40 cm above the withers of the animals. These are still used in MS such as Austria, Germany (although currently being phased out) and France. A fattening animals will also experience inability to perform sexual behaviour when anti-mounting devices are present. Although no information was found in the literature on the welfare consequences of such devices, they fully restrict mounting and should not be used.

FIGURE 4 Anti-mounting devices in a beef cattle pen (© Florian Krottenthaler).

Restriction of movement is also linked with the **'inability to perform comfort behaviour'** when flooring is slippery and does not provide sufficient grip for cattle to keep balance or easily change posture. Comfort behaviour is more frequently expressed by animals housed on RMs overlaid on CSFs compared to bare CSFs, due to improved traction (Absmanner et al., 2009; Elmore et al., 2015; Magrin, Brscic, et al., 2020; Platz et al., 2008). However, the effect of flooring on comfort behaviours was not consistently observed across studies. Floor type did not affect social, stereotypic or self-grooming behaviour of cattle (Lowe et al., 1999; Smits et al., 1995), nor were differences on the frequency of grooming observed in cattle housed at 3 m^2 per animal in either deep littered floor (straw) or CSFs (Gottardo et al., 2003). No differences were observed on the frequency of behaviours such as caudal licking on three or on four legs in bulls housed in either CSFs, RMs and straw bedded pens during their fattening cycle (Absmanner et al., 2009). The inability to perform comfort behaviour may be more severe in dirty floor conditions which lead to soiling of the hair coat and skin which in turn may result in itching. RMs have been associated with poorer hygienic conditions and higher frequency of dirty animals compared to CSFs due to a reduced total draining gap surface of the floor (Brscic et al., 2015; McGettigan et al., 2022). In line with this, Lowe et al. (2001) reported cleaner animals accommodated on rubber strips placed directly over slats compared with those accommodated on holed RMs posed over the slats, as the former had a greater drainage area. Bedded pens provide good grip and prevent the inability to perform comfort behaviour; but as they tend to accumulate more dirt than CSFs or RMs, a frequent cleaning and renewal of the bedding material is important to ensure animal cleanliness (Iglesias et al., 2018).

Restriction of movement resulting from slippery flooring is also likely linked with the **'inability to perform play behaviour'** (specifically locomotor play) because floors with minimal traction are likely to hamper play behaviour. Although no specific studies on the relationship between play behaviour and flooring conditions were found for housed cattle, results from studies in other cattle categories (such as calves) suggest this may also impact fattening cattle. For a discussion on this aspect, see Section 3.2.4 on lack of outdoor access.

3.2.2.3.5 | *Welfare consequences relevant to suckler cows and suckler calves*

No additional welfare consequences related to flooring were identified specifically for suckler cows and suckler calves.

3.2.2.4 | *Conclusions on flooring*

1. Flooring systems are broadly classified into concrete slatted floors (CSFs), CSFs overlaid with rubber mats (RMs) and bedded floors.
2. Bedded floors usually have a concrete base with loose material on top. Straw is the most common bedding material for fattening cattle accommodated indoors, but sawdust, wood chips or more rarely sand are also used.
3. CSFs are a common type of flooring system in fattening cattle but in recent years there has been a tendency to overlay the slats with rubber mats.
4. Highly relevant welfare consequences of hard and slippery floors are resting problems, restriction of movement, soft tissue lesions and integument damage, locomotory disorders (including lameness) and respiratory disorders. Restriction of movement is linked with the inability to perform comfort behaviour, inability to perform sexual behaviour and inability to perform locomotor play behaviour. Resting problems are linked with the welfare consequence inability to chew and/or ruminate.
5. CSFs cause animals to change their normal lying down and standing up movements. This results in more time standing on CSFs than in RMs or bedded floors (certainty > 90%).
6. The risk of lameness is higher on CSFs than on bedded floors due to the hard slippery floors and gaps between the slats (certainty > 90%).
7. Resting problems are more frequent in CSFs and RMs compared to bedded floors with clean bedding (certainty > 90%).
8. In addition to allowing comfortable resting, clean straw bedding provides an opportunity to ingest fibre, chew and ruminate (certainty > 90%).
9. The risk of slipping and injury is higher on CSFs (certainty > 90%) compared to RMs and bedded floors.
10. Restriction of movement due to slippery floors is mitigated by overlaying CSFs with rubber mats (certainty > 90%). The positive effect of RMs is more pronounced in heavier than in lighter cattle (certainty > 90%).
11. RMs improve the resting of beef cattle compared to CSFs. The frequency of lying down interruptions or deviations from the normal getting up and lying down movements is lower on RMs (certainty > 90%) compared to CSFs.
12. While RMs improve traction, they do not provide as comfortable a lying area as straw bedding and cannot be considered equivalent to straw bedding (certainty > 90%).
13. RMs with low abrasiveness can lead to an increase in the occurrence of overgrown claws compared to CSFs (certainty > 90%).
14. Cleanliness of flooring is an important factor in claw health in terms of infectious diseases and slipperiness of flooring surfaces (certainty > 90%). If concrete slatted floors are covered with rubber mats, the drainage area/void space may be reduced, leading to increased soiling (certainty > 90%).
15. The prevalence of skin lesions on the limbs and the tail is greater in cattle housed on CSFs compared to RMs and bedded floors (certainty > 90%).
16. Due to the higher flooring traction, more sexual and comfort behaviour is shown in animals housed on RMs and bedded floors compared to CSFs (certainty > 90%).
17. High levels of particulate matter, noxious gases and infectious agents in the air increase the risk of respiratory disorders.

3.2.2.5 | *Recommendations on flooring*

1. A choice of different floors for different activities appears to be the best way to improve welfare. Where possible, provide bedded solid floors in the lying area in preference to concrete slatted floors.
2. The quantity and replenishment frequency of straw bedding should ensure dry underfoot conditions and animal cleanliness, and also facilitate foraging, exploratory, resting and comfort behaviours.
3. High-quality straw litter (i.e. dry litter with low levels of particulate matter) should be used to minimise the emission of dust and mould. Studies on the amounts of other bedding materials should be carried out.
4. Overlay concrete slatted floors with non-slip rubber mats, keep them clean and make sure the drainage area/void space allows sufficient drainage.
5. Cubicles are not recommended for growing and fattening cattle because there is a risk that cubicle dimensions do not match the animal size due to the dynamic growth of fattening cattle and increase risk of soiling in male animals.

3.2.3 | Nutrition and feeding

3.2.3.1 | *Current Practices*

3.2.3.1.1 | *Feeding practices – fattening cattle*

Young beef bulls and heifers under intensive production are usually raised in their suckler farms of origin and then transferred to the fattening farms to complete their growing cycle (Herve et al., 2020). Upon arrival to the fattening farms, beef cattle are transitioned from forage-based to concentrate-based diets during the early finishing period. After the completion of this adaptation to the new feeding regime cattle are fed high-concentrate diets with limited amounts of forage to maximise daily gain (Campbell et al., 1992).

For this reason, concentrate feeding is integral to beef production systems, especially during indoor winter periods, as well as while on pasture, particularly in autumn at the end of grass vegetative stage. Concentrates play a vital role in achieving performance targets. Increasing concentrate levels in the diet reduces forage intake (due to substitution effects) but promotes daily and carcass weight gains.

Feed for fattening cattle is usually provided as a total mixed ration (TMR) in order to ensure a balanced nutrient intake. TMR comprises a mix of forage and concentrate with ratios ranging from 45:55 to 10:90 (Cozzi & Gottardo, 2005; Nagaraja & Titgemeyer, 2007). The daily diet is generally offered in a single delivery, but to prevent sorting towards out some components of the TMR it is either delivered several times a day (e.g. using machinery) or via automatic feeding systems. Some fattening systems provide the concentrate and a source of forage (often straw) in separate feeders, leaving cattle the free choice of intake (Verdú et al., 2015, 2017).

3.2.3.1.2 | *Feeding practices – suckler cows*

Suckler cows' diets are mainly based on forage, are lower in energy and tend to be of lower quality (e.g. lower quality silage) than those of fattening beef cattle. In grass-based systems, to match feed demand and feed supply, the average calving date is typically around mid-March to coincide with the start of the grass grazing season. The mobilisation and deposition of body reserves are key components of suckler cow nutrition, whereby cows mobilise body fat during the indoor winter period and replenish it again post-turnout to grass (Drennan & Berry, 2006; Drennan & McGee, 2009). Central to feeding suckler cows kept indoors is having them in optimum body condition pre- and post-calving. Energy restriction pre-calving to prevent over-conditioning is achieved by offering moderate digestibility (ca. 660 g/kg digestible dry matter) grass silage *ad libitum*. When feeding high quality grass silage, the energy restriction is achieved by replacing part of it with straw.

3.2.3.2 | *Welfare consequences*

The WCs selected as highly relevant for beef cattle because of nutrition and feeding were **'metabolic disorders'**, **'gastro-enteric disorders'**, **'group stress'**, **'inability to chew and/or ruminate'** and **'inability to perform exploratory or foraging behaviour'**. 'Metabolic disorders' are linked with **'locomotory disorders (including lameness)'**. While 'prolonged hunger' can also be present in cattle arriving on farm, this is considered to be a consequence of transport and hence is not further discussed in the context of this Scientific Opinion. The definition of each WC is available in Section 2.3 and the ABMs used to identify and assess each WC are defined in Section 3.10.

3.2.3.3 | *Preventive and mitigating measures*

3.2.3.3.1 | *Metabolic disorders and gastro-enteric disorders*

Subacute rumen acidosis (SARA) is the dominant metabolic disorder in beef cattle and its occurrence has been associated with the provision of diets characterised by excessive amounts of starch and an insufficient content of structured fibre. At rumen level, the excessive starch load might cause a temporary imbalance between production and absorption of fatty acids with a consequent drop in ruminal pH (Kleen et al., 2003). When a prolonged condition of low rumen pH (5.5–5.0) persists, bacteria may invade the rumen wall and which may eventually lead to ruminitis and severe damage to the rumen mucosa papillae (Wiese et al., 2017). The intake of an excess of dietary cereals increases the proportion of the ingested starch that bypasses fermentation in the rumen and digestion in the small intestine reaching distal sections of the gut (Li et al., 2012). This can induce rapid fermentations, also in the large intestine, leading to different degrees of diarrhoea (Sanz-Fernandez et al., 2020). The monolayer structure of the epithelium of the large intestine, compared to the more complex structure of the ruminal wall, is more sensitive to both the high acidity and the toxins concentration induced by a grains-based SARA, which increases the risk of a dietary induced systemic inflammation (Khiaosa-Ard & Zebeli, 2018). Clinical signs of SARA can vary depending on the severity of the acidotic load and include different degrees of anorexia, dehydration, decreased rumen motility and diarrhoea (Sanz-Fernandez et al., 2020). Hyperkeratosis, signs of ruminitis, ulcers and star scars are the most common ruminal lesions related to SARA observed *post-mortem* in beef cattle (Magrin et al., 2021).

Feeding less grain and more fibre is the main preventive measure against SARA (González et al., 2012; Magrin et al., 2021). The EFSA Opinion on the welfare of cattle kept for intensive beef production (EFSA AHAW Panel, 2012b) recommended the inclusion of more than 15% of physically effective fibre (peNDF) in TMR to reduce the risk of SARA, based on results from Mertens (1997). This author defined the minimum particle size of effective fibre as > 1.18 mm for dairy cows, based on the assumption that smaller particles are expected to pass the reticulo-omasal orifice and not be exposed to rumen fermentation. However, no recent studies investigating this 15% peNDF threshold and whether it is associated with a lower prevalence of gastro-enteric disorders were found. A more recent study proposed a threshold of 10% but the particle size considered as peNDF were particles > 4 mm (Llonch et al., 2020), so the results are not directly comparable with the study previously mentioned. A further study investigated peNDF of 1.18 mm and 8 mm and suggested staying above 10% of DMI for both particle sizes (Niwa et al., 2023), but no optimum value was defined. In sum, as very limited numbers of studies comparing roughage amount and particle size in beef cattle finishing diets are available, further research is needed to determine a reference value for beef cattle as well as an optimum value of peNDF.

In beef cattle fed TMR, an increase in the roughage particle size can be a further mitigating action of SARA. A larger particle size stimulates chewing activity which enhances saliva secretion and consequently sodium bicarbonate which acts as a natural buffer in the rumen (Plaizier et al., 2008). This strategy must be carefully applied to maintain the appropriate particle size distribution in the TMR over time, ensuring that it does not excessively promote cattle sorting behaviour. Conversely, highly homogeneous rations with excessively short particle sizes reduce sorting behaviour but increase the risk of rumen acidosis (Hindman, 2023).

In parallel, the supplementation of feed additives or feed materials including mineral buffers, yeast products and phytogenic compounds may help attenuate SARA. Mineral supplements, especially bicarbonates, have been routinely used in ruminant diets for their ruminal buffering capacity in the therapy of acute ruminal acidosis (Calsamiglia et al., 2012). Bicarbonates might prevent pH depression when high amounts of concentrate are fed by controlling an overgrowth of acid-tolerant lactobacilli (Garry, 2002; as cited in: Humer et al., 2018). Regarding yeast and phytogenic compounds, their positive effects against SARA after feeding grain-rich diets are through a modulatory effect on the fermentation process and ruminal microbiome, such as by stimulating lactate utilisers, an increase in cellulolytic bacteria and fungi (Calsamiglia et al., 2012) and a decrease of starch utilisers (Neubauer et al., 2018). However, the use of these feed additives/materials cannot fully compensate for suboptimal feeding (Humer et al., 2018).

In addition, a gradual transition from forage-based to concentrate-based diets during the early finishing period at the fattening farm is essential to prevent gastro-enteric disorders. This process requires a progressive feed transition to the fattening diet by sequentially increasing concentrations of concentrates during the first 2-to-4 weeks of fattening (Bevans et al., 2005). Reducing the duration of this feed transition to less than 2 weeks can impair subsequent performance and health (Brown et al., 2006).

3.2.3.3.2 | *Group stress*

Prevention and mitigating actions of group stress in the context of nutrition and feedling are addressed in a dedicated section on 'space allowance' at the feed trough (see Section 3.3 on minimum space allowance).

3.2.3.3.3 | *Inability to chew and/or ruminate and inability to perform exploratory or foraging behaviour*

Under intensive conditions, fattening cattle are fed high-concentrate diets to promote their maximum daily gain and only a limited amount of roughage is provided to maintain rumen function (Campbell et al., 1992). A reduction in rumination time is expected in these conditions (Gentry et al., 2016). Concentrate-based diets fed in confinement contain less roughage and require cattle to spend less time engaged in oral behaviours (e.g. mastication of the cud, using the tongue to grasp and pull on grass) which further promotes the development of stereotypic oral behaviours such as non-nutritive oral manipulation, tongue rolling and tongue flicks (Bergeron et al., 2006). Oral stereotypes are rarely observed in beef cattle on pasture (Ishiwata et al., 2007). Observations on housed dairy heifers have shown that they look for opportunities to process long forage, particularly when fed an *ad libitum* low-roughage diet (Van Os et al., 2018).

The main prevention and mitigating strategy in this context is to increase dietary roughage (Ridge et al., 2020). This recommendation is particularly relevant for cattle housed in slatted floor pens, as bulls kept in straw bedded pens have the possibility to some extent compensate the lack of dietary roughage by ingesting litter substrate (Schulze Westerath et al., 2009). In the case of cattle fed TMR, additional actions for promoting rumination are the increase of forage particle size (Gentry et al., 2016) or the use of coarsely chopped corn silage (Cozzi et al., 2005).

3.2.3.3.4 | *Linked welfare consequences*

'Metabolic disorders' are linked with '**locomotory disorders (including lameness)**'. Several induction studies showed relationships between diet, ruminal acidosis and laminitis (reviewed by Passos et al., 2023). The ingestion of high amounts of readily fermentable concentrates leads to a rapid decline in rumen pH which in turn results in the death of ruminal bacteria. The release to the bloodstream of lipopolysaccharide endotoxins from the bacteria cell wall generates a systemic response with some of these toxins affecting the vascular perfusion of the hoof leading to locomotor disorders.

In this context, the main preventive measure is to ensure sufficient fibre intake (see Section 3.2.3.3.1 a discussion on dietary fibre thresholds). Increasing neutral detergent fibre (NDF) content of the TMR was identified as a preventive factor for the development of sole haemorrhages and white line abscesses and infectious lesions in a risk-factor analysis

(Magrin, Brscic, et al., 2020). As discussed in the Section 3.2.3.3.1, the recommendation to provide additional dietary fibre to lower the risk of lameness is particularly relevant for beef cattle housed in slatted floor pens (Schulze Westerath et al., 2009).

High dietary protein levels have also been identified a risk factor (Ranjbar et al., 2016) due to the toxic effect of ammonia arising from the protein degradation in the rumen. High concentrations of ammonia or urea in the blood can damage sensitive lamellae and corium in the hoof (Lean et al., 2013). Although the excess of dietary protein is not frequent in indoor beef cattle, it can occur in 'high quality' pastures without an adequate energy supplementation (Langova et al., 2020).

In addition, as the ingestion of mouldy feeds by beef cattle can be associated with impaired locomotion resulting from a mycotoxin-induced immune suppression (EFSA AHAW Panel, 2012b), performing periodic analyses of feedstuff at risk of mycotoxin contamination is recommended (Cozzi, Brscic, & Gottardo, 2009).

3.2.3.3.5 | *Welfare consequences relevant to suckler cows and suckler calves*

'Group stress' and **'inability to perform exploratory or foraging behaviour'** were selected as highly relevant welfare consequences experienced by suckler cows and suckler calves. However, the severity of the inability to perform exploratory or foraging behaviours were considered to lower because these animals are typically kept in deep-bedded pens.

3.2.3.4 | *Conclusions on nutrition and feeding*

For conclusions and recommendations on minimum space at the feed trough, see Section 3.3.

1. Intensively fattened young bulls and beef heifers are fed high-concentrate diets to maximise daily weight gain. Under current practice, roughage represents only a limited share of the whole diet composition.
2. The WCs selected as highly relevant for fattening cattle resulting from common nutrition and feeding are metabolic disorders, gastro-enteric disorders, group stress and inability to perform exploratory or foraging behaviour. Group stress is linked with soft tissue lesions and integument damage, and metabolic disorders linked with locomotory disorders (including lameness).
3. Subacute rumen acidosis (SARA) results from an excess of dietary concentrate and insufficient structured fibre. SARA is the most prevalent metabolic and gastro-enteric disorders in beef cattle and comprises a drop in ruminal pH, potentially resulting in damage to the rumen wall and liver.
4. Feeding less grain (starch) and more structured fibre (peNDF) is the main mitigation strategy against SARA (certainty > 90%).
5. Increasing proportions of readily fermentable starch in the diet increase the risk of hoof problems as secondary welfare consequences of subacute or acute ruminal and hind gut acidosis conditions (certainty > 90%).
6. Up to date, there are no specific reference values on suitable thresholds for inclusion of concentrates and roughage in fattening diets for beef cattle to control metabolic and gastro-enteric disorders.
7. Compared to yeast and phytogenic compounds, mineral buffers are more effective against rumen acidosis resulting from the ingestion of too much concentrate feeding (certainty > 90%). These compounds have only a modulatory effect on the fermentation process of the ruminal microbiome (certainty > 50%). No feed additive can compensate for an inadequate feeding management (certainty > 90%).
8. As beef cattle are typically fed forage-based diets before transfer to the fattening farms, a gradual change from forage-based to concentrate-based diets during the early fattening period is crucial to prevent gastro-enteric disorders (certainty > 90%).
9. *Ad libitum* feeding with a constant availability of feed in the manger mitigates group stress and reduces the risk of prolonged hunger (certainty > 90%).
10. Competition and aggressive interactions in the feeding areas are lowered by the provision of a space at the manger sufficient to allow the simultaneous presence of all group mates (certainty > 90%).
11. High-concentrate diets reduce chewing and rumination time compared to predominantly forage-based diets, and lead to stereotypic oral behaviours such as non-nutritive oral manipulation, tongue flicks and tongue rolling (certainty > 90%).
12. The ingestion of mouldy feeds increases the risk of impaired locomotion that results from a mycotoxin-induced immune suppression (certainty > 90%).

3.2.3.5 | *Recommendations on nutrition and feeding*

1. In order to prevent or reduce SARA and hoof problems, feeding less grain and more structured fibre (peNDF) is the main recommendation. A suitable proportion of effective fibre in fattening diets should be included to promote chewing and rumination time, and reduce the occurrence of stereotypic oral behaviours in beef cattle.
2. When feed additives or feed materials are used to reduce SARA, mineral buffers should be preferred over yeast products and phytogenic compounds.
3. A gradual transition from forage-based diets to more concentrate-based fattening diets should be implemented in the first 4 weeks after arrival at the fattening farm to prevent digestive disorders.
4. To lower aggressive interactions in the feeding areas, *ad libitum* feeding should be combined with a space at the manger that allows simultaneous access to feed to all the group mates.

5. Visibly mouldy or potentially mycotoxin-contaminated feeds should not be included in beef cattle rations. It is recommended to carry out analyses of feedstuffs prone to mycotoxin contamination.

3.2.4 | Lack of outdoor access

3.2.4.1 | *Current practices*

Most beef cattle are fattened in specialised farms under intensive conditions, although some may have been bred and reared as young calves on pasture. Most of the intensive fattening units house the animals indoors in multiple pens in closed or partially open barns for the entire fattening period (Cozzi, Brscic, & Gottardo, 2009). However, also extensive outdoor production systems with pasture access during summer or the whole year and usually slower growth rates of the animals can be found (see Section 3.4.1). In addition, there are a few farms with loose housing systems with access to an additional outdoor loafing area. An outdoor loafing area (paddock, outdoor yard, outdoor bedded pack) can be defined as an open or partly roofed area that is not part of the main structure of the building but is adjacent to it or a short distance away (EFSA AHAW Panel, 2023b). The floor is usually (bedded) concrete or slatted, although natural floors are also possible. In organic farming, an outdoor loafing area is mandatory when no pasturage for grazing is granted. Outdoor feedlot systems are another infrequent beef production system in the EU where the animals have outdoor access, with some more significance in Southern Europe (Agethen et al., 2023) (see Section 3.4.2).

3.2.4.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle lacking outdoor access are **'restriction of movement'**, **'inability to perform play behaviour'**, **'sensory under- and/or overstimulation'**, **'group stress'**, **'inability to avoid unwanted sexual behaviour'**, **'inability to perform exploratory or foraging behaviour'** and **'heat stress'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3 and the ABMs used to identify and assess each WC are defined in Section 3.10.

3.2.4.3 | *Preventive and mitigating measures*

In general, nearly no research has been carried out on welfare effects of outdoor access vs. no outdoor access in beef cattle. However, it can be expected that potentially mitigating properties of outdoor access in terms of animal welfare are largely similar to the ones described for dairy cows (EFSA AHAW Panel, 2023b). The literature cited in the following therefore relates to dairy cattle, if not stated otherwise.

3.2.4.3.1 | *Restriction of movement and inability to perform play behaviour*

The extent of restrictions depends on the indoor conditions, but outdoor access has a high potential to provide an expansion of exercise and loafing space, which may positively affect behavioural freedom (EFSA AHAW Panel, 2023b). Higher space allowances have positive effects on locomotory and play behaviours (Jensen et al., 1998). In addition, in outdoor areas flooring conditions may be more suited for cattle. This likely was a further cause of the increased frequency of play behaviour observed by Boyle et al. (2008) in heifers on an outdoor wood-chip pack compared to heifers housed inside a free-stall pen, apart from the higher space allowance in the outdoor area. Furthermore, the outdoor area was less restricted by building structures.

3.2.4.3.2 | *Sensory under- and/or overstimulation*

Outside conditions usually provide more diverse and changing sensory stimulation than indoor conditions. For visual stimulation, Haskell et al. (2013) found no effect on outdoor yard use when free view on the surroundings was available compared to a view blocked by fabric screens. However, also the possibility to experience sunlight, rain, wind and different air qualities with different olfactory characteristics needs to be considered. For example, in practice it can be observed that on sunny winter days, cattle place themselves to receive maximal sunlight exposure. However, certain climatic conditions, such as precipitation at lower temperatures or high temperatures and solar radiation, are also reportedly avoided (e.g. Charlton et al., 2011; Legrand et al., 2009). Free access to shelter or shade (e.g. Tucker et al., 2008) or an indoor area provides a choice between different environmental conditions.

Depending on indoor flooring, an outdoor area with natural floor can also provide a more comfortable surface for lying. If pasture access for grazing is allowed, this can be seen as provision of additional nutritive and environmental stimuli. When given a free choice between feedlot (with gravel base covered with 25 cm feedlot compost) and pasture, beef steers preferred pasture for 75% of their time and performed the large majority (81%) of their lying on pasture (Lee et al., 2013).

3.2.4.3.3 | *Group stress and inability to avoid unwanted sexual behaviour*

Especially for lower ranking individuals, the additional outside area offers the possibility of retreat and avoidance of unwanted interactions with conspecifics including unwanted sexual behaviour. For instance, Haskell et al. (2013) found a significantly higher percentage of dairy cows using an outdoor loafing area after feeding in the barn (29%) compared to before (9%) or during feeding time (7%), with low-ranking individuals more often outside during feeding than high-ranking cows, which suggests that they used the outdoor area to avoid dominant animals. The extent of such effects depends on the barn design and space available indoors and outdoors. When groups of 20 cows were confined for 1 h in outdoor areas of 5, 8, 12 or 15 m^2/cow, Lutz et al. (2019) observed decreasing numbers of agonistic interactions with increasing space allowance both in horned and hornless groups. However, knowledge on possible effects of different space allowances in freely accessible outdoor loafing yards in beef cattle is lacking.

3.2.4.3.4 | *Inability to perform exploratory or foraging behaviour*

More complex and frequently changing stimuli and resources that promote exploration and foraging can be expected on pasture, followed by feedlots or barns with outdoor loafing areas where the animals have a choice between different environmental conditions.

In addition to the natural stimuli and resources present in the outdoor area, which in the case of pasture include the possibility to forage, it is often more feasible to provide environmental enrichment such as additional racks with roughage, that stimulate and allow exploration and foraging in outdoor areas (see also Section 3.2.5). Indoors, it is often challenging to provide additional enrichment devices without restricting unhindered access to the feeding table or lying area.

3.2.4.3.5 | *Heat stress*

A loafing area adjacent to a barn provides the opportunity to move outside if it is hot or humid inside the building (EFSA AHAW Panel, 2023b). In fact, with free access to an outdoor pack, cubicle housed cows spent 25% of the time outside in summer, mostly during the night and only 2% in winter (Smid et al., 2019). They generally avoided adverse weather, i.e. precipitation during summer nights and precipitation and high wind speeds during winter. It can be questioned whether cows in summer went out for thermoregulatory reasons or because of more comfortable lying conditions as long as weather was not too aversive. Haskell et al. (2013) found in their study that as the temperature-humidity index (THI) increased indoors, more cows moved to an adjacent outdoor loafing area. In general, variation in environmental conditions (different microclimates) and freedom to choose between them increases the animals' possibility to behaviourally adapt to unfavourable conditions according to their individual needs. For example, for beef cattle only housed outdoors, access to shade or shelter provides different microclimatic conditions and is a measure to mitigate heat stress (Tucker et al., 2008).

3.2.4.3.6 | *Welfare consequences relevant to suckler cows and suckler calves*

All welfare consequences described above also apply to suckler cows and suckler calves kept indoors with the exceptions of the 'inability to avoid unwanted sexual behaviour' which was not considered highly relevant in the case of suckler cows and suckler calves.

3.2.4.4 | *Conclusions on lack of outdoor access*

1. Most beef cattle are fattened under intensive conditions in closed or partially open barns without outdoor access for the entire fattening period. Provision of outdoor access can range from an outdoor loafing area with free passage between indoor and outdoor areas, over housing in outdoor feedlots, possibly with the provision of some freely accessible shelter, to access to pasture of different sizes and qualities for different times of the year and day.
2. Highly relevant welfare consequences related with lack of outdoor access are restriction of movement, inability to perform play behaviour, sensory under- and/or overstimulation, group stress, inability to avoid unwanted sexual behaviour, inability to perform exploratory or foraging behaviour and heat stress. No linked welfare consequences were identified.
3. Outdoor conditions provide more environmental complexity and changing sensory stimulation (e.g. sunlight, wind, rain or olfactory stimuli) than indoor conditions. While little research is available on the importance of such stimulation to beef cattle, in general, free choice between different environmental conditions lowers the risk of sensory understimulation (certainty > 90%).
4. Outdoor access that includes pasture promotes exploration and foraging behaviour (certainty > 90%).
5. Freely accessible outdoor loafing areas with well-managed underfoot conditions provide enlarged space and opportunity for locomotion and play (certainty > 90%).
6. An easily accessible outdoor loafing area allows lower-ranking individuals in particular to withdraw and avoid unwanted interactions with dominant individuals, thereby helping to reduce group stress (certainty > 90%).
7. A shaded outdoor area next to the barn provides cattle the opportunity to move outside if inside conditions are too hot or humid, mitigating heat stress (certainty > 66%).

3.2.4.5 | *Recommendations on lack of outdoor access*

1. From the point of view of animal welfare, it would be desirable to provide housed beef cattle with a freely and easily accessible outdoor area adjacent to the barn, to stimulate and allow more locomotion-related behaviours, reduce sensory understimulation and the associated experience of negative affective states. Access to a loafing area also allows more efficient retreat from unwanted social interactions, thereby helping to reduce group stress.
2. At least part of the outdoor area should provide shade to further give beef cattle the opportunity to move outside if inside conditions are too hot or humid, and help mitigate heat stress.
3. Underfoot conditions in the outdoor area should be well-managed in order to avoid mud build-up and provide sufficient grip for locomotion.

3.2.5 | Lack of environmental enrichment

3.2.5.1 | *Current practices*

Environmental enrichment is defined in this context as the modification of the environment of captive animals with the goal to improve animal welfare (Newberry, 1995) by 'providing them sensory and motor stimulation, through structures and resources that facilitate the expression of species-specific behaviour and promote psychological well-being through physical exercise, manipulative activities and cognitive challenges according to species-specific characteristics' (NRC, 2011). As a rule, enrichment increases the complexity of the environment, but its extent can differ. While the increased complexity can mean an increased management challenge, it provides more opportunities for the animal to interact with the environment in an adaptive way. It allows an increased fulfilment of behavioural needs, thereby reducing frequencies of abnormal behaviour, enhancing the animal's ability to actively cope with challenges and providing opportunities to experience positively valenced affective states.

Enrichment material investigated so far for beef cattle falls into the following categories: (i) manipulable material that can be ingested, e.g. roughage (Berges & Stracke, 2023) or salt blocks (Matković et al., 2020), (ii) inedible material for exploration, including olfactory exploration and manipulation (Berges & Stracke, 2023; Schulze Westerath et al., 2009; Wilson, Mitlöhner, et al., 2002), (iii) equipment allowing comfort behaviour, i.e. brushes (Braghieri et al., 2011; Matković et al., 2020; Park, Schubach, et al., 2020; Tuomisto et al., 2015; Wilson, Mitlöhner, et al., 2002) or rubbing objects (Dickson, Campbell, Lee, et al., 2022; Matković et al., 2020; Park, Schubach, et al., 2020; Wilson, Mitlöhner, et al., 2002) and (iv) pasture access (Braghieri et al., 2011; Tuomisto et al., 2015). Dickson, Campbell, Lee, et al. (2022) also regarded a woodchip pile on poor pasture as environmental enrichment, because it may facilitate lying behaviour. Access to pasture and material that can be ingested not only fulfil the function of enrichment, but also have nutritive and metabolic effects. Auditory enrichment (e.g. music) so far was only investigated in dairy cattle (reviewed by Ciborowska et al., 2021), and cognitive enrichment only in farms animals other than cattle (e.g. pigs, Zebunke et al., 2013). In beef cattle, it is even less common practice to provide specific environmental enrichment than in dairy cattle and only little specific research has been carried out (reviewed by Park, Foster, & Daigle, 2020).

3.2.5.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of lacking environmental enrichment are **'inability to perform exploratory or foraging behaviour'**, **'inability to chew and/or ruminate'**, **'inability to perform comfort behaviour'**, **'sensory under- and/or overstimulation'** and **'inability to perform play behaviour'**. Furthermore, 'sensory under- and/or overstimulation' due to lack of enrichment may increase the risk of **'group stress'** and the **'inability to avoid unwanted sexual behaviour'**. The definition of each WC is available in Section 2.3 and the ABMs used to identify and assess each WC are defined in Section 3.10.

3.2.5.3 | *Preventive and mitigating measures*

3.2.5.3.1 | *Inability to perform exploratory or foraging behaviour and inability to chew and/or ruminate*

Exploratory behaviour in cattle includes olfactory, visual, auditory or tactile information gathering General information gathering is largely intrinsically motivated (Wood-Gush & Vestergaard, 1989). In addition, exploration is very often carried out in association with foraging and feeding (including chewing and ruminating). It can be expected to be intrinsically pleasant or self-rewarding and be associated with positive emotions (Boissy et al., 2007; Schulze Westerath et al., 2009).

General information gathering also includes stimuli that potentially have no biological significance. For beef cattle this has been shown by Wilson, Mitlöhner, et al. (2002), who presented a milk-scent or lavender-scent releasing device (plastic pipe filled with cotton balls saturated with a milk solution or lavender oil) to beef heifers in a feedlot (3 groups with each 10 heifers, 18 months old) and found that on average, over the 22 days of the experiment, 50% of the heifers interacted with the milk-scent releasing device (but only 20% with the lavender-scent releasing device). Interactions with the milk-scent releasing device decreased after the first observation day (day 2 of the experiment). This is not surprising, because novelty is an important feature in stimulating exploration (Murphy, 1978) and exploration behaviour declines with the decline of novelty. The challenge in terms of environmental enrichment for promoting exploration behaviour is the provision of novelty. In this regard, more complex systems with naturally changing stimuli are superior to highly controlled systems, i.e. pasture systems to systems with outdoor runs to confined barren systems. In addition, Berges and Stracke (2023) found in beef bulls on fully slatted floors that within objects allowing oral behaviour, organic ones were greatly preferred over non-organic objects.

Regarding foraging and feeding, the way in which the diet is provided is paramount. The common feeding of high-concentrate diets to beef cattle may not only increase the risk of metabolic disorders with further negative consequences for animal health and welfare (see Section 3.2.3), but may also thwart the motivation to consume forage and ruminate thus leading to frustration, although studies quantifying this motivation are lacking. However, the occurrence of tongue rolling and the extent of oral manipulation of inanimate objects may be measures of the inability to perform this behaviour (Bergeron et al., 2006), with the additional provision of structured dietary fibre (roughage) being an important mitigating measure (see Section 3.2.3). In addition, the possibility to choose between different components of the diet allows more behavioural freedom and better adaptation to individual physiological needs, although sorting behaviour can lead to unbalanced and unhealthy diets when feeding TMR alone, and it is usually sought to be prevented. Nevertheless, there are indications of individual differences in diet selection for hedonic and health reasons (reviewed by Miller-Cushon & DeVries, 2017). For example, beef cattle fed a high-grain, low-forage feedlot diet increased their sorting for the forage component of their diet upon experiencing a bout of acidosis (DeVries et al., 2014). However, the few investigations on free-choice feeding under intensive and controlled conditions did not reveal major animal welfare consequences of the type of feeding (e.g. Devant et al., 2015; Iraira et al., 2015; Moya et al., 2011). Freedom of choice may be more important for grazing, e.g. when contrasting pastures with high forage diversity, providing varied sensory and post-ingestive experiences, with monotonous swards (reviewed by Distel et al., 2020). However, more research in this complex field is necessary.

Even enrichment not stimulating oral activity may affect oral behaviour. Park, Schubach, et al. (2020) found that the provision of a brush to steers in a feedlot with earthen flooring led to less frequent and shorter bouts of bar licking and tongue rolling, compared to steers in similar pens without a brush. Both in steers with and without brush, tongue rolling increased in frequency and duration over the 9-week study. In contrast, Dunston-Clarke et al. (2024) found no differences in abnormal behaviour (tongue rolling, bar/fence chewing) between a group of feedlot heifers and steers (14 months old, mean weights 434 and 508 kg) with a brush and a control group over an observation period of 94 days, but with very low levels of this behaviour in general.

3.2.5.3.2 | *Inability to perform comfort behaviour*

Comfort behaviour includes (besides thermoregulatory behaviour which is covered in Section 3.2.7) licking, scratching with hind hooves, scratching with horns, shaking, striking one part of the body against another part, rubbing, pawing and social grooming (allogrooming) (Simonsen, 1979). These behaviours may be carried out to relieve itching, to remove aversive objects (e.g. dirt, insects) or to stimulate the skin. However, self-grooming can also be carried out as a displacement activity (reviewed by Boissy et al., 2007), so the interpretation of the extent of self-grooming needs to be cautious. Nevertheless, self-grooming as described above is an important behaviour to maintain good physical conditions and is internally and externally motivated.

It is well established that cattle use inanimate objects for the grooming of body parts that they are unable to reach. The provision of such objects is a relatively easy means to more fully allow beef cattle the performance of comfort behaviour. Dairy cows are highly motivated to access a grooming brush (McConnachie et al., 2018) and it is likely that this applies to all cattle. Pasture-based beef cattle, used to have access to a grooming brush, became dirtier and showed reduced average daily gain when access to the brush was blocked for 1 week; 'medium and high' brush users also showed elevated levels of faecal cortisol metabolites (Dickson et al., 2024). When a fixed L-shaped brush was installed in a feedlot, all steers interacted with the brush within the first 2 days. Brush use declined afterwards, but remained on a steady level over the observation period (64 days) with an overall daily (8:00 to 17:30 h) mean brush use of about 583 s/steer (Park, Schubach, et al., 2020). A similar use pattern was described by Wilson, Mitlöhner, et al. (2002). It is possible that the initially high usage is rebound behaviour due to built-up motivation for grooming behaviour, but novelty of the enrichment may also play a role. Dunston-Clarke et al. (2024) observed that a vertical grooming brush placed in the middle of a feedlot pen was steadily used by beef heifers and steers throughout the observation period which ended after 94 days. Although the study was limited by lacking repetitions, the authors report that in addition to the brush use, levels of self-grooming and allogrooming events were similar to the cattle in the control group without a brush. Pointing to a similar direction, Kohari et al. (2007) found (in four beef cows) that unavailability of trees for grooming on pasture was not compensated by more self- or allo-grooming, although trees were intensively used when available. In contrast, the steers in the experiment of Park, Schubach, et al. (2020) with a brush available performed fewer and shorter bouts of allo-grooming than those without brush. Besides brushes and natural structures, other objects can be used. For instance, Ishiwata et al. (2006) found that a drum can wrapped with artificial turf (30 × 120 cm) around the upper third (and filled with hay) was used for grooming by steers (7–11 months old, around 300 kg liveweight).

3.2.5.3.3 | *Sensory under- and/or overstimulation*

Visual, auditory or olfactory under- or overstimulation by the physical environment can lead to the experience of stress or negative affective states such as fear or discomfort. As environmental enrichment aims to reduce sensory understimulation, only this aspect will be discussed here. Sensory understimulation can be decreased by a higher degree of the general complexity and variability of the environment. A more appropriate level of stimulation is expected to be reflected by less redirected or vacuum behaviour and a higher general activity. Tuomisto et al. (2015) observed less manipulation of objects by fattening bulls in pasture paddocks than in barns with a straw and peat-bedded lying area and feeding area with solid concrete floor. Steers in feedlots with earthen flooring with a brush showed in general a greater duration of movement activity than steers without a brush (Park, Schubach, et al., 2020). In addition, the use of resources per se reflects that animals have been stimulated to perform associated behaviours. For example, steers already receiving hay *ad libitum* in a trough besides concentrate, used extra drum cans filled with hay steadily (Ishiwata et al., 2006). However, they did not show less tongue rolling than steers without this enrichment; possibly the stereotypy was already established before the start of the study.

Studies examining different enrichment devices evaluated these devices as more or less recommendable based on the extent of their use (Dickson, Campbell, Lee, et al., 2022; Pelley et al., 1995; Wilson, Mitlöhner, et al., 2002). However, a brush, olfactory enrichment, salt blocks, a straw bale, a stump, a woodchip pile or a hanging rope provide very different stimulation and allow the performance of different behaviours. It is the sum of different stimuli that makes up a complex and changing environment. For instance, Matković et al. (2020) offered beef heifers both a brush and salt blocks and found that enrichment material was used more at higher stocking densities than at lower densities, but only when both provisions were taken into account. However, more research is needed on the comparison of the effects of complex versus single enrichments.

3.2.5.3.4 | *Inability to perform play behaviour*

The occurrence of play may both signal the absence of poor welfare and the experience of positive emotions (Boissy et al., 2007; Held & Špinka, 2011). It can be hypothesised that the provision of enrichment devices can promote object play, as e.g. reported for piglets (Yang et al., 2018) or stimulate locomotory and social play, as reported for an announced short-term enrichment for piglets (Dudink et al., 2006), but similar studies in beef cattle are lacking. Only Wilson, Mitlöhner, et al. (2002) mention that the use of a movable scratching/rubbing object may have included some play behaviour as they observed the beef heifers to push the device around the pen. Dunston-Clarke et al. (2024) observed more play behaviour in beef heifers and steers in a feedlot with a brush than in the control group without brush, but the study was limited by the fact that repetitions were lacking and that the treatment group had lighter cattle than the control group.

3.2.5.3.5 | *Linked welfare consequences*

The WC 'sensory under- and/or overstimulation' is linked with '**group stress**' because quantitative or spatial restrictions on access to enrichment can lead to increased inter-individual competition. Park, Schubach, et al. (2020) found that the provision of a brush for steers in a feedlot (one brush/nine steers) led to fewer head butts, and mounting behaviour, thus reducing the risk of unwanted sexual behaviour, but also to fewer allo-grooming bouts compared to steers without a brush. However, they found no differences in hair cortisol concentrations. Matković et al. (2020) investigated social effects of brush and salt block provision vs. an unenriched group in fattening heifers (one enrichment each 14 or 19 heifers). With a higher space allowance of 4.5 m^2/heifer (compared to 3.3 m^2/heifer of 250–450 kg liveweight on solid bedded floor) the unenriched group showed increased head butting and for both space allowances increased chasing compared to the enriched group. The authors emphasised the possible reducing effect of enrichment on agonistic behaviour, but give no explanation for the increased butting in the lower density group. However, as only one group per treatment was investigated, single animals may have largely affected results with independence of the statistical units being questionable. Dunston-Clarke et al. (2024) found no differences in agonistic behaviour between a group of feedlot cattle with a brush and a control group, with in general very low levels of this behaviour. Moreover, the same statistical limitations apply as discussed above. Pelley et al. (1995), on the other hand, highlighted the possibility of increased competition over a limited resource. In their cross-over experiment with three groups of each eight steers (8 months old, around 204 kg liveweight), the steers interacted more frequently with a straw bale than with suspended salt/mineral blocks and with a brush, but they also showed more agonistic behaviour that might not only be due the higher attractiveness of the straw bale, but also to the diminishing of the enrichment in the course of its use. Therefore, care should be taken to offer enrichment objects in a way that all animals have easy access and to replenish material if necessary. However, similar to the lack of information on animal:brush ratios in dairy cows (EFSA AHAW Panel, 2023b), no information is available on the necessary number of enrichment devices in relation to the number of animals in fattening cattle. In the studies on the provision of brushes or rubbing objects for beef cattle, animal:brush or rubbing object ratios ranged from 4:1 to 11:1 (Ishiwata et al., 2006; Kohari et al., 2007; Matković et al., 2020; Park, Schubach, et al., 2020; Pelley et al., 1995; Wilson, Mitlöhner, et al., 2002).

Effects of environmental enrichment are not always easy to distinguish from effects due to other linked factors. For instance, pasture access does not only provide additional stimulation, but usually also increased space and different floor qualities. Unexpectedly, Tuomisto et al. (2015) observed more mounting behaviour in fattening bulls in pasture paddocks than in barns with a straw and peat-bedded lying area and feeding area with solid concrete floor. There was no significant effect on butting, but housed bulls showed more licking of conspecifics. The authors speculated that allo-grooming may have functioned to reduce social tension, which was less necessary with increased space, but on the other hand, floor conditions in the barn may have hampered the execution of mounting behaviour.

3.2.5.3.6 | *Welfare consequences relevant to suckler cows and suckler calves*

All welfare consequences described above also apply to suckler cows and suckler calves kept indoors, with the exceptions of the 'inability to avoid unwanted sexual behaviour' which was not considered highly relevant in the case of suckler cows and suckler calves.

3.2.5.4 | *Conclusions on lack of environmental enrichment*

1. The extent and diversity of structures and resources that facilitate the expression of species-specific behaviour vary in beef cattle husbandry from little in rather monotonous housing and feeding conditions of intensively kept beef cattle to great in extensive and biodiverse pasture systems.
2. Highly relevant welfare consequences related with lack of access to environmental enrichment are inability to perform exploratory or foraging behaviour, inability to chew and/or ruminate, inability to perform comfort behaviour, sensory understimulation, inability to perform play behaviour, group stress and inability to avoid unwanted sexual behaviour.
3. Environmental enrichment in general reduces sensory understimulation (certainty > 90%) and leads to increased activity (certainty > 90%).
4. Abnormal behaviour like tongue rolling and excessive oral manipulation of inanimate objects occurs more frequently in intensive beef systems with high-concentrate diets than in pasture systems (certainty > 90%). Enrichment of intensive systems with long fibrous organic manipulable material that can be ingested, such as roughage, leads to a reduction of these behaviours (certainty > 90%). The provision of brushes as enrichment also contributes to a reduction of abnormal oral behaviour (certainty > 66%).
5. Material that can be ingested and pasture access not only fulfil the function of enrichment, but also nutritive and metabolic effects need to be considered.
6. Free choice between different components of the diet also enriches the environment of beef cattle, allowing more behavioural freedom and better adaptation to individual physiological needs (certainty > 90%). However, more research is needed on the welfare effects of free-choice feeding in intensive systems, with particular focus on the risks of metabolic disorders.
7. Exploration for the purpose of information gathering allows the experience of positive emotions and is stimulated also by non-organic enrichment material, although these effects are linked to the degree of novelty, which call for frequently changing stimuli (certainty > 90%).
8. Beef cattle have a high motivation to use brushes or rubbing objects for comfort behaviour, which induces positive emotions and alleviates stress and soiling (certainty > 90%).
9. The provision of brushes can further help to reduce agonistic interaction and thus group stress, although more research is needed to confirm this effect (certainty > 66%). Insufficient knowledge is also available on the possible effects of the provision of brushes on mounting behaviour.
10. The simultaneous provision of different enrichment objects that target different behavioural motivations has a greater overall effect on activity levels than single enrichments (certainty > 66%), but to date this has not been addressed in adult cattle research.
11. Limited access to enrichment objects or rapidly diminishing material increases social competition (certainty > 90%). Research is necessary on a minimum number of enrichment devices in relation to the number of animals.
12. Very limited research has yet explicitly addressed the effects of environmental enrichment on play behaviour in beef cattle, but the provision of novel objects promotes play (certainty > 66%).

3.2.5.5 | *Recommendations on lack of environmental enrichment*

1. The housing environment of beef cattle should provide environmental enrichment in order to reduce sensory understimulation, abnormal behaviours (tongue rolling, excessive oral manipulation of inanimate objects) and allow activities such as exploration and foraging. This can comprise (i) manipulable material that can be ingested, e.g. roughage or salt blocks, (ii) inedible material for exploration (including olfactory exploration) and manipulation, (iii) equipment allowing comfort behaviour(i.e. brushes or rubbing objects) and (iv) pasture access for cattle housed indoors.
2. Preferably different enrichment objects that target different behavioural motivations should be provided simultaneously.
3. In any case, enrichment should include the provision of brushes or rubbing objects, which further help to reduce stress and soiling.
4. In addition, long fibrous organic manipulable material that can be ingested (e.g. roughage in a rack) should be provided, thus allowing animals to choose between different feeds.
5. If inedible material is used for enrichment, it should be changed frequently to provide a sufficient degree of novelty.

6. Further research is needed on the welfare effects of free-choice feeding in intensive systems, with particular focus on the risks of metabolic disorders, as well as in general on minimum numbers of enrichment devices in relation to the number of animals in order to limit social competition for these resources.

3.2.6 | Mixing of cattle

3.2.6.1 | *Current practices*

Cattle are social animals that tend to live in groups. Hurnik et al. (1995) defined a group 'as a collection of animals in which the animals are of the same species and the composition of the group is relatively stable over time'. Under natural conditions, the social structure of cattle is based on groups of females accompanied by their offspring (Reinhardt & Reinhardt, 1981). In a stable group, there is a well-established hierarchy that determines the priority access to resources (such as feed, space, sexual partners) based on dominance-subordination relationships expressed through agonistic interactions and preferential links (Bouissou et al., 2001). In a group where the hierarchy is stable, direct agonistic interactions are infrequent with mostly indirect forms (threats, avoidance) which makes it possible to limit fights as the origin of injuries. In a stable group, preferential links are also stronger. These links ensure group cohesion by reducing agonistic interactions and their consequences on dominated animals and increasing tolerance in competitive situations (Rault, 2012). There are favourable periods for the establishment of preferential relationships, such as a young age. For example, calves raised together since birth develop strong preferential inter-relationships (Bouissou & Hovels, 1976).

Mixing animals is a common practice in beef cattle management after weaning in assembly centres or at the arrival at the farm but from that point onwards mixing does not further occur. Different practices may be considered under different circumstances and involve either a single or several animals:

a. The most common practice is to mix male calves together after weaning or after the arrival at the fattening unit to form a new group. After weaning, male calves from different suckler farms are gathered in assembly centres and mixed to form new groups before being transferred to the fattening units. At arrival at the fattening unit then they may be remixed during the receiving period at the farm of destination. The objective of such mixing practices at the fattening unit is to create homogenous groups based on one or more characteristics (age, weight, sex, physiological stage) or health state to facilitate the management of the herd by the farmer (Bøe & Færevik, 2003). Once created, these groups may remain stable until slaughter.
b. Alternatively, groups of animals are divided into smaller sub-groups at arrival at the fattening unit. In this case, it is argued that this does not consist of a 'true mixing event' but that it may still disrupt the previous social dynamic.
c. Less frequently, a single animal is isolated from their group and later reintegrated into its original group or placed in another group. This case can happen for example when an individual shows clinical signs of disease, is placed in isolation in the hospital pen and reintegrated in its group after recovery. It may also happen for the cows at certain physiological stages, such as calving period or during the dry period, that lead to a temporary change in group composition. As in (b), this is not considered 'true mixing' but may still disturb the existing social dynamic.

3.2.6.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of mixing are **'group stress'**, **'inability to avoid unwanted sexual behaviour'**, **'handling stress'**, **'separation stress'**, **'respiratory disorders'**, **'soft tissue lesions and integument damage'** and **'bone lesions (including fractures and dislocations)'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3 and the ABMs used to identify and assess each WC are defined in Section 3.10.

3.2.6.3 | *Preventive and mitigating measures*

3.2.6.3.1 | *Group stress and inability to avoid unwanted sexual behaviour*

Mixing animals, or even splitting the group without introducing a new individual, disrupts the established hierarchy and new relationships of dominance-subordination must be formed (Bouissou et al., 2001). The establishment of these new relationships often involves agonistic interactions, such as butting and mounting behaviour, which potentially lead to group stress (Bouissou, 1980; Hubbard et al., 2021; Mench et al., 1990; Mounier et al., 2005) and inability to avoid unwanted sexual behaviour. These activities may continue throughout a few days (Hubbard et al., 2021), although at lower levels while the social hierarchy becomes established. Moreover, mixing beef bulls at the beginning of fattening may lead to less cohesiveness; this renders social buffering less effective during stressful situations (Bolt et al., 2017; Mounier, Veissier, et al., 2006). In cows, allogrooming events decrease after mixing (von Keyserlingk et al., 2008). The total duration of lying behaviour and the number of lying bouts are reduced after mixing (von Keyserlingk et al., 2008). Furthermore, calves and heifers exposed to repeated social mixing have been observed to have increased plasma cortisol concentrations after adrenocorticotropic hormone (ACTH) and CRF challenges (Raussi et al., 2006; Wilcox et al., 2013).

Problems related to social integration are normally greater for the introduced animal than for the resident animals, which are socially dominant (Bøe & Færevik, 2003; Mench et al., 1990; Nakanishi et al., 1993). Nevertheless, a recent study suggested that in dairy cows, the introduction of cows affects also the welfare of the cows already present in the herd by increasing walking time and decreasing milk production (Scheurwater et al., 2021). If mixing cannot be avoided, factors related to the animals and to the environmental should be taken into account.

2.6.3.1.1 | Factors related to the animals

Because of the existence of preferential links between individuals, there is some evidence that mixing of animals that have already met earlier in their life will lead to less negative consequences (Kondo et al., 1984). To the authors' knowledge, there is no information on how long cattle recognise each other after separation.

In dairy cattle, multiparous cows usually meet already familiar individuals when introduced to the lactating group after calving which is mostly not the case in primiparous cows. After parturition, integration into the milking group is challenging for primiparous fresh cows that have no experience of regrouping. Their lying behaviour is affected, they lied less and behaved less synchronous than the resident cows whereas multiparous did not (Gutmann et al., 2020). There is evidence that mixing at least two familiar individuals into a new group may result in less welfare problems compared to mixing a single individual into a new group (Bolt et al., 2017; Rault, 2012). However, in horned dairy cattle it has been found that introduction of single animals led to less horn-related skin lesions in the herd, possibly due to groups of introduced animals being more prepared to fight with resident animals (Johns & Knierim, 2019; Menke, 1996).

Although there is evidence that having experience of previous mixing reduces the problems associated with the integration of individual animals (Bøe & Færevik, 2003; Raussi et al., 2005), it was considered that mixing inevitably leads to welfare consequences. Additionally, too frequent mixing seems to be detrimental (Raussi et al., 2005). A relevant behavioural problem in this context is the 'buller syndrome'. This is characterised by repeated mountings of one bull/steer by other bulls or steers (Blackshaw et al., 1997). Buller syndrome can cause injuries, such as swelling and trauma on the rump and tail head, and increased incidence of health issues in the 'buller' and recipient steer and penile injuries in the initiating steer (i.e. the rider). Several factors have been suggested to induce buller syndrome, including mud, dusty pens and group size. Aggression is a key element in bulling behaviour. Klemm et al. (1983) reported in their study on feedlot steers that the amount of bulling was much greater during the periods of greatest social stress, such as after the herds were formed and new steers were introduced to the pen. At present, there is no clear solution to the problem, except to remove the recipient animals from the pen.

The sex of animals can influence the level of aggression after mixing, and vasectomised bulls are less aggressive compared with entire bulls (Mohan Raj et al., 1991). With the exception of fighting breeds such as Hérens, breed seems to have no influence on the level of aggression (Plusquellec & Bouissou, 2001). Body weights also play a role; agonistic and sexual interactions are more frequent immediately following mixing between bulls of homogeneous BW than between bulls of heterogeneous BW (Mounier et al., 2005). A similar effect has been described in pigs (Andersen et al., 2000; Rushen, 1987, 1988). The increase in aggressive interactions between animals of homogeneous weight may reflect their greater difficulty in establishing dominance relationships. Nevertheless, no effect of the homogeneity or heterogeneity of weights within groups of beef bulls was found on agonistic or non-agonistic behaviour throughout the fattening period or on stress at slaughter. Variability of body weights within groups had no effect on average daily gain. The variability of body weights within groups decreased in groups that were initially heterogeneous whereas it increased in groups that were initially homogeneous (Mounier et al., 2005).

The age of cattle at the time of mixing also seems to play a role on the welfare consequences of such practice. Compared to sub-adult and adult cattle, calves respond to regrouping with less aggression and the social disturbance appears to be limited to a few days after regrouping (Veissier et al., 2001). Therefore, mixing young animals reduces group stress compared to mixing older animals.

Caretakers must pay particular attention to the animals the following days after mixing to be able to intervene if needed.

3.2.6.3.1.2 | Factors related to the environment: space

The amount of available space may influence the consequences of mixing. Reduced stocking density decreases the competition at the feed bunk (Talebi et al., 2014). When competition for food increases, the cohesive interactions performed by mixed beef bulls are reduced (Mounier, Dubroeucq, et al., 2006; Verdú et al., 2017). Therefore, providing more space during a social mixing event reduces social stress. Moreover, after regrouping, the extent to which competition relates to feeding behaviour varies between animals within the group. The strange cow in each group spent less time eating and more time in locomotion than residents (Nakanishi et al., 1993). After regrouping, the feeding of the low rank animals is more frequently interrupted than the feeding of the high-ranking animals (Hasegawa et al., 1997; Zobel et al., 2011).

In calves, either no correlation between group size and frequency of agonistic interactions has been found (Kondo, Sekine, et al., 1989) or the number of agonistic interactions decreased when the group size increased (Færevik et al., 2007). In adult cattle, the relationship between group size and agonistic behaviour is complex. Krahn et al. (2024) found that the number of replacements per cow (i.e. interactions that result in one cow leaving the feed bin and another taking her place) was similar regardless of whether the cows were housed in groups of 50 or 10 although Kondo, Sekine, et al. (1989) found that the number of agonistic behaviours increased as the group size increased.

3.2.6.3.2 | *Handling stress*

Bulls mixed at the beginning of fattening were more stressed by pre-slaughter handling than unmixed bulls (Mounier, Veissier, et al., 2006).

3.2.6.3.3 | *Separation stress*

With the exception of the calf-cow separation (Costa et al., 2016), only a few studies have focused on separation stress in cattle. In heifers, Boissy and Le Neindre (1997) observed that vocalisations, heart rate and plasma cortisol concentration were positively correlated with the duration of social contacts with the pen mates prior to separation, and these responses decreased when pen mates were brough to the pen (Boissy & Le Neindre, 1997). In a study with beef cattle, unmixed bulls displayed less fear responses during separation than mixed bulls (Mounier, Veissier, et al., 2006). Differences between mixed and unmixed bulls were slight and expressed only by the frequency of elimination which was higher in mixed bulls. This suggested they were more stressed by the separation than the unmixed animals, possibly due to a weaker social buffering between mixed bulls. Further studies are needed on this topic.

3.2.6.3.4 | *Respiratory disorders*

BRD is one of the major health issues in beef cattle. Mixing animals from different farms can lead to a mix of different microbiomes favourable to the development of respiratory diseases (Morel-Journel et al., 2021). Moreover, group stress contributes to higher disease susceptibility (Masebo et al., 2023). In beef bulls the first 2 weeks following the introduction of cattle to beef-fattening facilities appears to be the most vulnerable time for the development of BRD, even when antimicrobial metaphylactic treatments and vaccines for BRD are administered (Assié et al., 2009; Pratelli et al., 2021).

3.2.6.3.5 | *Soft tissue lesions and integument damage and bone lesions (including fractures and dislocations)*

No publications on the occurrence of 'soft tissue lesions and integument damage' or 'bone lesions (including fractures and dislocations)' after mixing events in beef cattle were found. Nevertheless, mixing leads sometimes to agonistic interactions involving forceful physical contact (e.g. fights or butts) (Mounier et al., 2005). These agonistic interactions may result in integument damage as reported for dairy cows and sometimes can even cause bone lesions (Menke et al., 1999). During mixing involving beef bulls, it may be assumed that agonistic behaviours are stronger than among dairy cows and then the risk of injuries higher. Physical interactions seem less frequent between horned cattle than between hornless cattle. Nevertheless, when physical interactions occur between horned cattle, the risk of injuries is higher than with hornless cattle (Ebinghaus et al., 2023; Knierim et al., 2015).

3.2.6.3.6 | *Welfare consequences relevant to suckler cows and suckler calves*

While mixing is more likely to be experienced by fattening cattle, suckler calves and suckler cows may experience its consequences of mixing at the time they are brought indoors at the beginning of the winter housing period. If kept in group pens, they may experience group stress. The severity of this welfare consequence will depend on whether they already knew the pen mates prior to mixing. Overall, it was considered that the welfare consequences of mixing will be less severe for suckler cows and suckler calves compared to fattening cattle.

3.2.6.4 | *Conclusions on mixing of cattle*

1. Mixing is a common practice in cattle management to create homogeneous groups based on one or more characteristics, such as age, weight, sex, physiological stage or health state. Mixing involves either a single animal being reintegrated into its original group or placed in a new group, or several animals from different groups being moved to form a new group.
2. The WCs selected as highly relevant for cattle as a result of mixing are group stress, separation stress, inability to avoid unwanted sexual behaviour, soft tissue lesions and integument damage, handling stress, respiratory disorders and bone lesions (including fractures and dislocations).
3. Problems related to social integration are greater for introduced animals, but this integration also disturbs the behaviour of cattle in the receiving group.
4. Mixing leads to increased agonistic and sexual interactions, such as butting and mounting behaviours, and to decreased affiliative behaviours.
5. Lying behaviour is disturbed after mixing, with a longer duration of standing and a reduced number of lying bouts.
6. Mixing animals that have met before leads to fewer agonistic interactions (certainty > 66%).
7. Animals with previous experiences of mixing are less disturbed by regrouping (certainty > 66%).
8. Mixing animals at a young age results in fewer agonistic interactions than in more mature subjects (certainty > 90%).

9. Agonistic and sexual interactions immediately following mixing are less frequent between bulls of heterogeneous body weight than between bulls of homogeneous weight (certainty > 66%). There are currently no grounds to suggest that homogeneous weights at the beginning of fattening are beneficial to minimise agonistic and sexual behaviour.
10. Higher space allowance, increased manger space, *ad libitum* feeding and easy access to feeders and drinkers reduce social stress in groups of cattle after mixing (certainty > 90%).
11. The relationship between group size and agonistic behaviour is complex and needs further research.
12. Mixing animals from different farms contributes to higher respiratory disease prevalence due to a mix of different microbiomes and social stress (certainty > 90%).
13. Mixing is frequently associated with aggressive interactions, which increase the risk of integument damage and bone lesions. The risk of injuries is higher in horned cattle, even though physical interactions appear to be less frequent than between hornless cattle (certainty > 90%).

3.2.6.5 | *Recommendations on mixing of cattle*

1. Groups of cattle should remain stable as much as possible, and mixing should be avoided to reduce group stress, separation stress, unwanted sexual behaviour, resting problems, handling stress, respiratory disorders, integument damage and bone lesions (including fractures and dislocations).
2. If mixing of animals is necessary, mixing animals that have already met should be preferred over mixing unfamiliar cattle, it should be performed at a young age, in a pen providing enough space, and without competition for food and water.
3. Mixing of beef bulls of heterogeneous weight should be preferred to the mixing of bulls of homogeneous weight.
4. If the mixing of animals from different pens is necessary, it should be performed between animals from the same farm.

3.2.7 | High environmental temperatures

This section discusses the consequences of high environmental temperatures on the welfare of housed cattle. Consequences of heat experienced by animals kept on grass and in feedlots are discussed in Section 3.4.

3.2.7.1 | *Current practices*

High temperatures are expected to become increasingly common due to significant warming trends in Europe (Renaudeau et al., 2012) and therefore housed beef cattle are expected to more frequently be exposed to heat. In the EU, beef cattle are kept in closed barns or in partially open barns. Although the latter allow for some natural ventilation, cattle are still frequently facing the effects of high environmental temperatures. While most of the research on this topic has been done on dairy (reviewed by Mishra, 2021), comparable effects (i.e. with the exception of the higher metabolic rates observed in lactating dairy cows) on beef cattle are expected. These are discussed below.

3.2.7.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of high environmental temperatures in indoor housing systems are **'heat stress'**, **'prolonged thirst'** and **'resting problems'**. '**Locomotory disorders (including lameness)'** are linked with 'resting problems'. In the context of this Scientific Opinion, the inability to thermoregulate was defined as part of heat stress and not as part of comfort behaviour as often reported in the scientific literature . The definition of each WC is available in Section 2.3 and the ABMs used to identify and assess each WC are defined in Section 3.10.

3.2.7.3 | *Preventive and mitigating measures*

3.2.7.3.1 | *Heat stress*

The experience of heat stress in cattle is influenced by internal and external factors. Examples of external factors are ambient temperature, relative humidity (RH), thermal and solar radiation, wind speed, presence of ventilation systems, drinking water temperature and barn characteristics (such as amount of vertical space in the barn, placement of pen partitions and barn construction materials) (Gaughan et al., 2002; Gaughan, Mader, Holt, & Lisle, 2008a; Polsky & von Keyserlingk, 2017). Internal factors include cattle genotype (e.g. *Bos indicus* being more heat tolerant than *Bos taurus* (Blackshaw & Blackshaw, 1994), or double-muscled (DM) cattle being more susceptible to heat than non-DM cattle) (see Section 3.7.4), coat colour and type, body size and condition, health status and degree of adaptation (Lees, Sejian, et al., 2019). Some native breeds have also been reported to be more resistant to heat (Pereira et al., 2014).

For an assessment of the consequences of high environmental temperatures on the welfare of beef cattle, it is useful to discuss the concepts of thermoregulation, thermoneutral zone (TNZ), thermal comfort zone (TCZ) and how they link with the 'heat stress' welfare consequence definition from EFSA. An overview on these aspects is provided below, but for a more detailed discussion of these concepts in the context of welfare of cattle, see the Scientific Opinion on the welfare of cattle during transport (EFSA AHAW Panel, 2022b).

3.2.7.3.1.1 | Thermoregulation, TNZ and TCZ

Thermoregulation is the physiological process that maintains a balance between heat production and heat loss. The TNZ covers the range of environmental temperatures within which metabolic rate and heat production are constant and independent of the ambient temperature (described by the EFSA AHAW Panel on the Scientific Opinion on the Welfare of cattle during transport, 2022b), and originally formulated by Mount (1974). The TNZ boundaries are named lower critical temperature (LCT) and upper critical temperature (UCT). The UTC is the temperature above which an homeotherm animal must increase evaporative heat loss in order to maintain heat balance (reviewed by Shephard & Maloney, 2023).

The TCZ is considered to be within the TNZ and is described as a zone where the animal is in the preferred or chosen thermal environment (based on perception) and the energetic and physiological efforts of thermoregulation are minimal.

According to the EFSA definition, heat stress is defined as 'the animal experiences stress and/or negative affective states such as discomfort and/or distress when exposed to high effective temperature'. Hence, heat stress may begin as soon as the animal moves out of its TCZ and starts to experience discomfort. The risk and severity of heat stress increase as the animal approaches the UCT; at this stage, the rate of evaporative heat loss rises sharply and visible signs of heat stress intensify as the animal attempts to prevent a dangerous increase in core body temperature. The identification of precise thresholds for each one of these zones (TNZ and TCZ) is difficult. Up to 25°C, the respiratory rate gradually increases and changes in core body temperature are not observed. Very shortly thereafter, at ~26°C, the rectal temperature starts to increase the sweating rate significantly increases (reviewed by EFSA AHAW Panel, 2022b). Therefore, it would be expected that UCT would be between 24°C and 26°C when cattle are experiencing mild heat stress based on Mader, Gaughan, et al. (2010). However, beef cattle experiencing heat stress increase drinking, change their posture, including increasing standing, reduce eating, especially of grain (Blackshaw & Blackshaw, 1994; Idris et al., 2024; Shephard & Maloney, 2023) and these may occur before UCT.

It is important to note, however, that the consideration of temperatures alone may be reductive in light of the other atmospheric factors (e.g. humidity, wind speed, solar radiation) that may affect the experience of heat. There has been an attempt to capture the effects of such factors through the development of mathematical indices to predict the risk of heat stress in animals, however, it is unlikely that a single index is applicable in all circumstances (reviewed by Shephard & Maloney, 2023). In light of this, recommendations are to activate heat mitigation measures when heat-related ABMs are observed such as sweating and panting.

Short-term actions to mitigate the effects of heat stress include *ad libitum* water provision (see Section 3.2.7.3.2 on 'prolonged thirst'), use of fans and sprinklers, diet management (Brown-Brandl, 2018) and minimisation of handling stress.

The use of sprinklers or mister systems for cooling is common on dairy farms where positive effects on respiration rates and rectal temperature have been observed (Chen et al., 2015; Gaughan, Mader, Holt, & Lisle, 2008; Parrini et al., 2022). To the EFSA experts' knowledge, this practice is uncommon in beef cattle. The only study known to the authors on sprinkler use in beef cattle took place on a feedlot setting (Mader et al., 2007) and not indoors. While the use of sprinklers effectively reduced ambient temperature, it was associated with an increased risk of elevated RH (Mader et al., 2007). In bedded pens, using sprinklers indoors can be effective where ambient humidity is sufficiently low to allow water droplets to dissipate before reaching the pen floor, or when there is high level of ventilation allowing particles to dissipate (e.g. sprinklers used in combination with fans). Alternatively, sprinklers can be placed outside the bedded area in pens with a clear functional area separation. Sprinklers and misters have both shown to cool the atmosphere, however sprinklers generate more wastewater than misters (Lin et al., 1998).

Another strategy frequently used in dairy farms is the use of fans, however only a few studies have been conducted evaluating their impact on the welfare of beef cattle kept indoors (Magrin et al., 2017; Marchesini et al., 2018; Parrini et al., 2022). Magrin et al. (2017) observed a positive effect of use of fans when the THI was above 75 with animals showing a reduction of panting and abnormal respiration. Research on calves also reported a positive effect of fan use; calves kept in barn with ceiling fans spend more time lying than calves allocated in a barn without ceiling fans (Parrini et al., 2022), and calves kept in pens with ceiling fans spent more time ruminating, had greater average daily gain and clean coats compared to calves kept in pens with axial fans (Marchesini et al., 2018). Further research is needed to determine optimal fan design and placement to effectively reduce heat load in indoor beef cattle.

Additionally, diet management may help mitigating the effects of heat stress. A reduction of feed intake is observed in periods of high temperatures (Blackshaw & Blackshaw, 1994; Gaughan et al., 2002; Mader et al., 2002). In dairy cows, a reduced feed intake resulted in a decreased total calory intake directly affecting how energy was distributed in the cattle's body (Rhoads et al., 2009). Increasing fat content as partial replacement of starch in the diet may help in these cases, although this strategy alone was insufficient to alleviate heat load during very high temperatures (Gaughan, Mader, & Holt, 2008). Supplementation of sodium bicarbonate and dietary potassium, but not potassium bicarbonate, were shown to be beneficial to heat-stressed lactating dairy cows (Schneider et al., 1988). However, no specific data were found for beef cattle. In any case, it is recognised that some of these unbalances are difficult to manage from a dietary point of view when cattle are at the finishing stages in fattening farms.

If possible, cattle should be progressively (within 2–7 weeks) exposed to heat so acclimatisation takes place (Blackshaw & Blackshaw, 1994; Shephard & Maloney, 2023). Handling stress should be minimised by reducing handling frequency and applying gentle handling techniques. Long term strategies include design and constructions of barns optimised to minimise indoor heat load.

3.2.7.3.2 | *Prolonged thirst*

In a situation of high environmental temperatures and water restriction there is a risk of prolonged thirst. Water is critical to maintain homeostasis because it facilitates the transfer of heat from the interior of the body of cattle to their surroundings (Wagner & Engle, 2021). In a situation of high environmental temperatures, availability and access to water become even more important. For recommendations on water, see Section 3.2.1.5).

3.2.7.3.3 | *Resting problems*

Exposure to high environmental temperatures leads to significant changes in cattle behaviour. In response to high temperature-humidity index (mean THI ranging from 56.2 to 73.8) dairy cows reduced their lying time by approximately 30%, likely to increase heat dissipation rates (Cook et al., 2007a). When cattle were provided with more space (5.1 m^2 vs. 3.6 m^2), lying time increased (Llonch et al., 2022), suggesting that during high environmental temperatures lower stocking rates may help reducing resting problems and help with heat dissipation.

3.2.7.3.4 | *Linked welfare consequences*

Resting problems are linked with **'locomotory disorders (including lameness)'** because prolonged standing increases the risk of lameness with studies indicating a rise in lameness during periods of heat stress in dairy cows (Cook et al., 2007b; Sanders et al., 2009). Mitigating resting problems is expected to reduce the risk of locomotory disorders.

3.2.7.3.5 | *Welfare consequences relevant to suckler cows and suckler calves*

The same welfare consequences apply to suckler cows and suckler calves. However, it is considered that the likelihood of suffering heat stress by suckler cows and suckler calves when kept indoors is low because typically they are kept indoors over winter only. See Section 3.4 for a discussion of heat stress in animals kept outside.

3.2.7.4 | *Conclusions on high environmental temperatures (indoor housing)*

1. Heat waves are becoming more common in the EU, and this increases the likelihood of fattening animals to be exposed to high environmental temperatures.
2. Most of the research on high environmental temperatures and its consequences have been done in dairy cattle but similar effects on beef are expected.
3. The severity of heat stress will be higher in instances where night temperatures remain high.
4. Highly relevant negative welfare consequences of exposure to high environmental temperatures are heat stress, prolonged thirst and resting problems. Heat stress is likely to start when temperatures exceed the upper boundary of the TCZ but there are no precise estimates of such threshold for cattle. The risk of heat stress increases when temperatures reach the UCT threshold (~24°C–26°C) (certainty > 66%).
5. Physiological and behavioural attempts to adapt to high environmental temperatures include increased respiratory rate, sweating, a reduction of feed intake and an increase in standing times.
6. Water demand under high environmental temperatures increases up to double of bseline needs. Increasing the fat content in the diet is a strategy to reduce the heat load (certainty > 50%) but is insufficient under high environmental temperatures (certainty > 90%).
7. Sprinklers are an effective cooling system as long as air humidity is not too high (certainty > 90%), but optimum placement and usage frequency has not yet been determined. Misters are an effective cooling system to be used in beef cattle farming, as long as air humidity is not too high (certainty > 66%). The use of sprinklers and misters in the bedded lying area carries the risks to increase the moisture of the bedding material leading to negative welfare consequences (certainty > 90%).
8. The use of fans under hot environmental conditions reduces heat stress (certainty > 90%). Additionally, it keeps the bedding material dry, promoting better cattle comfort (certainty > 90%). Further research is needed on type of fan design and fan placement that minimise air recirculation and maximise ventilation in beef cattle farming.
9. Barn design and construction elements (such as building orientation, insulated roofs) have a great impact on the mitigation of heat stress.
10. The effectiveness of cooling and ventilation systems in confined beef cattle are little studied and need more research.

3.2.7.5 | *Recommendations on high environmental temperatures (indoor housing)*

1. *Ad libitum* water should be provided under high environmental temperatures via a through. Bowls should not be used.
2. Sprinklers should not be used in bedded lying areas. More research is needed on the use of fans and sprinklers in beef pens for a fully effective use (optimum placement, frequency of usage and effects on cattle adaptation).

3. Barns should be built in such a way to maximise natural ventilation (doors, windows, roof ridge), to have insulated roofs, include more than one water trough per pen and include a permanently accessible outdoor loafing area. Fans should be placed in such a way that air circulation above the animals is maximised.

3.3 | Minimum space allowance (feed trough, lying area and total space requirements)

3.3.1 | Current practices

There is currently no EU legislation setting minimum space allowances for beef cattle. Some MSs have such requirements, e.g. Austria, where a minimum space of 2.7 ^{2} is required for an animal of 650 kg kept on fully slatted flooring. No such quantitative requirements are specified for bedded systems, for which a 'sufficiently sized lying area' is requested by the Austrian legislation. Recommendations for space allowance found in the EU literature for commercial beef farms range from 2.4 to 5.5 m^2 per animal for bedded pens and from 1.8 to 3.2 m^2 for slatted pens, depending on the weight (and age) of cattle. For more details on existing recommendations on space allowance per MS, please consult the EFSA 'Technical Report on the most common husbandry systems and practices for keeping beef cattle' (EFSA, 2025).

3.3.2 | Feed trough space requirements

3.3.2.1 | *Welfare consequences of limited feeding space*

'Group stress' was identified as a highly relevant welfare consequence of restricted space at the feed trough. Feeding behaviour and activity patterns of managed beef cattle are influenced by the individual's rank within the social hierarchy (Phillips, 1993). Dominant animals are typically able to access resources according to their motivation, whereas a subordinate might have to adapt to dominant group members' preferences (Llonch et al., 2018). Studies on beef cattle housed in pens with continuous access to the feed trough have shown that the simultaneous feeder use by all animals in the pen is not frequent (e.g. less than 10% of all observations in Gottardo et al., 2004) and is mainly observed immediately after feed delivery in case of farms with a single daily distribution of the feed (Cozzi & Gottardo, 2005; Gottardo et al., 2004). In a study with automatic feeding systems providing feed 6 times a day, on average 20% of bulls accessed the feed trough simultaneously, with short peaks of visits where 40% of the animals accessed the feeder simultaneously (Schneider, Volkmann, Kemper, & Spindler, 2020).

3.3.2.2 | *Calculation of feed trough linear space requirements (cm/animal)*

A linear feed space requirement of 46 cm and 56 cm per animal, respectively, was estimated using the equation proposed by Petherick and Phillips (2009) for feed troughs (see Section 2.2.3.1) with $k = 0.064$ and two different liveweights (400 and 700 kg).

Alternative feed trough spaces have been evaluated in experimental studies. Gottardo et al. (2004) did not observe any change in the number of conflicts (fights and mounting activities) when comparing feed trough spaces of 60 and 80 cm/head for Simmental bulls fattened from 320 to 615 kg liveweight under *ad libitum* feeding regimen. Schneider, Volkmann, Kemper, and Spindler (2020) reported that in a study with an automatic feeding system (providing feed 6 times a day) with a feed trough of 4.85 m in a pen with 14 animals (equivalent to 34.6 cm trough space per animal or 6.5 feeding spaces of 75 cm width) the most frequent observation was one to three bulls feeding at the same time. This is consistent with results from a study with 95 cm feed trough space per animal, where the simultaneous presence of more than three bulls at the feeder was rare, and most often only one or two bulls were standing at the feed trough at the same time (Cozzi & Gottardo, 2005).

In light of these results, the EFSA experts concluded that there is sufficient evidence to state that cattle's motivation to synchronise their feeding behaviour is reduced when feed is provided *ad libitum*. Therefore, a feeding space of 60 cm per animal was considered appropriate based the *ad libitum* feed regime recommended in the 'Feeding and nutrition' section. This results, for example, in 4.80 m of total feed trough length for a group of 8 animals.

3.3.2.3 | *Calculation of space needed for standing while eating (m^2/animal)*

Petherick and Phillips (2009) suggested that two-dimensional space allowance requirements can be estimated through the allometric equation $A = kW0.66$ where the k value stands for a constant and W for animal weight. Different values are proposed in the scientific literature to estimate the space required for cattle to stand. For indoor housing, Gallo et al. (2023) proposed a value of $k = 0.014$ based on estimated area requirements based on photographs (resulting in 0.76 and 1.10 m^2/animal for animals of 400 and 700 kg, respectively). Also based on image analysis, Volkmann et al. (2021) proposed similar values: 0.73, 0.97 and 1.09 m^2/animal for weight classes < 450, 450–650 and > 650 kg, respectively, but do not provide *k*-values. In the context of animal transport, Petherick and Phillips (2009) recommended $k = 0.02$ to estimate space allowance requirements for standing. The authors noted that livestock transported in these conditions would have little additional space beyond what they physically occupy when standing. The UK Farm Animal Welfare Council (FAWC, 2019 as cited in EFSA AHAW Panel, 2022b) proposed a minimum *k*-value of 0.021 'for an acceptable floor space for cattle' while the EFSA Scientific Opinion on the welfare of cattle during transport recommended $k = 0.034$ to allow for sternal recumbency and keeping balance (EFSA AHAW Panel, 2022b).

Considering the range of *k*-values proposed in the scientific literature, and the fact that cattle standing at the feed trough on farm do not require additional space to cope with transport conditions (e.g. vehicle acceleration), the EFSA experts decided to adopt the value proposed by Petherick and Phillips (2009) ($k = 0.02$). This is higher than the space requirements proposed by Gallo et al. (2023) and by Volkmann et al. (2021) for on-farm conditions; the additional space resulting from a slightly higher *k* as proposed by Petherick and Phillips (2009) was assumed to provide the animals with room to reach for feed while standing at the feed trough.

In summary, assuming $\text{Area} = kW^{2/3}$, and $k = 0.020$, 1.09 m^2 and 1.58 m^2 are the required spaces for standing while feeding for animals weighing 400 and 700 kg, respectively.

3.3.3 | Lying area space requirements

3.3.3.1 | *Welfare consequences of restricted space allowance in the lying area*

The EFSA experts identified several highly relevant welfare consequences associated with restricted space allowance: **'resting problems'**, **'restriction of movement'**, **'group stress'**, **'soft tissue lesions and integument damage'**, **'bone lesions (including fractures and dislocations)'**, **'locomotory disorders (including lameness)'**, **'inability to perform exploratory or foraging behaviour'** and **'inability to perform play behaviour'**. No linked welfare consequences were identified in this context.

3.3.3.1.1 | *Resting problems, restriction of movement and inability to perform exploratory or foraging behaviour*

Cattle are very motivated to lie down, prioritising lying time over feeding when having to choose after deprivation of both (Tucker et al., 2021). To assess lying behaviour in cattle, the literature refers to ABMs such as duration of standing and lying, number of lying bouts and number and type of movements involved in getting up and lying down.

Steers and heifers housed indoors spent less time lying when provided with less than 2 m^2 per animal (Fisher, Crowe, O'kiely, & Enright, 1997; Hickey, Earley, & Fisher, 2003; Keane et al., 2018b). When provided with more space (from 2.5 m^2/animal to 4.0 m^2/animal; 7 animals/pen; pen width varying from 3.5 to 5.6 m; pen depth 5 m kept constant), 56 finishing bulls performed more lying bouts and kept a greater distance from one another, avoiding the central area of the pen (Gygax, Siegwart, & Wechsler, 2007). With increasing space, bulls lay for longer on their sides or their belly with at least one fore and one hind leg stretched out (Gygax, Siegwart, & Wechsler, 2007). The mean distance between a lying bull and its nearest lying neighbour ranged from 114 cm when housed at 2.5 m^2/animal to 161 cm when housed at 4.0 m^2/animal (Gygax, Siegwart, & Wechsler, 2007). This distance increased on average by 25 cm per each additional square metre of space allowance and did not change with increasing live weight ranging from 405 to 543 kg (Gygax, Siegwart, & Wechsler, 2007). However, no statistically significant differences in total lying duration were detected among the different space allowances investigated in bulls (Gygax, Siegwart, & Wechsler, 2007) due to the similar mean lying times observed across treatments. No detectable differences were also reported in a separate study of 240 heifers housed at 3.0, 4.5 or 6.0 m^2 per animal (Keane et al., 2017).

In contrast, a higher total lying time was observed in fattening bulls housed at 5.1 m^2/animal compared to 3.6 m^2/animal (Llonch et al., 2022). In a study in Korea, 36 steers spent more time standing when housed at 10 m^2/animal (five animals/pen) than when housed at 12.5 m^2/animal (four animals/pen) or 16.67 m^2/animal (three animals/pen), while they spent more time walking and lying when provided with 16.67 m^2/animal rather than at smaller space allowances (Ha et al., 2018). The authors hypothesise that larger space allowances allow the animals more possibility for movement (Ha et al., 2018), while giving more opportunity to lie down comfortably and keeping greater inter-individual distance when lying. When interpreting the results of these studies, it should be considered that increasing the space allowance per animal by changing the number of animals per pen may introduce confounding of space, resource access and social aspects.

In addition to the amount of space available, the type of housing (indoor or outdoor) may also play a role on lying behaviour, although due to confounding effects it is difficult to disentangle effects of space and floor properties and indoor/outdoor conditions. Finishing steers ($N = 960$) housed in groups of 40 animals in an open feedlot in the USA at 14.7 m^2/animal spent less time lying and more time walking than steers housed in a bedded hoop barn at 4.65 m^2/animal (Johnson et al., 2011). This difference may be due to longer distances required to reach feed troughs. When comparing groups of 6 individuals housed indoors in CSFs at a space allowance of 3 m^2/animal with groups housed outdoor with at least 6 m^2/animal, the ones housed outdoor performed more lying bouts per day and 'displayed less hesitation before lying when compared with animals housed indoors' (Hickey et al., 2002). Therefore, larger space allowances might increase walking behaviour while not hampering resting opportunities although interpretation of the results is difficult due to confounding effects mentioned above.

3.3.3.1.2 | *Group stress*

Group stress is influenced by the frequency and type of social interactions. Several authors (Cortese et al., 2020; Fisher, Crowe, O'kiely, & Enright, 1997; Fisher, Crowe, Prendiville, & Enright, 1997; Hickey et al., 2002; Hickey, Earley, & Fisher, 2003; Keane et al., 2017) did not report statistically significant effects of different space allowances on the occurrence of agonistic interactions. Thirty-two heifers kept in groups of eight animals/pen did not show differences in pushing, butting or threatening other individuals at a stocking density 1.5 or 3.0 m^2/animal (Fisher, Crowe, Prendiville, & Enright, 1997). Neither 96 heifers housed in groups of 8 individuals either at 1.5 m^2/animal, 2.0 m^2/animal, 2.5 m^2/animal or 3.0 m^2/animal differed in performing aggressive (butting, pushing, threatening) or social (licking, sniffing, nuzzling) behaviours (Fisher, Crowe, O'kiely, & Enright, 1997). Similarly, 75 finishing steers did not differ in the amount of aggressive behaviour (butting or threatening another individual, or interrupting pen mates' lying or feeding bouts) performed when housed at 1.5 m^2/animal, 2.0 m^2/animal, 3.0 m^2/animal or 4.0 m^2/animal (Hickey, Earley, & Fisher, 2003). Mounting or head-butting behaviour was not influenced by space allowance neither in 240 heifers housed in groups of 10 individuals at either 3.0 m^2/animal on CSFs, 4.5 m^2/animal on CSFs or 6.0 m^2/animal on straw (Keane et al., 2017). Finishing bulls housed at a stocking density of 10 animals/pen (3.5 m^2/animal) did not differ in mounting, chasing or displacing pen mates compared to those housed at a lower stocking density of 8 animals/pen (4.37 m^2/animal) (Cortese et al., 2020). These results suggest that an increase in space allowance up to 4 m^2/animal is not associated with a reduction in aggressive behaviour, although the lack of statistically significant differences may be due to the relatively small sample sizes observed in the studies. There is no sufficient evidence on the exact space allowance value above which a reduction in aggressive behaviour seems to occur.

In contrast, fighting (illustrated in the article with a photograph of two steers standing and showing frontal head-to-head contact) occurred more frequently in steers housed at 10 m^2/animal (five animals/pen) compared to treatments that provided either 12.5 m^2/animal (four animals/pen) or 16.67 ^{2}/animal (three animals/pen) (Ha et al., 2018) in a study with 36 steers. However, Hickey et al. (2002) did not detect differences in aggressive interactions (defined as 'any behaviour initiated by a standing animal towards a standing counterpart, which was confrontational in nature and resulted in the latter retreating from the action') in 126 finishing steers kept indoors at 3 m^2/animal and animals housed outdoors at 18 m^2/animal. In summary, a decrease in fighting behaviour (Ha et al., 2018) was only found when comparing generally much larger space allowances than studied by Fisher, Crowe, O'kiely, and Enright (1997); Hickey, Earley, and Fisher (2003); Keane et al. (2017); and Cortese et al. (2020) with the exception of Hickey et al. (2002). However, in the latter study the overall number of aggressive interactions was low (mean of seven interactions during 3 h in groups of six animals) and it compared two different housing systems and hence the results are considered less comparable to the other studies.

With regards to non-agonistic social behaviours (licking, sniffing, nuzzling), their frequency was reduced in 75 steers housed in groups of 5 at 1.5 m^2/animal compared to steers housed at 4.0 m^2/animal (Hickey, Earley, & Fisher, 2003). A reduction in the frequency of such social interactions was also found in 32 heifers housed in groups of 8 individuals at 1.5 m^2/animal compared to those housed at 3.0 m^2/animal (Fisher, Crowe, Prendiville, & Enright, 1997). The authors hypothesise that larger space allowances may allow more voluntary social contact, which is often restricted to involuntary contact in higher stocking densities (Fisher, Crowe, Prendiville, & Enright, 1997). Keane et al. (2017) did not observe differences in self- and allo-grooming among 240 heifers housed at either 3.0, 4.5 or 6.0 m^2/animal.

The potential impact of environmental enrichment on agonistic interactions was tested by Matković et al. (2020) in a study involving a total of 66 heifers divided in four groups. The enrichment consisted of a mechanical grooming brush and two salt blocks. Heifers housed at high stocking density (3.3 m^2/animal; 19 animals/pen) used enrichment material more frequently than those in low density (4.5 m^2/animal; 14 animals/pen). Head butting was largely increased in the low-density group without enrichment (21 times during the 2 h/week observations throughout the four-month study period, compared to five or four times in the other groups) and chasing occurred more frequently in non-enriched pens, both with low and high stocking density. The authors give no explanation for the increased butting in the lower density group. However, as only one group per treatment was investigated, single animals may have largely affected results, with independence of the statistical units being questionable.

3.3.3.1.2.1 | Synchronous behaviour

Group stress can also result in lack of synchronous lying behaviour. Synchronous behaviour refers to the simultaneous voluntary exhibition of a certain behaviour (Duranton & Gaunet, 2016). A review paper on behavioural synchronisation argued that synchronous behaviour has different adaptive values, such as decreasing the pressure of predation on offspring by synchronising reproduction, but also increasing the effectiveness of anti-predation strategies through collective avoidance of threats and predators or the so-called dilution effect, and increasing social cohesion (Duranton & Gaunet, 2016). Although direct links between synchronous behaviour and positive welfare have not (yet) been demonstrated by research, a high degree of synchronous behaviour has been proposed as an indicator of positive welfare in cattle (Napolitano et al., 2009), sheep (Gautrais et al., 2007) and goats (Miranda-de la Lama & Mattiello, 2010; reviewed by Mattiello et al., 2019).

Voluntary synchronicity is especially observed on pasture. The synchronisation of behaviour in fattening bulls was found to be higher on pasture than in pens (Tuomisto et al., 2019), and on outwintering pads compared to slats (Hickey et al., 2002), and dairy cows were more synchronised on pasture than in tie stalls (Krohn et al., 1992). Nevertheless, synchronous behaviour also occurs indoors. A study on the lying synchronicity of a dairy cow herd housed under two different systems (a conventional milking unit and an automatic milking system) determined that the lying synchronicity (calculated from overdispersion of a binomial process, i.e. lying/not lying) tended to be slightly higher in the automatic milking unit (Raussi et al., 2011). The authors concluded that synchronised lying in cows appears to be a 'constant phenomenon that depends on social facilitation rather than on external cues', i.e. is little influenced by milking or feeding events. This is further supported by findings from (Flury & Gygax, 2016) who studied behavioural synchronicity across different farm types (farms with suckler cows, farms with dairy cows milked by staff in a milking parlour and farms with dairy cows milked by a robot). They concluded that even in systems with the weakest synchrony-promoting factors (i.e. milked by a robot), a high level of synchronicity was still observed. Based on this, the authors suggested that 'synchrony may be a behavioural need for cows' (Flury & Gygax, 2016). Although there is not sufficient evidence to state that synchrony is a behavioural need i.e. a biological requirement, evidence indicates that synchronicity has adaptive values and that cattle will synchronise their behaviour if they have an opportunity to do so.

Social cohesion might also play a role in synchronous lying, as observed in an Australian study with 60 steers in groups of five individuals per pen (indoor pens with concrete flooring covered by RMs, (Mayes et al., 2025)). Synchronous lying increased with the number of days the group of steers spent together, likely impacted by the adaptation to the new social group (Mayes et al., 2025). Also, the authors suggested that 'more pen space led to a slight increase in synchronous lying' (Mayes et al., 2025). Suckler cows demonstrated a daily pattern of lying and feeding synchrony at least as strong as the one observed in dairy cows milked in a parlour, suggesting a role of internal motivation factors in synchronous behaviour in addition to external ones (e.g. milking and feeding times) (Flury & Gygax, 2016).

3.3.3.1.2.2 | Spacing behaviour

Beef cattle unable to show spacing behaviour due to insufficient space may also experience group stress. The term 'social space' has been coined by Dawkins (1985) and was further defined by Keeling (1994) as 'the space required by a group of animals to position themselves appropriately in relation to each other'. Spacing behaviour was observed in beef cattle (8 steers and 20 heifers of Hereford breed) kept in large areas (estimated as ~890 m^2/animal in pasture, during summer and ~ 15 m^2/animal in a dry lot, over winter). The mean distance between individuals (across all behaviours) was 49 m on pasture and 12 m on dry lot, while the mean distance to the nearest neighbour was 4.5 m on pasture and 1 m on dry lot (Kondo, Masato, et al., 1989). In a study involving 196 calves and 602 heifers and dairy cows (Hereford, Holstein, and Holstein crosses) the mean head-to-head distance to the nearest neighbour increased as group size decreased, and space allowance generally increased. However, beyond a space allowance of 360 m^2 per animal, no further increase in spacing behaviour was observed. At this space allowance, the average distance to the nearest neighbour in the adult group reached a plateau at approximately 10–12 m (Kondo, Sekine, et al., 1989).

A study on bulls indicated that the mean distance between animals increased when more space was provided: the mean distance between a lying bull and its nearest lying neighbour went from 114 cm when housed in 2.5 ^{2}/animal to 161 cm when housed in 4.0 ^{2}/animal (Gygax, Siegwart, & Wechsler, 2007). This distance increased by 28.0% with each additional square metre of space allowance and did not change with increasing live weight ranging from 405 to 543 kg (Gygax, Siegwart, & Wechsler, 2007). Spacing behaviour has also been reported in dairy cows, the median distance reported in cows kept in cubicles in six dairy herds was between 6 and 7 m (Gygax et al., 2010).

3.3.3.1.3 | *Soft tissue lesions and integument damage, bone lesions (including fractures and dislocations) and locomotory disorders (including lameness)*

No studies were found investigating a relationship between soft tissue lesions, integument damage or bone lesions and space allowance. Keane et al. (2018b) found no influence of different space allowances (2.0 ^{2}/animal, 2.5 ^{2}/animal or 3.0 ^{2}/animal) on claw lesions of 120 steers observed. However, different space allowances influenced the occurrence of mild lameness (categorised as such when it did not impair the regular conclusion of the fattening cycle of the affected bull) and severe lameness (when it required early culling of the animal) in fattening bulls in a separate study (Magrin, Gottardo, Contiero, et al., 2019). An increase in space allowance from 3.5 ^{2}/animal to 4.0 ^{2}/animal for bulls housed in CSFs led to a smaller prevalence of mild (from 4.45% in 3.5 ^{2}/animal to 1.43% in 4.0 ^{2}/animal) and severe (from 2.24% in 3.5 ^{2}/animal to 1.54% in 4.0 ^{2}/animal) lameness events (Magrin, Gottardo, Contiero, et al., 2019). Additionally, bulls housed on deep litter at 5.5 ^{2}/animal were less affected by mild lameness than bulls housed at 5.0 ^{2}/animal (3.12% of affected bulls in 5.0 ^{2}/animal, 0.57% in 5.5 ^{2}/animal, Magrin, Gottardo, Contiero, et al., 2019). The authors suggested that a space allowance above 5.0 ^{2}/animal should be provided to prevent lameness (Magrin, Gottardo, Contiero, et al., 2019). Also 1350 finishing bulls housed in outdoor feedlots in Brazil in groups of 150 individuals were affected by lameness more frequently when housed at 6 ^{2}/animal compared to higher space allowances (12 ^{2}/animal, 24 ^{2}/animal) (Macitelli et al., 2020). Prevalence of lameness did not differ between bulls housed at 3.5 ^{2}/animal or 4.37 ^{2}/animal (Cortese et al., 2020), although Cortese et al. (2020) speculated that larger space allowances might give bulls more chances of complete recovery after lameness events. These observations suggest that even a small increase of 0.5 ^{2}/animal may contribute to a decreased risk of lameness, although factors such as housing, flooring, bedding type and material also play a role. Therefore, further research is needed to confirm such a relationship between increased space and lameness reduction in beef cattle.

3.3.3.1.4 | *Inability to perform play behaviour*

There are currently no studies looking at the relationship between space allowance and play behaviour in adult beef cattle. However, based on the behaviour of younger beef animals (e.g. steers and heifers performing social play (Bagnato et al., 2023; Francesconi et al., 2024), and of dairy calves (e.g. dairy calves performing locomotor play and social play (Bertelsen & Jensen, 2019; Jensen et al., 1998), it is hypothesised that adult beef animals will also demonstrate play behaviour, even if at lower frequencies, when space is not restricted.

Motivation to play was investigated by Jensen (1999), who observed the behaviour of 48 heifers in an open field test, after having been tethered by a neck-bar tie for a minimum of 1 week to a maximum of 4 weeks in an individual pen measuring 3.6 × 1.75 m. While there was no effect of the time spent tethered on the duration of walking and trotting, the time spent tethered influenced the number of heifers that galloped and buckled in the test arena (Jensen, 1999). These results might indicate a motivation to perform locomotory behaviour when the possibility to do so has been previously restricted. No other studies on the relationship between space allowance and play behaviour in adult cattle were found.

An overview of the main welfare effects reported in the reviewed studies is presented in Table 6.

TABLE 6 Summary of results from literature on the relationship between space allowance and beef cattle welfare.

Minimum space allowance investigated per study (m^2/animal)	Main welfare effects
1.5	Daily lying time was lower for heifers at 1.5 m^2 compared to 2.0 m^2, 2.5 m^2 and 3.0 m^2/animal (Fisher, Crowe, O'kiely, & Enright, 1997)
	The duration of each lying bout was lower for heifers at 1.5 m^2 compared to 2.0 m^2, 2.5 m^2/animal (Fisher, Crowe, O'kiely, & Enright, 1997)
	No difference in aggressive (butting, pushing, threatening another animal) or social behaviours (licking, sniffing, nuzzling another animal) between heifers housed at 1.5 m^2/animal, 2.0 m^2/animal, 2.5 m^2/animal or 3.0 m^2/animal (Fisher, Crowe, O'kiely, & Enright, 1997)
	No difference in aggressive interactions (butting, pushing, threatening another animal) among heifers at 1.5 m^2 compared with 3.0 m^2/animal (Fisher, Crowe, Prendiville, & Enright, 1997)
	Higher frequency of head-resting behaviour (when a standing animal rests its head on a lying conspecific) and lower social interactions (licking, sniffing or nuzzling another animal) in heifers housed at 1.5 m^2/animal compared to heifers housed at 3.0 m^2/animal (Fisher, Crowe, Prendiville, & Enright, 1997)
	No difference in time spent eating defined as an animal being at the feed trough with head lowered into the feed bin and/or visible mastication of feed while at the feed bin) nor in aggressive interactions (butting, threatening, interrupting another animal lying or eating) for animals housed at 1.5 m^2; 2.0 m^2; 3.0 m^2 or 4.0 m^2/animal (Hickey, Earley, & Fisher, 2003)
	Lying time was reduced for finishing steers at 1.5 m^2/animal compared to 2.0, 3.0 or 4.0 m^2/animal (Hickey, Earley, & Fisher, 2003)
	The social interactions (licking, sniffing or nuzzling) observed in finishing steers at 1.5 m^2/animal on CSFs were lower than for animals housed at 4.0 m^2/animal on straw (Hickey, Earley, & Fisher, 2003)
2	The lying time, the number of steers lying simultaneously and the number of steers observed self-grooming were lower at 2.0 m^2 than at 2.5 m^2 and 3.0 m^2/animal (Keane et al., 2018b)
2.5	No statistical differences in bulls' lying time when housed at 2.5 m^2/animal compared to 3, 3.5 or 4.0 m^2/animal (Gygax, Siegwart, & Wechsler, 2007)
	Bulls showed less lying bouts when housed at 2.5 m^2/animal compared to 3.0.5, 3.5 or 4.0 m^2/animal (Gygax, Siegwart, & Wechsler, 2007)
	Bulls spent less time in an outstretched body posture when housed at 2.5 m^2/animal compared to 3.0, 3.5 or 4.0 m^2/animal (Gygax, Siegwart, & Wechsler, 2007)
	Bulls kept a shorter lying distance to the nearest lying bull when housed at 2.5 m^2/animal compared to 3.0, 3.5 or 4.0 m^2/animal (Gygax, Siegwart, & Wechsler, 2007)
	Bulls housed at 2.5 m^2/animal kept shorter inter-individual distances compared to bulls housed at 3.0, 3.5 or 4.0 m^2/animal (Gygax, Siegwart, & Wechsler, 2007)
3	No difference in aggressive interactions (standing animal towards a standing counterpart, confrontational in nature and that resulted in the latter retreating from the action) between steers housed indoors at 3 m^2/animal and animals housed outdoors at 18 m^2/animal, but agonistic interaction levels were generally low (Hickey et al., 2002)
	Animals kept indoors at 3 m^2/animal had a lower number of daily lying bouts compared to animals confined in outwintering pads (OWPs) at 18 m^2/animal (Hickey et al., 2002)
	The frequency of synchronised lying behaviour was lower for animals housed indoors at 3 m^2/animal than for animals confined on OWPs at 18 m^2/animal (Hickey et al., 2002)
	No difference in lying time, eating time (head down, actively biting feed), social (self- and allogrooming) and aggressive interactions (mounting, head-butting) among animals housed at 3.0 m^2 or 4.5 m^2/animal on CSFs and at 6 m^2/animal on straw (Keane et al., 2017)

(Continues)

TABLE 6 (Continued)

Minimum space allowance investigated per study (m^2/animal)	Main welfare effects
3.5	More lameness cases detected in bulls at 3.5 m^2/animal compared to 4.0 m^2/animal (Magrin, Gottardo, Contiero, et al., 2019)
	Finishing bulls showed no differences in social interactions (mounting, chasing, head/butt displacements) at 3.5 m^2/animal compared to 4.37 m^2/animal (Cortese et al., 2020)
	Daily activity was lower in animals housed at 3.5 m^2/animal compared to 4.37 m^2/animal (Cortese et al., 2020)
	Daily rumination did not differ between animals housed in 3.5 m^2/animal compared to 4.37 m^2/animal (Cortese et al., 2020)
3.6	Shorter lying time of fattening bulls at 3.6 m^2/animal compared to 5.1 m^2/animal (Llonch et al., 2022)
4.65	Steers housed in an hoop barn (4.65 m^2/animal) spent more time lying and less time standing and walking compared with steers housed in an open feedlot with shelter (14.7 m^2/animal) (Johnson et al., 2011)
5.0	More mild lameness cases detected in bulls housed at 5.0 m^2/animal compared to 5.5 m^2/animal (Magrin, Gottardo, Contiero, et al., 2019)
6	Higher occurrence of lameness in bulls at 6 m^2/animals compared to 12 or 24 m^2/animal (outdoor feedlots) (Macitelli et al., 2020)
10	Bulls at 10 m^2/animal spent more time standing and more time fighting compared to 12.5 and 16.67 m^2/animal (Ha et al., 2018)
	Bulls housed at 10 m^2/animal spent less time walking than bulls housed at 16.67 m^2/animal (Ha et al., 2018). Bulls housed at 12.5 m^2/animal also spent less time walking than bulls housed at 16.67 m^2/animal (Ha et al., 2018). There was no difference in walking time between bulls housed at 10 m^2/animal and at 12.5 m^2/animal (Ha et al., 2018)

3.3.3.2 | *Results from the behavioural model and expert knowledge elicitation (EKE)*

3.3.3.2.1 | *Results of lying area requirements*

It was estimated that beef cattle in groups of 8–20 animals are motivated to keep on average an inter-individual distance to the nearest neighbours of 4.7 m (median estimate from the EKE, with a 90% certainty interval of 2.2 and 10.2 m) (Table 7).

TABLE 7 Results of EKE-estimated values and of values estimated for different percentiles following the fit of the beta distribution.

Parameter	Minimal inter-individual distance														
Question	What is the minimum (average) inter-individual distance to the nearest neighbours that cattle are motivated to keep when all animals are lying synchronously under unrestricted conditions?														
Unit	[m]														
Percentiles	P1	P2.5	P5	P10	P16.7	P25	P33.3	P50	P66.7	P75	P83.3	P90	P95	P97.5	P99
EKE results	2.0	2.1	2.2	2.4	2.7	3.2	3.6	4.7	6.0	6.8	7.9	9.0	10.2	11.1	12.0
Fitted distribution	BetaGeneral ($\alpha = 0.97751$, $\beta = 2.6953$, min = 1.95, max = 14.3) with shape parameter α, β indicate a positive-skewed distribution on the range from min to max.														

Abbreviation: P, percentile.

These values were then used as input in the behavioural model described in Section 2.2.3.2 to estimate the lying area requirements.

For eight animals, this results in a lying area of 11 m^2 per animal (with a 90% certainty interval of 2.7–48 m^2/animal). Figure 5 depicts the assumed animal distribution and the corresponding pen dimensions assuming a long-to-short pen side length ratio of 1.15 (which corresponds to an optimal use of space).

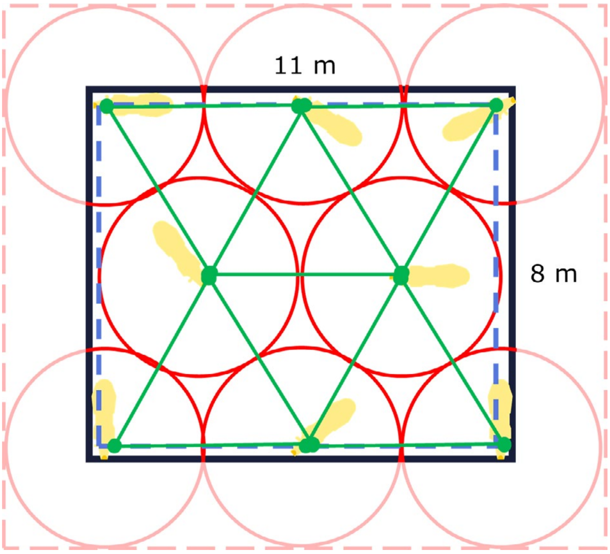

FIGURE 5 Animal distribution and pen dimensions estimated via the behavioural model for groups of eight animals. Assuming a median distance of 4.7 m between animals and a long-to-short pen side ratio of 1.15, this results in a pen of ~8 × 11 m (total area of 88 m^2) for a pen keeping eight animals.

Based on the current available knowledge, the most likely required space allowance is 11 m^2/animal (for animals > 400 kg kept in groups of 8), but it may be that due to uncertainties the value can be as low as 3 m^2/animal or as high as 48 m^2/animal. Due to the effects of animal distribution in the pen, the calculations of necessary space will vary depending on the group size. Estimation of space allowance per animal for groups of 8, 14 and 20 animals is shown in Table 8.

TABLE 8 Estimation of space allowance per animal based on behavioural model and EKE outputs.

Group size	Median space allowance per animal in the lying area [m^2/animal]	95% confidence interval [m^2/animal]
8	11	3–48
14	13	3–60
20	14	3–65

The large space interval indicated in the 90% certainty interval is due to the unknown effect of some factors on space allowance. Table 9 summarises the sources of uncertainty on the estimate.

TABLE 9 Sources of uncertainty when determining space allowance needs for the lying area.

Source of uncertainty	Reasoning	Direction of effect
Missing data on effects of indoor space allowances > 6 m^2/animal	Missing studies on the spacing behaviour of cattle in large space allowances in indoor pens and potential influence of other factors (e.g. floor, climate).	Under- or overestimation
Effects of the presence of horns	Unknown effect of the presence of horns, i.e. horned animals may need larger space	Under- or overestimation
How the quality of space influences space allowance needs	A more complex environment may stimulate animals to perform a wider behavioural repertoire, and this may impact space allowance requirements	Under- or overestimation

3.3.3.2.2 | *Summary of the discussion of EFSA experts during the EKE*

Reasoning behind lower and upper ranges (P1% and P99%): During the EKE, experts explained the reasoning behind their estimates for the upper and lower bounds. For the lower bound, reference was made to Gygax, Siegwart, and Wechsler (2007) reporting an average distance between a lying bull and his nearest lying neighbour of 1.6 metres in a pen of 4.0 m^2/animal. However, since this study did not evaluate larger space allowances, the EFSA experts opted for increasing the average minimum distance to 2 metres. This adjustment reflects the group's view that the animals' welfare will be impaired and the animals will not be motivated to lie down with an inter-individual distance lower than two metres. For the upper bound, experts referred to (Kondo, Sekine, et al., 1989), reporting an average distance between an adult animal and the nearest neighbour of 10–12 metres across a range of behaviours, and EFSA experts considered that there will be no further addition to animal welfare and the animals' motivation to lie down will no longer increase with an inter-individual distance higher than 12 metres.

Reasoning behind median value (P50%): The experts considered that a value of 4.5 m was a fair estimate of the median inter-individual distances beef cattle are motivated to keep while lying indoors. The individual judgements provided by the experts were closer to each other, reflecting a low uncertainty among the experts about the choice of the 1st quartile (P25%, ~3 m). The individual judgements provided by the experts for the third quartile were spread along a higher range of values, reflecting a higher uncertainty among the experts about the choice of this quartile (P75%) (~6 m) compared to the 1st quartile. Sources of uncertainty around the estimates were also discussed.

3.3.4 | Total space requirements

Total space requirements in both slatted and bedded pens were calculated by adding the space required for feeding and lying (see results Sections 3.3.2 and 3.3.3, respectively). For cattle above 400 kg kept in groups of 8, a total indoor space allowance of ~13 m^2 per animal (90% certainty interval 5–50) was estimated.

3.3.5 | Conclusions on minimum space allowance (feed trough, lying area and total space requirements)

1. Current space allowances observed in commercial beef farms range from 2.4 to 5.5 m^2 per animal for bedded pens and from 1.8 to 3.2 m^2 for slatted pens, depending on the weight (and age) of cattle.
2. Highly relevant welfare consequences of restricted space allowance are resting problems, restriction of movement, group stress, soft tissue lesions and integument damage, bone lesions (including fractures and dislocations) and locomotory disorders (including lameness).
3. There is little research on the effects of space allowance > 6 m^2/ animal on the welfare of housed cattle, but providing larger space allowances generally increases lying time and allows for more inter-individual spacing, as well as more movement opportunities (certainty > 90%).
4. An increase in space allowance up to 4 m^2/animal is not associated with a reduction in aggressive behaviour (certainty > 66%). There is not sufficient evidence on the exact space allowance value above which a reduction in aggressive behaviour is observed.
5. There are no studies investigating the relationship between space allowance and play behaviour in beef cattle older than 6 months, although evidence from other cattle categories suggests that adult cattle are motivated to perform locomotory play.
6. There is limited data on the spacing behaviour of beef cattle when indoors. More information on the spacing behaviour of beef cattle is available for animals kept on pasture, where space allowance is typically not restricted.
7. It is estimated that a minimum feed trough space of 60 cm per animal is sufficient when feed is provided *ad libitum*.
8. A space allowance of 1.1 and 1.6 m^2 is needed for standing while feeding for animals weighing 400 and 700 kg, respectively. It is estimated that fattening cattle > 400 kg need ~11 m^2 per animal for lying (> 90% certainty interval 3–48 m^2). It is expected that younger animals with lower body weights are motivated to keep shorter inter-individual distances.
9. A total indoor space allowance of ~13 m^2 per animal > 400 kg is estimated (> 90% certainty interval 5–50 m^2).
10. Additional outdoor space has benefits (see recommendations in Section 3.2.4.5). Depending on outdoor conditions (e.g. presence of covered area, outdoor feed trough, dry and comfortable lying area), sharing of space between indoor and outdoor areas is possible (certainty > 66%).

3.3.6 | Recommendations on minimum space allowance (feed trough, lying area and total space requirements)

1. Regardless of the type of flooring, space allowance per animal should be increased in relation to current practice (ranging from 2.5 to 4.5 m^2/animal) to reduce resting problems, restriction of movement, group stress and

locomotory disorders (including lameness). It is recommended to increase the total space allowance to ~13 m^2 per animal (for animals >400 kg) to allow for synchronous lying and further reduce group stress.
2. A minimum feed trough space of 60 cm per animal is recommended when feed is provided *ad libitum*.

3.4 | Welfare of cattle kept outside

This section addresses the welfare of cattle kept on pasture including the use of outwintering pads (Section 3.4.1) and cattle kept in feedlots (Section 3.4.2).

3.4.1 | Welfare of cattle kept on pasture

3.4.1.1 | *Nutrition and feeding*

3.4.1.1.1 | *Current practices*

Cattle at grass predominantly rely on forage including grasses, legumes, and other vegetation as their primary source of nutrition, with minimal or no supplementation of grains or concentrates. Outwintered cattle frequently receive supplementary conserved forage, i.e. hay or silage, and may also receive some additional concentrate feed. Supplementary forage is commonly offered via round or long feeders, or by placing bales directly on the ground, with varying proximity to shelters, ease of access and quality of the ground around the feeding points.

3.4.1.1.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of nutrition and feeding practices when kept on pasture are **'prolonged hunger'**, **'gastro-enteric disorders'** and **'metabolic disorders'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3.

3.4.1.1.3 | *Preventive and mitigating measures*

3.4.1.1.3.1 | Prolonged hunger

As cattle on pasture receive most of their nutrition from it, the availability and composition of the sward is a critical factor in determining their health and welfare. The energy requirements of the animals vary considerably with their metabolic needs (for example, affected by size, growth, lactation or pregnancy), activity level, heat loss due to climatic conditions (i.e. low temperatures, there is a wind chill and/or wet coat) and the degree of insulation by fat and coat (Cabezas-Garcia et al., 2021; Caton & Olson, 2016) (see also Section 3.4.1.3.3.1 on 'cold stress'). Beef cattle at pasture spend between 7 and 13 h grazing per day (4.5–9 h during daylight) (22 studies reviewed by Kilgour, 2012). When there is insufficient sward and/or supplementary feed is not provided, it is likely that the animals will experience hunger, and over time fail to grow as expected and to produce the expected sufficient milk for a calf, and/or lose body condition.

Cattle may experience hunger at any time of year, but outwintering presents a particular challenge in ensuring adequate nutrition for cattle. Ryegrass blades barely grow under 5°C (Nagelmüller et al., 2016) and therefore there either needs to be sufficient grass already grown for the animals to cover the periods of time with temperatures below 5°C or supplementation will be required. The feed provided must be sufficient to cover energy requirements including heat loss, and in addition must be accessible to the animals, not covered by snow or under water or far away from shelter during harsh weather. A Swiss study of Scottish Highland 13 cows kept outside for 13 daysand then housed for 13 days found that the cows spent 48% more time eating when outside (6 h vs. 4 h), and significantly more time ruminating, with more chewing cycles related to eating and rumination, more regurgitated cuds and more chewing cycles per cud than when housed, suggesting they change their feeding behaviour in response to climatic conditions (Braun et al., 2014).

Apart from winter, other situations when beef cattle may be particularly at risk of experiencing hunger include periods of poor grass growth, for example during a drought period (seasonal conditions or climatic event); inability to access grass, for example due to flooding; overstocking/overgrazing of the pasture, for example through disease control restrictions limiting cattle movements; individual animals within a group experiencing hunger, for example through not being able to compete for food when availability is limited in amount or area; or when facing particularly high metabolic demands, for example when having twins.

Monitoring both eating in the short term, and body condition score (BCS) in the longer term, are critical to ensuring that animals are consuming sufficient food. These and other outcomes such as live weight gain or physiological parameters are reported in studies of different nutritional regimes over winter when risk of poor nutrition is high (e.g. Capitan et al., 2004; Kelln et al., 2011; Legesse et al., 2012; Manninen et al., 2007; Manninen et al., 2008; Morgan et al., 2009).

Provision of supplementary feeding in periods of low grass growth is crucial to ensure feed resource availability and maintenance of BCS.

3.4.1.1.3.2 | Gastro-enteric disorders and metabolic disorders

3.4.1.1.3.2.1 | Endoparasites

The impact of endoparasite infection on welfare is not always predictable, ranging from sub-clinical infections with few adverse effects occur for some parasite species in some host individuals to clinical manifestations in others such as soft faeces, anaemia or poor body condition depending on factors such as host susceptibility, type and prevalence of parasite or pasture management. A range of gastro-intestinal parasites can affect beef cattle reared in a grass-based system with or without winter housing. The most frequently identified parasites on five German beef suckler cow herds were *Fasciola hepatica*, gastro-intestinal nematodes (GIN), *Eimeria* spp., *Moniezia* spp. and *Dictyocaulus viviparus*, with one or more species identified in 41% of 708 samples taken over 17 months, although clinical signs were never observed (Gillandt et al., 2018). A study of German suckler beef calves found *Giardia duodenalis*, *Cryptosporidium parvum*, *Eimeria* spp., *Strongyloides papillosus* and other strongyles (Jäger et al., 2005). Samples from three pasture-based beef farms in Romania found evidence of GIN (family *Trichostrongylidae*), tapeworms (*Moniezia* spp.) and oocysts of coccidia (*Eimeria* spp.) on all of the farms, and fluke eggs (*Paramphistomum* spp.) on one farm (Kubelka, 2016). In 5573 faecal samples from 115 beef cattle farms across Czechia a 30% prevalence of paramphistomid fluke eggs was found (Červená et al., 2022), and a study of 32,007 slaughtered Irish fattening beef cattle found a prevalence of 22% for *Fasciola hepatica* (Carroll et al., 2020). Many of these species rely on aspects related to grazing pasture for transmission, for example the presence of an intermediate host such as a fresh-water snail (*Gastropoda: Lymnaeidae*) for *Fasciola hepatica*. Pasture management is part of a suite of preventative or treatment measures, together with including diagnostic testing and anthelmintic administration (Kumar et al., 2013).

3.4.1.1.3.2.2 | Trace mineral deficiencies, metabolic diseases and toxicities associated with grazing

A range of trace mineral deficiencies can occur in grazing cattle depending on the sward composition, soil type, climate and individual requirements, with selenium, copper, zinc, manganese and iodine deficiencies being most common. Prevention and/or treatment utilises supplementation via salt licks, boluses, injections or fortification of energy or protein supplementary feed (Arthington & Ranches, 2021). Hypomagnesemia, sometimes known as 'grass staggers' or 'grass tetany', is a metabolic condition that typically, but not exclusively, occurs in lactating animals grazing fast-growing grass in the spring or sometimes autumn. Due to the rapid progression of clinical signs that may include muscle fasciculations, elevated heart rate and nystagmus, up to seizures and collapse, urgent treatment with intravenous magnesium solution is required to prevent death. Pre-emptive magnesium supplementation may help prevent cases at high-risk times, in particular following a case in the group (Hindman, 2023).

Furthermore, a wide variety of toxic plants can cause disease in grazing cattle. The likelihood of ingestion and clinical signs or death depends on the species eaten, availability of other food and amount ingested (Anadón et al., 2018).

Active health and welfare planning in conjunction with a veterinarian and/or nutritional advisor may help prevent welfare problems associated with grazing (Caldrow, 2016).

3.4.1.2 | *Water access*

3.4.1.2.1 | *Current practices*

Drinking water may be provided to cattle at pasture from natural sources such as ponds, streams or springs, or from troughs or tanks fed by pipes from mains or springs. Checking whether water is available (for example, not frozen), and that the water filling system is working is an important daily task for stock people caring for cattle at pasture.

3.4.1.2.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle related to water access when kept on grass are **'prolonged thirst'**, **'heat stress'** and **'group stress'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3.

3.4.1.2.3 | *Preventive and mitigating measures*

3.4.1.2.3.1 | Prolonged thirst

Cattle may experience thirst, if insufficient water is available to supplement that available through grazing. In northern Europe a suckler cow with her calf may drink 50 L of water per day, and a 350 kg fattening animal may drink 14 L (Farm advisory service, 2022). Animals may become thirsty if water sources dry up, for example during a drought period, or if there are problems such as a cracked trough, frozen pipe or broken tap system. When cattle become thirsty, they may initially appear restless around the expected water sources, however as dehydration progresses, they become subdued and physiological processes are further altered (Silanikove, 1994).

The mineral and pathogen content of water sources for cattle on pasture affect water palatability and vary depending on the quality of the source and transmission, for example, the cleanliness of pipes and troughs. In one study, water consumption and weight gain of calves at pasture was greater when water from a dugout was aerated and pumped to a trough compared to drinking directly from the dugout source, assumed to be due to better palatability (Lardner et al., 2005). Bica et al. (2021) found that beef cattle drinking from troughs gained more weight and had more frequent drinking bouts and less time overall spent drinking than those drinking from with a pond as their water source. Cattle drinking from natural or artificial waterholes can also facilitate the transmission of water-borne diseases such as tuberculosis (Herrero-García et al., 2024) or leptospirosis (Zamir et al., 2022). For a discussion on how water quality (regarding microbial contamination, salinity and sulfate content) affects drinking behaviour of beef cattle, see Section 3.2.1 on water access for housed animals.

3.4.1.2.3.2 | Heat stress

When cattle are under heat stress the physiological mechanisms employed to dissipate heat, such as sweating and increasing respiration, also increase water loss, requiring increased water intake to prevent dehydration (Edwards-Callaway et al., 2021). Likewise, limited access to water will increase the risk of experiencing heat stress due to the inability to employ preventative physiological mechanisms.

3.4.1.2.3.3 | Group stress

Competition over resources may result in stressful agonistic interactions of cattle at pasture and influence the ability of individual animals to avail themselves of important elements, including shade and water (Schütz, Rogers, et al., 2010). Social hierarchy can affect access to resources of cattle at pasture with dominant cows reducing access of lower-ranked animals to food (Bica et al., 2020; Phillips & Rind, 2002) or water (Coimbra et al., 2012). It is important to ensure the amount of water and number of watering points are sufficient to prevent the negative effects of competition, particularly when competition is likely to be increased when there is a high risk of heat stress.

3.4.1.3 | *Outwintering (protection from cold, wind, rain and underfoot conditions)*

3.4.1.3.1 | *Current practices*

Grass-based husbandry systems involve keeping cattle on pastures. Usually this takes place during the summer, as well as during spring and autumn depending on grass availability and weather conditions (Figure 6). Keeping fattening cattle on pasture during the vegetation period is commonly practised in northern and western European countries like Ireland, France and Belgium whilst keeping suckler cows and calves at pasture over the summer is more widespread. Cattle are housed over winter to protect them from poor welfare associated with a muddy and waterlogged environment, enable easier management of the cattle and prevent damage to pastures by the cattle, what will in turn improve grass growth the following spring. In some cases, beef cattle may also be kept outdoors during winter. This outwintering of cattle usually occurs on pasture, with supplementary feeding frequently being required in both lowland grass fields and more extensive hill-based systems. Less common approaches for outwintering include the use of outwintering pads (Figure 7) which are small group outdoor paddocks surfaced with woodchip or similar materials and artificially drained. Besides a fence and a water trough, outwintering pads typically have no shelter structures and no grooming objects. Alternatives to keeping cattle in outwintering pads are keeping them grazing on brassica, turnip or arable fields, again usually with supplementary forage feeding.

FIGURE 6 Cattle on pasture (© Luc Mounier).

FIGURE 7 Fattening cattle on outwintering pads (© Teagasc).

3.4.1.3.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of outwintering are **'cold stress', 'resting problems'** and **'inability to perform comfort behaviour'**. No linked welfare consequences were identified in this context. In addition, outwintering of cattle can result in difficulty in monitoring the animals, increasing their risk of welfare impairments when problems arise. The definition of each WC is available in Section 2.3.

3.4.1.3.3 | *Preventive and mitigating measures*

3.4.1.3.3.1 | Cold stress

Cattle exposed to cold, especially in combination with rain and/or wind, change their behaviour to mitigate the physiological effects, for example by seeking shelter, increasing food intake (Fogsgaard & Christensen, 2018; Morgan et al., 2009) and, if there is a dry lying surface, increasing lying time to reduce heat loss (Olson & Wallander, 2002).

When ambient conditions are unfavourable and cattle have no or little access to shelter, cattle may increase standing time, reduce lying time and reduce eating (Schütz, Clark, et al., 2010; Webster et al., 2008) and show physiological changes indicative of a stress response (increased faecal and plasma cortisol and lower neutrophil count compared to housed cattle) (Webster et al., 2008). Cows reduced feed intake by 62% when exposed to rain and to the combination of wind and rain (Schütz, Clark, et al., 2010). A range of factors affect the likelihood of an animal experiencing cold stress, including temperature, rainfall and windspeed, body surface area: volume ratio, body condition, coat type and degree of adaptation (Van Laer et al., 2014). Cattle acclimatised to cold will have a reduced risk of experiencing cold stress; accordingly, before exposure to low temperatures, cattle should be gradually exposed to cold for several weeks to allow acclimatisation (Islam et al., 2023; reviewed by Shephard & Maloney, 2023).

The concepts of thermoregulation, TNZ and TCZ are discussed in Section 3.2.7.3.1 with a focus on the effects of high environmental temperatures on beef cattle welfare. Similarly to the challenges associated with defining the upper bound of the TNZ, establishing a precise threshold for its lower bound - referred to as the LCT - is also complex. However, existing literature offers some information on possible values for cattle. LCT in cattle has been suggested to be −21°C (Australian Agricultural Council. Ruminants Subcommittee, 1990; as cited in: Van Laer et al., 2014) in dry, still conditions. Mader, Johnson, and Gaughan (2010) described a 'Comprehensive Climate Index' that integrates temperature, wind speed, humidity and solar radiation. They concluded that unsheltered adult cattle may experience mild, moderate or severe cold stress below 0°C, −10°C and −20°C, respectively if they had adequate time to acclimate to outdoor environments through the acquisition of additional external or tissue insulation or both and are receiving nutrient supplies compatible with the level of environmental exposure. Morgan et al. (2009) calculated the LCT for suckler beef cows (Aberdeen Angus cross bred and Limousin cross bred) outwintered in Scotland using two methods that factored in heat production, body weight change, insulative value of fat and air (fat depth and coat length), wind speed and solar radiation. They found that the LCT ranged between −8°C and 13°C and that during two of the four 3-week study periods where temperatures fell below the LCT, and the cows increased their use of shelter (trees, ring feeders or straw bales). Taken together, these results indicate that although a specific threshold for LCT is hard to determine, in general for adult cattle in inclement weather, cold stress starts at temperatures below 0°C, and in still, dry conditions it does not occur until temperatures are lower (between −10° and −21°). No specific thresholds are available for the TCZ although cold stress may already be present when temperatures go below its lower boundary.

Fogsgaard and Christensen (2018) found that higher levels of both wind and rain increased the use of shelters by beef cattle. A study on dairy cows under experimentally manipulated environmental conditions found a wet coat to be particularly important in influencing behaviour, as cows under the 'rain' condition had reduced lying time, feed intake and skin temperature in comparison to a control group, and although this was exacerbated with additional wind, wind alone had little effect on the responses to the ambient temperatures (−1°C to 17°C, with mean temperature of 10°C) (Schütz, Clark, et al., 2010).

Beef cattle will use natural or artificial shelter to reduce the negative effects of cold, inclement weather (Fogsgaard et al., 2019; Fogsgaard & Christensen, 2018; Morgan et al., 2009), especially at night (Fogsgaard et al., 2019; Fogsgaard & Christensen, 2018; Van Laer et al., 2014). Cattle in temperate nature reserves with artificial shelters and a range of habitats with natural shelters, such as trees and shrubs, showed a preference to use natural shelter when it was available (Van Laer et al., 2014). Fogsgaard et al. (2019) found that an open-sided rectangular shelter was preferred to a partitioned rectangular shelter by overwintering beef cattle. In another study, Fogsgaard and Christensen (2018) found cattle increased their use of rectangular, open-sided field shelters that provided 6 or 8 m^2 per animal compared to 4 m^2 per animal.

3.4.1.3.3.2 | Resting problems

It is argued that during winter, cattle behaviour is a trade-off between maximising energy gain (thermal and food) and minimising energy loss (thermal and metabolic)' (Olson & Wallander, 2002) and that selecting the most appropriate behavioural strategy depends on the precise conditions in any given moment (convective heat loss reduced through lying as opposed to standing as wind chill is lower closer to the ground, conductive heat loss increased by lying on wet as opposed to dry ground, more efficient use of solar radiation more available when standing and a large area of the body is presented and the orientation can be changed easily, availability of food in a given area) (Morgan et al., 2009; Olson & Wallander, 2002). Lying is important for cattle to rest and ruminate. And a review of the behaviour of cattle at pasture concluded that 'the greater part of rumination occurs while animals are lying rather than standing' and that 'more ruminating and more resting occur at night than during the day', with a range of ruminating whilst lying occurring for 4–7 h/day (19 studies) and lying resting occurring for 2–6 h/day (16 studies) (Kilgour, 2012). Robért et al. (2011) found that feedlot fattening cattle during winter or spring spent between 45% and 55% of their time lying, especially at night (> 55% time between 8 pm and 4 am spent lying). Lying behaviour is reduced when the ground is wet (Tucker et al., 2021) and rebound behaviour is evident when clean, dry conditions are made available (Schütz et al., 2019). Lying time was increased when rectangular, artificial, open-sided field shelters provided 6 or 8 m^2 per animal as opposed to 4 m^2 per animal (Fogsgaard & Christensen, 2018). Despite a preference for rectangular over hexagonal shelters, the design did not affect the proportion of cattle lying in them (Fogsgaard et al., 2019). Dickson, Campbell, Monk, et al. (2022) compared behaviour of steers at pasture with those in feedlots with either a dry surface, mud up to the coronary band or mud past the fetlock and found that lying time was reduced and fewer steps were taken by the cattle when the mud was past the fetlock compared to pasture, and also reported evidence of a rebound effect for lying behaviours in the paddock after experiencing the high mud conditions (past the fetlock).

Although several studies have shown that pasture access during the vegetation period is associated with reduced lameness in dairy cattle (see review by Roche et al., 2024), the specific conditions of outwintering for fattening cattle could be hypothesised to increase the risk of laminitis due to cold weather (Vermunt, 1990 as cited in Manninen et al., 2008), although this was not found in outwintered suckler cows in Finland (Manninen et al., 2008). Wet conditions have been hypothesised to predispose to lameness through softening the horn and weakening the skin barrier (Borderas et al., 2004), and some studies have found a positive correlation in dairy cattle between lameness and rainfall rates (Ranjbar et al., 2016) and higher lameness prevalences for dairy cattle at pasture over winter (Williams et al., 1986). However, there is a paucity of information for beef cattle kept outdoors.

3.4.1.3.3.3 | Inability to perform comfort behaviour

Cattle are motivated to prevent the coat from becoming soiled (Chen et al., 2017; Schütz et al., 2019), as well as to groom and remove coat dirt when possible (Dickson et al., 2024; Kilgour et al., 2012). In the context of pasture, grooming objects may be natural, for example, trees (Kohari et al., 2007) or artificial, such as brushes. Dickson et al. (2024) showed that grazing beef cattle 'became dirtier, showed reduced average daily gain and had elevated faecal cortisol metabolites' when the brush was removed.

3.4.1.3.3.4 | Additional considerations: Insufficient monitoring for health/welfare issues

Observation of beef cattle is essential to prevent, detect and treat health and other welfare issues. Conducting such observations is more time-consuming when animals are outwintered at pasture, and sometimes it may be hindered by weather or ground conditions, or the movement of the animals in extensive settings. There is a lack of literature detailing the methods and frequency for monitoring or the impact of lack of monitoring. However, there is a growing literature describing innovations in automated monitoring technology for animals at pasture (e.g. for review see Aquilani et al., 2022). As yet, they are not widely adopted and do not have the capabilities to replace monitoring by a skilled stockperson. However, they may aid monitoring, for example, by identifying the location of animals in extensive settings.

3.4.1.4 | *Additional welfare consequences*

Other WCs selected as highly relevant for cattle when kept on grass are **'handling stress'**, **'predation stress'**, **'heat stress'** and **'sensory under- and/or overstimulation'**. These were not directly linked with water, nutrition or feeding or outwintering which were the topics identified in the mandate, but the EFSA experts considered them important to discuss these as well because they are generally relevant for cattle kept on grass. The definition of each WC is available in Section 2.3.

3.4.1.4.1 | *Preventive and mitigating measures*

3.4.1.4.1.1 | Handling stress

Cattle kept on pasture, particularly those in extensive settings or born at pasture, may have little exposure to humans and handling procedures, and consequently low levels of habituation to humans and handling processes. Farmers of extensively reared native breed cattle in Spain reported that these animals were particularly nervous and even aggressive during handling, and that some traits such as being strong, alert or on guard were important to protect against predators and survive in the mountains (Estévez-Moreno et al., 2021). Extensively reared cattle are more likely to find handling interactions stressful, and principles of low-stress handling, utilising flight zones and points of balance to move animals, and calm handling in optimal facilities, are particularly important for them (Grandin, 2021), and for the safety of the handlers (Titterington, Knox, Buijs, et al., 2022). Careful habituation of cattle on pasture to humans, and particularly associating human presence with positive experiences, are likely to be beneficial for future handling events. Destrez et al. (2018) studied 20 French beef farms and found that animals had a greater avoidance distance when farmers reported monitoring them less frequently, did not make contact with the animals during monitoring and did not include behaviour as a criterion for genetic selection. For further considerations on handling stress in cattle, see Section 3.6.1.3.2.

3.4.1.4.1.2 | Predation stress

Cattle are the second most common livestock species targeted by large predators in Europe after sheep, and data from 2018 to 2021 across 23 European countries showed that 20%–30% of all predated livestock were cattle in 2 countries, between 10% and 20% in 4 countries, and less than 10% in the remaining countries (Marsden, 2023). The absolute numbers of animals reported as killed in official data are likely to be underestimated as farmers do not always report killings (Marino et al., 2016). Grazed cattle, particularly those kept extensively, for example in the mountains, are at a particularly high risk of predation (Marsden, 2023). When the attack is not fatal, injuries can still occur and this is a welfare concern but there are no available figures on the extent of this.

In the presence of wolves, cattle become restless, agitated and group together for protection (Laporte et al., 2010). Breck et al. (2012) found that after the killing of calves by wolves, their dams increased vigilance and reduced foraging for several days. Although less targeted, cattle are reportedly harder to protect than sheep but measures trialled by farmers include the use of livestock guardian dogs, temporary fencing, especially when calves are young, using GPS collars to identify when cattle are behaving unusually and find them quickly, and including the 'gentle but protective' Hérens breed cattle within the herd to train the other cattle how to respond effectively to predation threat (Marsden, 2023).

3.4.1.4.1.3 | Heat stress

For a description of heat stress in beef cattle, see 'high environmental temperatures in housed cattle' (Section 3.2.7). In this section, only information relevant for cattle kept on pasture is discussed.

Cattle on pasture exposed to high temperatures are at risk of heat stress and this is more likely to occur in cattle with black hides (Brown-Brandl et al., 2006) and heavy weights (Grandin, 2016). Beef cattle under high heat load seek shade, increase drinking, change their posture (including increased standing), reduce eating, especially of grain and other active behaviours, increase respiration rate (Idris et al., 2024; Shephard & Maloney, 2023) and increase sweating (Gebremedhin et al., 2008; Pereira et al., 2014). Shade can be provided through shelters or through the natural environment, predominantly by trees. Beef cattle in silvopastoral systems have been shown to seek shade and have fewer signs of heat stress compared to cattle without shade (Barreto et al., 2022; Goncherenko et al., 2024). Short term management factors available to mitigate the effects of heat stress of cattle on pasture include managing the environmental conditions (e.g. provision of shade), diet management (timing, frequency and type of supplementary food), ensuring appropriate water provision (sufficient and easily accessible) and minimising handling stress (timing and type of handling) (Brown-Brandl, 2018). Cattle appear to acclimatise to high temperatures within 2–7 weeks (Blackshaw & Blackshaw, 1994; Shephard & Maloney, 2023), allowing the animal to better dissipate heat and therefore limit the risk heat stress.

3.4.1.4.1.4 | Sensory under- and/or overstimulation

Some pastures, whilst providing grazing and movement opportunities, may be otherwise relatively barren. Few studies have investigated the use of natural or artificial enrichments for beef cattle at pasture. Dickson, Campbell, Lee, et al. (2022) found beef cattle in a barren paddock made sustained use of a cattle brush, woodchip pile and tree stump, and less sustained use of a rope, with 75% of animals interacting with the cattle brush within the first 11 h. After removal of a cattle brush from beef cattle in a barren paddock the cattle 'became dirtier, showed reduced average daily gain and had elevated faecal cortisol metabolites, although this varied according to the degree of initial individual brush use. Additionally, allogrooming and grooming on other objects were reduced when access to the brush was returned, potentially indicating a rebound effect' (Dickson et al., 2024). Trees have also been shown to be used by cattle at pasture, and in one small study appeared to be used in addition, and not in substitution, for allogrooming and self-grooming (Kohari et al., 2007).

3.4.1.5 | *Welfare consequences relevant to suckler cows and suckler calves*

In relation to nutrition and feeding, **'prolonged hunger'** was identified as a highly relevant welfare consequence for both suckler cows and suckler calves at pasture. However, younger suckling calves may be less affected initially, as they rely primarily on milk until maternal lactation declines significantly. **'Gastro-enteric disorders'** associated with endoparasitism were also considered highly relevant for both suckler cows and calves, although endoparasites can affect all classes of beef cattle. Adult cows are particularly susceptible to hypomagnesemia, whereas fattening cattle are more prone to other trace mineral deficiencies.

Concerning water access, all classes of beef cattle may experience **'prolonged thirst'** when at pasture, although suckling calves may be less affected due to milk consumption. Poor water quality was identified as a potential welfare concern across all age groups. Similarly, **'heat stress'** is a risk for all classes of beef cattle, with larger animals being more vulnerable. **'Group stress'** at water points may also occur in both animal categories, though suckling calves are likely less affected.

Under outwintering conditions, **'resting problems'**, **'handling stress'** and **'sensory under- and/or overstimulation' were** all considered highly relevant welfare concerns for both suckler cows and calves. The **'inability to perform comfort behaviours'**, such as grooming, was also highlighted as a significant welfare consequence when grooming objects are lacking. While both suckler cows and calves may be susceptible to **'cold stress'**, calves are more vulnerable. Additionally, heat stress can affect both groups on pasture, particularly larger animals. Lastly, inadequate monitoring under extensive conditions was recognised as a relevant welfare risk for both suckler cows and suckler calves.

3.4.1.6 | *Conclusions on the welfare of cattle kept on pasture*

1. Grass-based husbandry systems involve keeping cattle on pastures from spring to autumn, and some cattle will also be kept outdoors over winter. Outwintering of cattle with supplementary feeding usually occurs on pasture and less commonly on outwintering pads (small group outdoor paddocks with a woodchip or similar surface and drainage) or on arable fields.

2. The highly relevant WCs for outwintered cattle are cold stress, resting problems and inability to perform comfort behaviour.
3. The likelihood of experiencing cold stress depends on external factors such as temperature, rain and wind, as well as on fat and coat coverage, size and acclimatisation (certainty > 90%).
4. Outwintered cattle exposed to low temperatures, especially in combination with rain or wind, increasingly use shelter and eat more. If shelter is insufficient and the lying area is not dry, cattle increase standing time, reduce lying time and reduce eating when this behaviour increases the risk of cold stress (certainty > 90%).
5. Cattle prefer natural over artificial shelter when available (certainty > 66%).
6. Cold stress is likely to start when temperatures fall below the lower boundary of the TCZ but there are no precise estimates of such threshold for cattle. The risk of cold stress increases when temperatures fall below the LCT threshold. For adult cattle in inclement weather, the LCT is approximately 0°C, and in still, dry conditions between –10° and –21° (certainty > 66%).
7. Lying is a behavioural need for resting and rumination and is reduced when the ground is wet and/or muddy (certainty > 90%). There is limited information about the impact of muddy pastures on lameness in beef cattle (certainty > 90%).
8. Poor weather and ground conditions present a challenge in ensuring sufficient monitoring of outwintered animals, increasing their risk of welfare consequences when problems arise (certainty > 90%).
9. The WCs highly relevant for cattle kept on pasture are prolonged hunger, gastro-enteric disorders, heat stress, group stress, handling stress, predation stress and sensory under- and/or overstimulation.
10. Hazards related to grazing are nutrient deficiencies (especially trace minerals), parasitic and metabolic diseases, and intoxications (certainty > 90%).
11. Access to palatable, clean and safe water is necessary at all times to prevent thirst, heat stress and group stress.
12. Cattle on pasture, especially in extensive settings, are at higher risk of handling stress when not habituated to human interactions (certainty > 90%).
13. Predation is a risk to cattle at pasture in many European countries, especially in extensive pasture settings.
14. Cattle in barren grazing paddocks benefit from trees or brushes and other natural or artificial grooming opportunities (certainty > 90%).
15. During times of high heat load, cattle at pasture are at risk of heat stress, especially when no shade is available (certainty > 90%).

3.4.1.7 | *Recommendations addressing the relevant welfare consequences of cattle kept on pasture*

1. Outwintered beef cattle should always have access to a dry lying area, and during times of climatic challenge should have shelter from wind and rain (natural shelter such as trees is preferred) and ready access to food (e.g. in the form of supplementary feed) and water.
2. It should be ensured that fat coverage, coat length and degree of acclimatisation are kept at a level that minimises the risk of cold stress in outwintered beef cattle.
3. The obligation to monitor cattle for signs of ill health or other welfare risks should also apply to cattle on pasture, even if outwintered or extensively kept.
4. Health and welfare planning for cattle on pasture should include nutritional planning and ensure that the risk of problems associated with mineral deficiencies, toxicities and metabolic or parasitic disease is minimised.
5. Grazing cattle should be provided with readily available clean, palatable water at all times, but particular attention should be paid when cattle are at risk of heat stress.
6. In addition, at times of high risk of heat stress, cattle on pasture should have easy access to shade and additional exertional stressors such as handling should be avoided.
7. All cattle kept on pasture should be habituated to humans and calm, low-stress handling methods should be employed to minimise stress.
8. Methods to reduce risk of predation of cattle at pasture should be employed according to local experience of successful initiatives, for example guardian livestock dogs, temporary fencing or including cattle that behave defensively towards predators within the herd.
9. When there is a risk of predation, monitoring of the herd should be carried out to identify and treat injured animals.
10. All cattle at pasture should be provided with grooming opportunities such as trees or brushes, or artificial grooming objects.

3.4.2 | Welfare of fattening cattle in outdoor feedlots

3.4.2.1 | *Current practices*

A feedlot is a specialised outdoor facility dedicated to the confined feeding of fattening cattle in large pens with compacted earth (Figure 8). These facilities are typically equipped with basic infrastructure such as feed and water troughs to support the intensive keeping of large numbers of animals. Although some feedlots have a small, roofed area over the feed troughs, shelter is not always provided. The primary objective of a feedlot is to 'finish' young beef bulls and heifers to achieve the desired final weight and muscle development suitable for slaughter. Further details on this system are provided in EFSA (2025).

FIGURE 8 Feedlot system in the south of Portugal (© George Stilwell).

While the feedlot model is prevalent in the USA, certain European regions have begun to adopt similar practices in recent years (Eurogroup for Animals, 2020 retrieved from EFSA Public call for evidence 2024 – PC-0742 4 – Four Paws). For instance, approximately 70% of beef cattle in central and southern Portugal are fattened in feedlots (Mr George Stilwell, Professor at Faculty of Veterinary Medicine, University of Lisbon, confirmed this by email on 17 January 2024) (Stilwell, 2024).

The principles for housed cattle generally apply to feedlots. This Section discusses feedlot-specific research regarding flooring, water access, nutrition and feeding, lack of environmental enrichment and high environmental temperatures.

3.4.2.2 | *Welfare consequences*

The WCs selected as highly relevant for feedlot cattle as a result of being kept in feedlots were considered to be similar to those applicable to housed cattle, with some exceptions. When differences exist, they are explained. No welfare consequences were identified for suckler cows and suckler calves because these animal categories are not kept in feedlots. The definition of each WC is available in Section 2.3.

3.4.2.2.1 | *Welfare consequences related with flooring/underfoot conditions*

The WCs selected as highly relevant for feedlot cattle as a result of poor flooring and underfoot conditions are '**resting problems**', '**restriction of movement**', **'locomotory disorders (including lameness)'** and '**respiratory disorders**'. The flooring hazards leading to 'soft tissue lesions and integument damage' in cattle kept indoors were considered not relevant in feedlots because of the different properties of underfoot conditions in feedlots (compact soil) compared to indoor housing. As described for cattle kept indoors, 'restriction of movement' is linked with the '**inability to perform sexual behaviour', 'inability to perform comfort behaviour'** and '**inability to perform play behaviour**'. Additionally, restriction of movement is linked with the WC '**bone lesions (including fractures and dislocations)'** in feedlot cattle due to slippery, muddy flooring conditions. The WC 'resting problems' is linked with welfare consequence **'inability to chew and/or ruminate'**.

Regarding underfoot conditions, increased precipitation can lead to problems associated with muddy feedlots. Most of the related research originates from North America and Australia, where muddy conditions have been identified as a serious hazard for animal welfare in outdoor feedlot beef production, particularly when annual precipitation exceeds 500 mm (Grandin, 2016). On the other hand, dust can also be an issue in feedlots (Urso et al., 2021). Welfare consequences resulting from muddy or dusty flooring are discussed below.

3.4.2.2.1.1 | Resting problems and restriction of movement

Muddy conditions often seen in feedlot pens result in an uncomfortable lying surface (reviewed by Grandin, 2016). When cattle were given the choice between pasture or feedlots with different levels of mud, the feedlots were preferred by steers only 40% of the time, independent of the mud level. However, lying times were reduced in feedlots with the highest level of mud compared to pasture with any level of mud (Dickson, Campbell, Monk, et al., 2022). It is likely that low traction due to muddy, slippery underfoot conditions results in restriction of movement (Dijkman & Lawrence, 1997). Increasing stocking rates have also been associated with increasing mud levels (Macitelli et al., 2020).

3.4.2.2.1.2 | Locomotory disorders (including lameness)

Similarly to animals kept on pasture, the risk of lameness in feedlots has been associated with increased precipitation and stocking rates (Marti et al., 2021). Research in USA feedlots showed that reduced available dry space to lie down due to overall muddy conditions was a risk factor for lameness incidence (Greenough, 1997; Mader, 2014), likely due to increased duration of standing in poor, humid flooring conditions.

3.4.2.2.1.3 | Respiratory disorders

When feedlot underfoot conditions are very dry, manure can become dust. Organic dust and particulate matter at relatively high concentrations increase the risk of respiratory diseases (Auvermann et al., 2001; Loneragan et al., 2001) because dust particles irritate the respiratory tract and are carriers of bacteria and fungi to the lungs (Wilson, Morrow-Tesch, et al., 2002). Windy conditions and cattle activity (e.g. locomotion) exacerbate dusty conditions.

3.4.2.2.1.4 | Linked welfare consequences

'Restriction of movement' is linked with the '**inability to perform sexual behaviour'** and the **'inability to perform comfort behaviour'** due to the low traction provided by muddy, slippery underfoot conditions. Dirty coats are more frequent in rainy rather than in dry periods (Macitelli et al., 2020) which potentially exacerbates this welfare consequence. Restriction of movement is also linked with **'bone lesions (including fractures and dislocations)'** because muddy and slippery conditions may also affect the incidence of falls (Marti et al., 2021) and the '**inability to perform play behaviour'**. Resting problems were linked with the '**inability to chew and/or ruminate'** because under uncomfortable underfoot conditions cattle will increase their standing times (Dickson, Campbell, Monk, et al., 2022) and this is likely to reduce the amount of time cattle spend ruminating.

3.4.2.2.1.5 | Preventive and mitigating measures

Wet climatic conditions are the main factor contributing to muddy pens. While rainy conditions cannot be prevented, there are some specific actions that reduce the wetness of the ground and accumulation of mud in feedlot pens, such as inclusion of bedding and frequent pen maintenance. Bedding materials absorb excess moisture from pen surfaces (Mader, 2011; Grandin, 2016). Drier underfoot conditions have been shown to increase feed efficiency in feedlot cattle under wet weather conditions (Birkelo & Lounsbery, 1992; Mader & Colgan, 2007). Mounds (i.e. a well-drained, elevated area made of compacted soil) are another strategy to improve resting (Grandin, 2016; Mader, 2003). An area of 2–2.5 m^2 per animal on the top of a 1.5 m high mound has been recommended (Holland, 2012). Existing feedlot design recommendations include a slope of 1%–6% and an analysis of the soil permeability levels (National guidelines for beef cattle feedlots in Australia, 2012). Scraping of pen surfaces may also reduce muddy conditions by allowing surplus water to be repelled (Grandin, 2016). Another strategy to reduce mud in feedlot pens is to reduce stocking density in the rainy season (Grandin, 2016). Furthermore, it is important to clean feedlot pens frequently and remove sharp objects (such as stones) to reduce the incidence of locomotory problems such as foot rot (Davis-Unger et al., 2019) during muddy conditions.

Prevention and mitigating actions against dust include maintaining a humidity level between 25% and 35% of the pen surface (Stokka et al., 2001; Sweeten, 1982). This can be achieved through the installation of sprinklers or the use of water trucks (Ouapo et al., 2013). Scraping can also help reducing dust in feedlot pens (Darrington, 2016; as cited in Urso et al., 2021). Another strategy to reduce exposure of cattle to dust is the modification of the feeding schedule and avoiding feeding provision at sunset because higher dust levels have been consistently reported during this period of the day (Mitloehner et al., 1999).

3.4.2.2.2 | *Welfare consequences related with water access*

The WCs selected as highly relevant for feedlot cattle as a result of limited water access are the same as those identified for housed cattle (**'prolonged thirst'**, **'group stress'** and **'heat stress'**). Similarly, linked welfare consequences with prolonged thirst are **'metabolic disorders'** and linked welfare consequences with group stress are **'respiratory disorders'**.

3.4.2.2.2.1 | Linked welfare consequences

Linked welfare consequences in this context are the same as those discussed for housed cattle in Section 3.2.1.3.4.

3.4.2.2.2.2 | Preventive and mitigating measures

As for cattle kept indoors, feedlot cattle should be provided with *ad libitum* clean good quality water at all times. Particular attention should be given to water availability in the context of feedlots because of their exposure to solar radiation and high environmental temperatures. Water requirements of beef cattle are discussed in Section 3.2.1.

3.4.2.2.3 | *Welfare consequences related with nutrition and feeding*

The WCs selected as highly relevant for feedlot cattle because of nutrition and feeding are the same identified for housed cattle (**'metabolic disorders'**, **'gastro-enteric disorders'**, **'group stress'**, **'inability to perform exploratory or foraging behaviour'** and **'inability to chew and/or ruminate'**). 'Metabolic disorders' are linked with **'locomotory disorders (including lameness)'**. While prolonged hunger can also be present in cattle arriving in feedlots, this is considered to be a consequence of transport and hence not further discussed in the context of this Scientific Opinion.

3.4.2.2.3.1 | Linked welfare consequences

Linked welfare consequences in this context are similar to those discussed for housed cattle in Section 3.2.3.3.4.

3.4.2.2.3.2 | Preventive and mitigating measures

All prevention and mitigation strategies for feedlot cattle are similar to those for housed cattle (see Section 3.2.3.3).

3.4.2.2.4 | *Welfare consequences related to high environmental temperatures*

The WCs selected as highly relevant for cattle in feedlots as a result of high environmental temperatures are the same identified for housed cattle (**'heat stress'**, **'prolonged thirst'** and **'resting problems')**. The same effects described for housed cattle apply in this context (see Section 3.2.7). Aspects of heat stress specifically applying to cattle kept outside are discussed in this Section. As for housed cattle, the WC resting problems is linked with **'locomotory disorders (including lameness)'**.

3.4.2.2.4.1 | Heat stress

Heat stress is more likely to occur when there is a lack of shade in the feedlot pen and in cattle with black hides (Brown-Brandl et al., 2006) and heavy weights (Grandin, 2016). Cattle with black hides get hotter than cattle with lighter colours when exposed to solar radiation, and heat dissipation is more difficult in cattle with heavy compared to lighter weights (Mader et al., 2006). Shade structures provide different levels of protection from heat depending on their capacity to block solar radiation. When comparing groups of dairy cows on pasture with access to shade structures with varying degrees of solar radiation protection (25%, 50% of 99%), dairy cows kept on pasture chose to spend more time under the shade that blocked a greater percentage of solar radiation (Tucker et al., 2008).

3.4.2.2.4.2 | Linked welfare consequences

Linked welfare consequences in this context are similar to those discussed for housed cattle in Section 3.2.7.3.4.

3.4.2.2.4.3 | Preventive and mitigating measures

Under high environmental temperatures, feedlot cattle use shaded areas when they are available (Brown-Brandl, 2018; Clarke & Kelly, 1996; Eisenberg et al., 2010; Gaughan, Bryden, et al., 2004; Sullivan et al., 2011). When there are no shaded areas in feedlot pens, cattle seek shade from the feed bunks, water troughs and fences (Castaneda et al., 2004; Gaughan & Mader, 2014; Lees et al., 2020; Mitlöhner et al., 2001). Care should be taken to provide shading structures that ensure sufficient air circulation (Gaughan, Bryden, et al., 2004). Wetting cattle is another strategy that feedlot managers may employ to manage high heat loads. This action has been shown to be associated with a reduction of body temperature, respiration rate and panting score in cattle (Brown-Brandl et al., 2010; Davis et al., 2003; Gaughan, Davis, & Mader, 2004; Mader et al., 2007; Tresoldi et al., 2018). It has also been reported that feedlot cattle voluntarily use overhead sprinklers during extreme environmental conditions (Mader et al., 2007; Parola et al., 2012). As described for indoor housed cattle, feedlot managers may also restrict feed or change the timing of feed delivery to reduce exposure to high environmental temperatures.

3.4.2.2.5 | *Welfare consequences related with a lack of environmental enrichment*

The WCs selected as highly relevant for cattle as a result of lacking environmental enrichment are the same identified for housed cattle (**'inability to perform exploratory or foraging behaviour'**, **'inability to chew and/or ruminate'**,

'inability to perform comfort behaviour', **'sensory under- and/or overstimulation'** and **'inability to perform play behaviour'**. As for housed cattle, sensory under- and/or overstimulation is linked with **'group stress'** and **'inability to avoid unwanted sexual behaviour'**.

Limited research exists on the use of environmental enrichment devices in feedlot cattle (Park, Schubach, et al., 2020; Wilson, Mitlöhner, et al., 2002). For a discussion of research on effects of environmental enrichment, see Section 3.2.5.

3.4.2.2.5.1 | Linked welfare consequences

Linked welfare consequences in this context are similar to those discussed for housed cattle in Section 3.2.5.3.5.

3.4.2.2.5.2 | Preventive and mitigating measures

All prevention and mitigation strategies for feedlot cattle are similar to those described for housed cattle – Section 3.2.5.

3.4.2.3 | *Conclusions on welfare of fattening cattle in outdoor feedlots*

The conclusions described for indoor housed cattle are also applicable to feedlot cattle, except those related to flooring/underfoot conditions and lack of outdoor access.

1. Feedlots are outdoor confinement facilities designed to accommodate and keep large numbers of animals. Feedlots have compacted soil flooring and basic infrastructure typically consisting of water and feed troughs sometimes covered by a roofed area.
2. The duration of lying is reduced and cattle movement impeded when pen surface is muddy (certainty > 90%).
3. Muddy conditions increase the risk of lameness mainly due to infections (certainty > 90%).
4. The risk of dust-related respiratory disorders is increased when the soil moisture is low (less than ~25%) (certainty > 66%).
5. Access to palatable, clean and safe water is necessary at all times to prevent thirst and group stress, and to mitigate heat stress, especially during high environmental temperatures (certainty > 90%).
6. Under high environmental temperatures, the lack of a sufficiently large shaded area for use by all animals increases the risk of heat stress (certainty > 90%).

3.4.2.4 | *Recommendations on the welfare of fattening cattle in outdoor feedlots*

The recommendations made for cattle housed indoors are valid for feedlot cattle, except for those related to flooring and lack of outdoor access.

1. Muddy conditions in feedlot pens should be avoided to ensure comfortable resting, ease of locomotion, reduce the risk of lameness and allow the performance of comfort behaviours. Measures to reduce exposure to mud include building a mound, providing bedding material, scraping the soil surface, ensuring a slope to naturally remove the excess of water from the enclosure and reducing stocking density.
2. Dusty conditions should be avoided to prevent respiratory problems. Strategies to reduce exposure to dust include scraping the soil surface and moisturising it with sprinklers or a water truck (aiming for a soil moisture of 25%–30%), and reducing stocking density.
3. Similar to indoor beef cattle, feedlot cattle should be provided with palatable, clean and safe quality water available *ad libitum* at all times.
4. When there is the risk of heat stress, feedlot cattle should have access to sufficiently sized shade for the simultaneous use by all animals, and handling should be kept at a minimum.

3.5 | Risks to the welfare of suckler cows and calves associated with the weaning of suckler calves

3.5.1 | Current practices

Weaning is an inherent husbandry practice in cow-calf beef production systems, otherwise known as suckler farms. Natural weaning in cattle typically happens between 7 and 14 months of age, enabling calves to gradually shift from nutritional and social maternal dependence to autonomy (Enríquez et al., 2011; Lynch et al., 2019). This extended period facilitates the development of the calf's rumen and social behaviour. However, in managed environments such as on farms, weaning of beef suckler calves tends to happen more abruptly and slightly earlier, i.e. between 5 and 11 months of age (EFSA, 2025). This practice aims to optimise the dam's body condition and to maximise reproductive potential (i.e. one calf per year) (Lynch et al., 2019).

Weaning and separation often occur simultaneously with other changes in husbandry conditions, which may also have a welfare impact on the animals. Seasonal grass-based integrated calf-to-beef production systems often combine weaning with housing, but calves and cows may remain in close proximity for several months. Non-integrated systems tend to combine weaning with transportation and marketing prior to entry into feedlots. In both systems, calves have to adapt to a new diet and group composition, thereby subjecting them to various stressors (Enríquez et al., 2011).

The weaning method can vary depending on the farming system and management practices. It can be one of the following methods.

3.5.1.1 | *Abrupt weaning*

Weaning of beef calves under management conditions is traditionally undertaken by abruptly separating the 5–11 month old calf from its mother (EFSA, 2025); Enríquez et al., 2011). This method remains widely adopted due to its operational simplicity and compatibility with reproductive management schedules.

3.5.1.2 | *Two-step weaning methods*

Two-step weaning methods aim to decouple the cessation of suckling from the social separation of the cow-calf pair (Enríquez et al., 2011). These methods include yard weaning (also called fenceline separation) and nose-flap weaning, both designed to end suckling behaviour prior to complete physical separation from the dam.

Nose-flap weaning comprises the fitting of plates to calves' noses to prevent suckling but still allow ingestion of solid food alongside their dams. After a period of adaptation of about a week, the calves are then fully separated from their dams. One drawback of this method is the risk of loss of individual flaps and return of the ability of calves to suckle, or some calves learning to suckle despite the flap.

In fenceline weaning, cows and calves are placed on opposite sides of a fence, allowing continued visual, auditory and limited physical contact while preventing suckling for several days prior to full separation (Enríquez et al., 2011).

Fenceline weaning can be made even more gradual by providing calves that remain with their mothers with high-quality supplemental feed or pasture in a designated area through a specially constructed 'creep gate' or opening in the fence line or gateway that allows the calves to pass through but not the mothers. This creep weaning stimulates the calves to increase solid food intake and thus progressively reduce their nutritional and social dependence on the dam. It also enables the calves to become accustomed to new feed types before they are separated from their mothers. Once the calves are comfortable feeding away from the cows, the creep opening is closed and the calves separated from their dams at weaning age.

A more gradual weaning process, by reducing contact times between calves and cows over some weeks, has been described for dairy calves by Vogt et al. (2024), with weaning starting at 3 months of age. However, this method has not been reported for suckler calves.

3.5.2 | Welfare consequences

The WCs selected as highly relevant for suckler cows as a result of weaning are **'separation stress'**, **'handling stress'**, **'inability to express maternal behaviour'** and possibly **'group stress'**, if weaning and separation are combined with regrouping. The WCs selected as highly relevant for suckler calves as a result of weaning are **'inability to perform sucking behaviour'**, '**prolonged hunger**' **'handling stress'**, **'separation stress'** and **'group stress'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3.

The severity of the WCs experienced by cows and calves is in general influenced by the weaning age of the calves. Many studies relate to weaning of dairy calves that are typically weaned much earlier than suckler calves, often around 6–12 weeks of age (Sirovnik et al., 2020). Although several studies also investigated weaning of suckler calves as early as 30 days (e.g. de Souza et al., 2021), such practices are not common in Europe (see Section 3.5.1) and results from studies with very early weaning may not directly be transferred to common suckler calf weaning in Europe. It can be expected that the intensity of WCs is higher the younger the calves are because older calves are physiologically and behaviourally better equipped to cope with the dietary and social changes. This has been confirmed with regard to separation stress and inability to perform sucking behaviour, indicated by increased vocalisation, reduced feeding frequency and increased cross-sucking by de Souza et al. (2021), when comparing weaning ages of 30 and 75 days vs. 180 days, while Blanco et al. (2008) found no differences in performance measures or serum IGF-I and leptin concentrations (reflecting nutritional state and growth potential) between calves weaned at 90 days versus 150 days of age. From the cow perspective, it is expected that they become increasingly inclined to stop suckling the calf as the suckling period progresses.

3.5.3 | Preventive and mitigating measures

3.5.3.1 | *Separation stress (suckler cows and calves)*

In the days following separation, in both cows and calves physiological stress markers include for example elevated cortisol levels and increases in heart rate (Hickey, Drennan, & Earley, 2003; Lefcourt & Elsasser, 1995). Behavioural indicators of stress include increased vocalisations, standing, walking and explorative behaviours (Haley et al., 2005; Price et al., 2003), sometimes increased activity is categorised as restlessness (e.g. Neave et al., 2024). In addition, an increase in the amount of visible eye white in cows has been reported after separation (Newberry & Swanson, 2008).

Increased vocalisation for several days after weaning, increased locomotory behaviour (Price et al., 2003) and reduced lying time (Haley et al., 2005; Mac et al., 2024; Price et al., 2003) can be reduced by applying two-step weaning procedures. This has been shown for fenceline weaning in calves (Mac et al., 2024; Price et al., 2003), although Boland et al. (2008) found only an effect on walking, but not on time spent standing or lying. High activity in cows was also seen during the first 2 days after fenceline separation, but it was lower than in cows abruptly separated from their calves (Mac et al., 2024).

Compared to abrupt weaning, two-step weaning using nose flaps similarly reduced vocalisation in calves (Haley et al., 2005) and in cows (Lambertz et al., 2015), locomotory behaviour in calves (Haley et al., 2005; Lambertz et al., 2015) and increased feeding in calves (Boland et al., 2008; Haley et al., 2005). However, there are frequent and consistent reports of complications such as nasal septum injuries caused by the flaps which raise welfare concerns (Kirk & Tucker, 2023; Lambertz et al., 2015; Taylor et al., 2020; Valente et al., 2022).

Although in some cases a mitigative effect of two-step weaning was not confirmed (Enríquez et al., 2010), and concerns were expressed that the total distress is rather redistributed in two stages (Enríquez et al., 2010), overall, the results of the different studies point at an advantage of two-step weaning methods. Positive effects on average daily weight gain have only been found inconsistently (Boland et al., 2008; Enríquez et al., 2010; Haley et al., 2005; Price et al., 2003; Taylor et al., 2020). Sometimes nose flap weaning was even associated with lower weight gains (Boland et al., 2008; Farney, 2023; Taylor et al., 2020).

Separation stress in calves may also be reduced by the presence of familiar peer calves that provide some social support or buffering and thus attenuate stress responses, as has been found with regard to isolation-induced heart rate responses in beef and dairy heifers (Boissy & Le Neindre, 1997). In addition, familiarising calves in advance with the solid food to be provided after weaning can help to ease the transition and avoid the occurrence of prolonged hunger (Enríquez et al., 2011).

3.5.3.2 | *Handling stress (suckler cows and calves)*

Handling is necessary to wean cattle. Cows and calves have to be gathered from pastures to where they will be separated. In large fields this can be done using a vehicle, and in small fields it may be done on foot and also herding dogs can be used.

Besides using well-designed facilities (e.g. one-way gates, crowding pens), several general strategies to reduce handling stress are available. The bunk training process consists of offering grain in an adjacent pen with the handler standing at the gateway. Walker et al. (2007) found a greater feeding activity during the first few days in the feedlot in weaned trained calves, but no positive effects in terms of reduced morbidity and weight gain compared to calves not trained. Ligon (2014) investigated a 'weaning training' where calves were trained to walk past a calm handler and be separated from their dam when cows were handled prior to weaning for reproductive synchronisation, artificial insemination, breeding and pregnancy checking. This led to numerically less walking (steps per hour) in the trained calves in the week post-weaning. However, depending on the type of pastures or fields where cows and calves are placed, this training can be difficult to implement. Another option is to use low-stress handling techniques (Ligon, 2014), which includes awareness of an animal's point of balance, of its field of vision and its flight zone and gentle handling (e.g. without shouting and hitting). Ligon (2014) reported a higher weight gain in low-stress handled calves for 1 week and 1 month post-weaning compared to conventionally handled calves, although this study had several methodological limitations. Another way to reduce handling stress is to apply creep weaning because calves can access creep feed independently without having to be handled (Enríquez et al., 2011). In addition, the presence of familiar conspecifics (social buffering) at the time of weaning can increase the ease of handling and reduce handling stress (Duve et al., 2012; Grignard et al., 2000).

3.5.3.3 | *Inability to express maternal behaviour (suckler cows)*

Increased vocalisation is an expression of negative affective states of the cows at the time of weaning. Two-step separation using nose flaps can help to decrease stress responses of cows such as pacing and vocalising compared to abrupt weaning (Ungerfeld et al., 2016), but the authors also observed decreases in milk yield after weaning regardless of the method. Therefore, independently of the method of weaning, cows will be unable to express maternal behaviour, but other welfare consequences can be minimised by allowing physical contact using two-step weaning methods.

3.5.3.4 | *Inability to perform sucking behaviour and prolonged hunger (calves)*

All weaning strategies (abrupt or two-stage weaning) result in the inability to perform sucking behaviour by the calf. The sudden disruption of the mother-calf bond, together with the calf's unpreparedness for the withdrawal of milk as a nutritional source, are major stressors (Newberry & Swanson, 2008; Weary et al., 2008) and may lead to hunger in the calf. Therefore, the decoupling of both stressors may reduce the welfare impairment of the calves (see Section 3.5.3.1). Nevertheless, the stress due to the inability to perform sucking behaviour is unavoidable, although its extent will depend on the degree of the calf's nutritional and social autonomy. Very early weaned calves (at day 30 or 75) show the greater negative impact of the inability to perform sucking behaviour by, for example, increased cross-sucking behaviour compared to calves weaned at day 180 (de Souza et al., 2021). Consequently, fostering the intake of solid feed before weaning and a higher weaning age are general mitigating measures. However, as studies comparing further weaning ages are lacking, no conclusive evaluation of any other weaning age below 6 months, e.g. 5 months, as practiced in some EU countries (EFSA, 2025), is possible. It furthermore appears unlikely that a clear limit can be set, as the loosening of the mother-young bond is a very gradual process and depends on many factors such as gestation stage of the cow (Albertsen & Held, 2017) or forage availability.

3.5.3.5 | *Group stress (suckler cows and calves)*

If weaning and separation are combined with regrouping, there is a risk of increased agonistic interactions, which for cows carry the further risk of soft tissue lesions and integument damage. The extent of this risk depends on several factors such as space allowance, design of pens, familiarity of the animals etc. (see Section 3.2.6 on mixing of cattle and related mitigation strategies). In calves, the presence of familiar peers can provide social support or buffering effects (Boissy & Le Neindre, 1997; Duve & Jensen, 2011; Færevik et al., 2006), potentially reducing stress during regrouping.

3.5.4 | Conclusions on weaning

1. Natural weaning is a gradual process that occurs when calves are between 7 and 14 months old. In European suckler herds, weaning commonly takes place more or less abruptly between 5 and 11 months of age in order to maintain high productivity and an adequate body condition of the suckler cows. This results in a disruption of the mother-calf bond along with the loss of milk as a nutritional source for the calf and the cessation of nursing for the cow.
2. The WCs selected as highly relevant for suckler cows and calves as a result of weaning are separation stress, handling stress and group stress if weaning and separation are combined with regrouping, as well as inability to express maternal behaviour in cows and inability to perform sucking behaviour in calves. These are expressed by increased vocalisation, exploration and pacing (locomotory behaviour) along with reduced feeding and lying in weaned calves. Additionally, very early-weaned calves (e.g. at 75 days of age) exhibit increased cross-sucking (certainty > 66%).
3. The later the calves are weaned, the better prepared they are physiologically and behaviourally to cope with the dietary and social changes. In addition, gastro-intestinal function is enhanced by promoting early intake of solid feed and familiarisation with post-weaning diet (certainty > 90%).
4. A decoupling of weaning and separation by using either fenceline weaning or nose flaps allows visual, auditive and physical cow-calf contact (more restricted in fenceline weaning) while preventing sucking behaviour before total separation occurs. These two-stage weaning methods contribute to a reduction of separation stress, compared to abrupt weaning (certainty > 66%).
5. Nose flaps, as they are currently used, carry an injury risk to the nasal septum (certainty > 90%).
6. Creep weaning methods are associated with less handling and separation stress compared to abrupt weaning (certainty > 90%).
7. The presence of familiar peer calves provides social support or social buffering and reduces separation stress during weaning (certainty > 66%).
8. Additional husbandry changes (e.g. relocation from pasture to housing, dietary changes, regrouping, transportation and marketing) often occur around weaning and increase negative welfare impacts on the calves (certainty > 90%).
9. When calves are weaned from the dams, both animal categories are handled. Strategies to reduce handling stress during weaning are little investigated. However, a decrease in handling stress is achieved by increased contact with handlers before weaning (certainty > 90%), gentle handling (certainty > 90%) and maintaining contact with familiar conspecifics during the weaning process to allow social buffering (certainty > 66%).

3.5.5 | Recommendations on weaning

1. Early weaning (e.g. before 6 months) should not be practiced. It is recommended to further investigate the welfare consequences of weaning at 5 months of age, which is common in some countries.
2. Weaning should occur as late as possible as long as the body condition of the cow allows.
3. Weaning should only take place once calves are ingesting solid feed that can cover their nutritional requirements and are familiarised with post-weaning feeds.
4. Regardless of age, two-stage weaning is recommended over abrupt weaning.
5. Creep weaning, habituation to human presence, gentle handling and maintaining contact with familiar calves during the weaning process are recommended strategies to reduce stress around weaning (including handling stress).
6. It is recommended to monitor the effects of nose flaps on nasal lesions and to further explore non-harmful flap models.

3.6 | Mutilations

The following chapters address the painful procedures of disbudding/dehorning, castration and tail docking by discussing their welfare consequences to beef cattle and reviewing studies investigating the efficacy of different anaesthetic and analgesic drugs. While it is acknowledged that pain is difficult to quantify in animals, many of the reviewed studies include physiological indicators such as cortisol as indicators of induced stress related pain. It is recognised that cortisol may not be a highly sensitive indicator of pain, or may merely indicate the level of arousal and not be reflective of the affective state being experienced by the animal. Given these limitations, relying solely on cortisol measurements to assess pain can be of limited informative value. Therefore, while cortisol levels are included in this literature review as one of the indicators of pain, their interpretation should be made cautiously and in conjunction with other behavioural assessments to provide a more accurate evaluation of the animal's affective state.

3.6.1 | Disbudding and dehorning

3.6.1.1 | *Current practices*

Disbudding, i.e. the destruction or removal of the free-floating horn buds in the skin above the skull of calves, is a common practice in beef cattle. Dehorning is the surgical removal of grown horns in calves over 2 months of age and in adult cattle. The distinction between disbudding (removal of the free-floating horn bud) and dehorning (removal after the bud has attached to the skull), is often not made that precisely. In the literature, dehorning is sometimes more related to adult cattle and disbudding to calves sometimes older than 2 months. Additionally, dehorning can be used as a generic term that may include disbudding and dehorning (Knierim et al., 2009).

Disbudding or dehorning are practiced in cattle farming with the aim to reduce animal injuries and damage to hides under constrained housing or transport conditions such as under high stocking densities, improve human safety, reduce damage to facilities and ease cattle handling (Knierim et al., 2015). In some EU countries, e.g. Ireland, horned cattle cannot be sold at a public market (Cozzi, Prevedello, et al., 2009).

According to a survey in 2009, about 47% of European beef farms and 68% of suckler farms kept disbudded or dehorned animals. However, there were large differences between regions, with disbudded or dehorned beef cattle mainly found in Northwest and central European countries like Finland, Ireland and Austria, while in France and Italy it was not a routine practice. In Eastern Europe the proportions of disbudded/dehorned beef cattle ranged from 8% in Romania to 75% in Hungary (Cozzi, Prevedello, et al., 2009). A similar pattern was observed in suckler cow herds, with a higher proportion of suckler herds being disbudded/dehorned in Northwest and Central Europe and a higher percentage of herds being disbudded/dehorned compared to fattening cattle (Cozzi, Prevedello, et al., 2009). Regarding horn removal methods in Western and Northern Europe, 71% of beef cattle farms that reared disbudded/dehorned animals used disbudding and 29% used dehorning, while 58% of suckler herds that reared disbudded/dehorned animals used disbudding and 42% used dehorning (Cozzi et al., 2015). However, in Eastern and Southern European countries, more than half of the cattle were dehorned rather than disbudded (Cozzi, Prevedello, et al., 2009).

During approximately the first 2 months of life, the horn buds of calves are free-floating in the skin layer above the skull, but this period also depends on the individual calf development, size and breed (Knierim et al., 2015). Later, the horn buds attach to the periosteum of the frontal bones and horns begin to grow. From about the age of 6 months onwards, the horns are increasingly pneumatised from the caudal frontal sinuses of the skull. They are supplied by blood vessels and nerves and continue to grow during the whole life (Budras et al., 2011).

Disbudding can be carried out using thermal cauterisation with a hot-iron, with chemical methods or by physical removal. For chemical disbudding, commonly caustic paste is used that contains e.g. sodium hydroxide or antimony trichloride, while other chemicals such as clove oil or isoeugenol (e.g. Schoiswohl et al., 2022), or liquid nitrogen for cryoablation (e.g. Sutherland et al., 2019), have been applied experimentally with inconsistent or negative results in relation to efficacy or pain induction. Physical removal involves surgery using knives, scoops or tubes (Marquette et al., 2023b) and can be also applied when the horn already started to grow (Knierim et al., 2009). Hot-iron disbudding is the most frequently applied method (about 68% of beef farms and 61% of suckler farms), and surgery is the least common (2%–3% of suckler or beef farms) (Cozzi et al., 2015).

The age at which disbudding is carried out varies depending on regulations and recommendations. In some MSs, it is recommended to perform the procedure between the second week and 4–6 weeks of the calf's life when horn buds are between 5 and 10 mm in length, before the horn bud attaches to the skull (EFSA Public call for evidence, 2024 – PC-0742 14 – Association of Veterinary Consultants).

The application of pain management during and after disbudding in order to reduce the pain associated with the destruction or removal of the horn bud (Hewson et al., 2007; Winder et al., 2017) differs widely between MSs and farms. Some MSs legally require the use of local anaesthetics in general (e.g. Austria, Finland and Netherlands) or after a certain age (e.g. after 2 weeks of age in Ireland or after 6 weeks in Germany), although the Council of Europe recommendations concerning cattle (Council of Europe, 1988) stipulate that disbudding without anaesthesia shall only be permissible in calves under 4 weeks of age. In addition, the application of analgesia is mandatory in some countries, either in general (e.g. in Austria, Finland, Germany) or after a certain age (e.g. Ireland). The use of sedation is mandatory in some MSs (e.g. Austria, Luxembourg) or a recommendation in others.

Shears, a tube or a scoop can be used for removing the horns of cattle younger than about 6 months (Knierim et al., 2009). For cattle older than 6 months, different dehorning tools are available that are either guillotine-type instruments or wire saws (embryotomy saw, Gigli saw) or butcher's saws. Data from 2009 indicate that saw and wire methods were favoured in

Europe, accounting for about 73% of farms that removed grown horns (Cozzi et al., 2015). The amputation of pneumatised horns leaves an open hole that reaches down into the sinuses of the head and takes about 4–8 weeks to heal (Rosenberger et al., 1978).

Different legal provisions also exist regarding the person performing the disbudding or administering anaesthesia, analgesia or sedation. The Council of Europe recommendations concerning cattle require that they are carried out by a veterinary surgeon or other persons qualified in accordance with domestic legislation. Most MSs allow farmers to perform the disbudding, sometimes only up to a certain age of the calves.

In some MSs (e.g. Germany) dehorning is forbidden by animal welfare law, except for veterinary medical purposes and may then only be performed by a veterinarian under anaesthesia. Also pain management varies from no requirements for anaesthesia, analgesia or sedation to mandatory administration of all of them (Cozzi et al., 2015).

The proportion of farms keeping genetically hornless (polled) cattle was low in 2009, with about 7% in beef and 5% in suckler cattle (Cozzi, Prevedello, et al., 2009) but has likely considerably increased in the meantime. For example, in the Czech Republic more than half of the animals were reported to be genetically hornless (EFSA Public call for evidence, 2024 – PC-0742 14 – Czech Beef Cattle Assosiation). The EU organic farming regulations allow disbudding or dehorning on a case-by-case basis only, which also contributes to a steady increase in the proportion of polled cattle, particularly in organic farms (Scheper, 2018).

3.6.1.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of disbudding or dehorning are **'soft tissue lesions and integument damage'**, **'bone lesions (including fractures and dislocations)'**, **'handling stress'**, **'eye disorders'**, **'separation stress'** and **'inability to perform sucking behaviour'**. No linked welfare consequences were identified in this context. Potential positive and negative WCs of the resulting lack of horns are elaborated in Section 3.7.2. The definition of each WC is available in Section 2.3.

3.6.1.3 | *Preventive and mitigating measures*

In general, the most efficient mitigation measures to reduce adverse welfare consequences is to refrain from disbudding or dehorning while better adapting housing, management and transport conditions to the needs of the animals (Knierim et al., 2009). Another alternative is to keep genetically hornless (polled) cattle (Grobler et al., 2021) (see Section 3.7.2).

3.6.1.3.1 | *Soft tissue lesions and integument damage*

Disbudding leads to soft tissue lesions and integument damage (the outer part of the horns being part of the integument) that in addition cause pain during and after the procedure and likely further negative affective states such as itching during the healing process.

With hot-iron cauterisation, the horn-producing cells are destroyed, resulting in burn wounds that can take from 6 to 13 weeks to re-epithelialise and are sensitive to mechanical stimulation during that time (Adcock et al., 2019; Adcock & Tucker, 2018; Casoni et al., 2019). During burning without anaesthesia, calves show struggling behaviours like scurrying, urging forward, head jerking, rearing and tail flicking, and after not being able to escape, some calves let themselves drop down (Graf & Senn, 1999; Taschke, 1995). In the hours after hot-iron disbudding (at least up to 24 h according to Faulkner and Weary (2000), several responses indicate pain and distress. They comprise restlessness (frequent standing up and lying down), head shaking, ear flicking, tail flicking, hind leg kicking, scratching the lesion with the hind foot, reduction of social behaviours, play behaviour and grooming, head rubbing, backwards movements, neck extension, prolonged lying and reduced exploratory behaviour, avoidance of head pushing against pen mates, reduced feeding and standing indifferently with lowered head as well as towards humans (Faulkner & Weary, 2000; Mintline et al., 2013; Taschke, 1995). These responses can be reduced or eliminated by local anaesthesia (cornual nerve blockade: CNB) and non-steroidal anti-inflammatory drugs (NSAIDs) (Heinrich et al., 2010; Herskin & Nielsen, 2018; Huber et al., 2012; Mintline et al., 2013; Stilwell et al., 2012). In addition to the pain response around disbudding, longer term alterations are also reported that can at least partly be reduced by analgesic treatment. Theurer et al. (2012) continuously monitored 10 week old male Holstein calves after hot-iron disbudding with or without analgesic treatment (oral meloxicam) for 7 days using accelerometers. They found that untreated calves without analgesic treatment spent less time lying for 4 days after disbudding and interpreted this as an indication of pain experience. This conforms to the findings of Gingerich et al. (2020) that showed hot-iron disbudded Holstein heifer and bull calves spending less time lying over the three observation days following the procedure than sham disbudded calves. In addition, they spent a greater percentage of their lying time inside a shelter in the group pen. Adcock et al. (2023) observed 4–10 days old female Holstein calves that were not disbudded or disbudded with hot-iron and local anaesthesia and analgesia (lidocaine cornual nerve block and oral meloxicam) at 3, 10 and 17 days after the procedure. They only found more lying behaviour in the disbudded calves at 17 days after disbudding. However, on all live observation days disbudded calves spent more time lying with their head down, which the authors altogether interpreted as attempts to reduce painful stimulation of the disbudding wounds and allocate energy to healing. Such further differentiation of response patterns and their interpretation need further investigation. Findings in humans suggest that tissue regeneration and the healing process of burn injuries not only involve a longer lasting pain component, but also intense tingling or itching sensations which may be almost equal in discomfort to the pain itself (reviewed by Choinière et al., 1989). Taschke and Fölsch (1997) observed large increases in head jerking and hind leg kicking after hot-iron disbudding in part of the observed calves for 11 days. Adcock et al. (2020) administered a local anaesthetic to female Holstein and Jersey calves around 11 days after hot-iron disbudding, when the necrotic tissue loosens from the scalp. Compared to a saline treated control, these calves showed less head shaking and in tendency ear flicking, with no differences in grooming and transitions between standing and lying. There are numerous brands of disbudding irons on the market. Their differences in recommended application time, heat capacity and tip size could all have an impact on tissue damage, pain inflicted and healing process. However, the few investigations conducted on comparisons between different disbudders did mostly not report major differences in their effects. Thomsen et al. (2021) registered 2.3 times higher odds of an inadequate local anaesthesia with procaine (indicated by behavioural responses) in calves disbudded with a large hot-iron compared to a small iron. However, Wohlt et al. (1994) did not find any differences in the calves' cortisol responses 12 h after disbudding when comparing two types of electric disbudding irons (conventional and Buddex™). Adcock et al. (2019) tested two types of hot-iron disbudders, a gas disbudder on one horn bud and an electric disbudder on the other, with similar application techniques. Although wounds tended to differ in size for 2 weeks following the treatment, the latency to re-epithelialise was unaffected by the kind of iron employed (53 ± 3 days vs. 55 ± 3 days). On the other hand, wounds due to electric disbudding tended to have more days of loosely attached necrotic tissue and less days of granulation tissue than wounds from gas disbudding. The smaller surface area of the gas disbudder tip may have led to a less severe burn and necrotic tissue falling off sooner. Most disbudding studies list the brand of iron that was used, but they omit additional information, including the name of the model (e.g. Kleinhenz et al., 2017), the iron temperature (e.g. Stilwell et al., 2010), the tip size (e.g. Mintline et al., 2013) or the application time (e.g. Heinrich et al., 2010), making it difficult to derive any recommendations.

While it is usually considered that disbudding should be carried out in calves as young as possible - because it is expected that a more developed horn bud leads to more pain and a slower healing process – there is no empirical evidence substantiating this. The number of comparative studies is low and mostly focused on calves in the first weeks of life. No significant differences were found in behavioural and physiological indications of pain perception up to 7 h past hot-iron disbudding (Caray et al., 2015) or in trigeminall sensitisation (Casoni et al., 2019; Mirra et al., 2018), comparing ages of 1 week with 4 weeks (Caray et al., 2015; Casoni et al., 2019; Mirra et al., 2018), nor comparing 4–10 days with 15–28 days regarding parameters of wound healing (Kretschmann et al., 2021). In addition, Marquette et al. (2021) found no consistent relationship between age of the calf and diameter and height of the horn buds, but rather an influence of breed when comparing Holstein-Friesian, Charolais, Simmental and Limousin suckler beef calves. On the other hand, there are indications that performing disbudding very early after birth (3 days vs. 35 days of age) while not improving welfare outcomes, may produce an increase in pain sensitivity (Adcock & Tucker, 2018) An increase in sensitivity to painful stimuli around the lesion (trigeminal hyperalgesia) was observed in 8 out of 31 calves disbudded at 1 or 4 weeks of age (Casoni et al., 2019). Thus, irrespective of calf's age, disbudding of calves may lead to persistent changes in their sensitivity towards mechanical stimulation or pressure near the site of the procedure, and this may be worsened in very young calves.

Caustic paste disbudding has been suggested as one of the least painful methods for horn bud removal (Vasseur et al., 2010) and considered an alternative to hot-iron disbudding, possibly because the manifestation of behavioural changes potentially indicative of pain by the calf is less immediate than with hot cautery (Stilwell et al., 2007; Stilwell et al., 2009). However, according to Winder et al. (2017), caustic paste is acutely painful for at least 180 min based on behavioural and pain sensitivity responses. They suggest that caustic paste may result in a different pain experience than cautery and therefore might require further pain indicators. The pain caused by alkali is described by humans as 'itching pain' or 'marked pain' (Ma et al., 2007; as cited in: Stilwell et al., 2009, p. 36). Rushen and de Passille (2012) found that calves disbudded with caustic paste played less than control animals the day after the procedure. Furthermore, Drwencke et al. (2023) report that the caustic wounds were more pain sensitive than undamaged tissue for at least 6 weeks and took twice as long to heal (on average 18.8 and up to 34.1 weeks) compared with the 7- to 9-week healing period reported for cautery methods (Adcock et al., 2019; Adcock & Tucker, 2018). This may also be due to the caustic wounds becoming much deeper than the ones from hot-iron disbudding (Lindén et al., 2023; Reedman et al., 2022). In addition, there are risks of undesired integument and soft tissue lesions due to chemical spread from the bud site e.g. in the eye of the treated calf, of group mates or e.g. in the udder region of the dam in suckler cows.

Scoop disbudding has the disadvantage of creating open wounds and a risk of bleeding. Scoop disbudding also resulted in significantly higher and longer lasting cortisol response compared to hot-iron disbudding (Petrie et al., 1996a; Stafford & Mellor, 2005b). Although Stilwell et al. (2007) found no behavioural differences in the first and third hour after application of the three disbudding methods. At 6 h and over a 24 h period pain indications were more severe in the scoop dehorned than in hot-iron or caustic paste disbudded animals, although it should be noted that the scoop and hot-iron 'disbudded' calves were actually dehorned, because they were older than 2 months of age (mean ages of 117 and 98 days).

When comparing disbudding and dehorning, the extent of damage is much higher for dehorning because the wounds caused by the procedure are larger and more severe, with even larger effects on physiological and behavioural responses such as an increase in plasma cortisol and in lying, head-shaking and ear-flicking or a reduction of rumination and grooming (reviewed by Stafford & Mellor, 2005b). It can also lead to major bleeding, which requires careful observation and control of bleeding by tourniquet or heat cauterisation (Jesse et al., 2016). After surgical dehorning in Brahman crossbred steers aged 4, 9, 19 and 30 months, weight gains were significantly reduced during the first 2 to 6 weeks, reflecting impaired welfare (Loxton et al., 1982). In mature steers with fully developed horns (Winks et al., 1977) and in Canadian feedlot cattle in winter, negative weight effects were still evident 106 days after dehorning (Goonewardene & Hand, 1991). In contrast, no long-term impairment of performance is reported for disbudded calves (e.g. Grondahl-Nielsen et al., 1999; Laden et al., 1985).

Neely et al. (2014) observed cattle dehorned at a live weight of about 312 kg with different methods for 28 days after the operation and found no difference in lying postures (head up and ruminating, head down, full or partial extension of hind legs, fully lateral position) between animals that were dehorned with a mechanical method (keystone dehorner) compared with control (not dehorned). Lying time was instead significantly higher for animals dehorned with the band method, which consists of applying a Callicrate Bander at the base of the horns that will occlude blood supply to the horn-producing tissue resulting in necrosis of the horn and its subsequent passive elimination. This led to greater and prolonged post-procedure discomfort for the animals as regards gait, lying postures, appetite and depression scores. Cattle dehorned with the mechanical method showed higher vocalisation and discomfort during the procedure, which was performed without anaesthesia and analgesia.

In general, there has been a lengthy history of attempts to mitigate the short- and long-term effects of disbudding and dehorning (reviewed by Winder et al., 2018), including the CNB (Emmerson, 1933). Disbudding and dehorning are unquestionably painful irrespective of method, and the CNB as well as administration of analgesics contribute to a considerable reduction of pain around the procedure for every method (Sheedy et al., 2024). However, there is a risk of incomplete desensitisation by the CNB due to an inadequate technique concerning placement of the injection (partly due to biological variation of the cornual nerve, and other nerves providing sensitisation to the horn region), type of drug used, injected volumes of the anaesthetic, too short time interval between injection, and inefficient or no testing of desensitisation (reviewed by Knierim et al., 2009). Sheedy et al. (2024) recommend adapting local anaesthesia approaches to include the infratrochlear nerve or a form of infiltrative or ring block. However, they state that more research is needed to validate these approaches. Furthermore, the choice of anaesthetic affects the efficacy of anaesthesia and the duration of action. The use of lidocaine in food-producing animals is restricted in the EU. When administering procaine alone, Adam et al. (2025) found higher tactile sensitivity and pain scores and lower pressure pain thresholds in hot-iron disbudded calves in comparison to lidocaine, but also in comparison to procaine combined with epinephrine. Moreover, a low pH of the product can be aversive to the calves during application (Adam et al., 2025). After the procedure, despite the use of anaesthesia and analgesia, pain and longer-term pain sensitisation at the pericornual sites can occur (Colston et al., 2024). Casoni et al. (2019) found indications of hyperalgesia and allodynia in 7 and 28 day old calves after hot-iron disbudding under sedation and local anaesthesia and with subsequent analgesia for up to 105 days of age (when the experiment ended), and in 38% of the disbudded calves they found indications of pain lasting more than 3 months. They concluded that the current recommendations of disbudding calves under sedation, with local anaesthesia of NSAIDs are insufficient to prevent the development of central sensitisation.

3.6.1.3.2 | *Handling stress*

Handling stress is a highly relevant welfare consequence in the context of mutilations. Disbudding in particular requires significant calf restraint to ensure correct procedure and human and animal safety, and it is therefore a source of stress for the calf. This is even more true for dehorning of older cattle. Fear during handling and restraint is greater in extensively raised cattle due to their limited contact with people and farming facilities (Kaurivi et al., 2020).

Mitigation strategies for handling stress include application of and principles of low-stress handling, such as utilising flight zones and points of balance to move animals, and calm handling in optimal facilities (Grandin, 2021), in addition to the adoption of correct protocols of local anaesthesia and pain control, which significantly reduce spontaneous animal movements and stress. Sedation mitigates handling stress and is especially relevant in animals not used to handling. However, sedation with xylazine and its reversal may be associated with 'unpleasant experiences' (reviewed by Stafford & Mellor, 2005b). Stilwell et al. (2010) also discuss possible stress-inducing effects of sedation, for instance due to muscle relaxation counteracting adequate responses of the calves to perceived challenges. Moreover, the induced central nervous system depression has unwanted side effects such as lowering body temperature (Vasseur et al., 2014). In addition, it must be considered that sedation, depending on its extent, might reduce physical responses, so that monitoring anaesthesia efficacy becomes more difficult. The pros and cons of sedation should further be addressed in future studies.

Although Casoni et al. (2019) mention that stress might alter pain sensitivity in humans and rats, Stewart et al. (2013) did not detect effects of the type of handling before disbudding on stress levels after the procedure. They compared the behavioural responses of 40 Holstein-Friesian calves that had been exposed to one of two handling treatments daily from 1 to 5 weeks of age prior to disbudding at 5 weeks of age: (1) positive, involving gentle handling (soft voices, slow movements, patting) and (2) negative, involving rough handling (rough voices, rapid movements, pushing). Heart rate, respiration rate and behaviour (activity, tail flicking) were measured before and after disbudding. Heart rate, respiration rate and tail flicking all increased after disbudding regardless of the type of prior handling possibly indicating that the 'effects of handling may have been overridden by the degree of pain and/or stress associated with the procedures' (Stewart et al., 2013).

3.6.1.3.3 | *Eye disorders*

The use of caustic paste carries the risk of eye damage, up to calf blindness. The active ingredients of caustic pastes are strong alkalis causing severe burns, and care has to be taken to prevent paste running into the eyes of calves (Stilwell et al., 2009), especially in case of rainfall over an active disbudding paste. If the calves can be kept dry for 24 h after paste application, the paste is dry and the risk is overcome.

3.6.1.3.4 | *Separation stress and inability to perform sucking behaviour*

When suitable facilities are available, separation stress can be mitigated by performing the disbudding procedure without moving the calf from its usual environment. However, this is not an option when caustic paste is used because it requires separation of the calf from the dam (or other calves) for at least 24 h to allow the paste to dry. This will avoid damage to the udder or tongue of the dam or other calves when the calf sucks or is licked by them.

Dehorning needs specific facilities for adequate animal restraint, thus separation of the animal from the herd-mates is required. Immediately after surgery, the animal will need a quiet, clean environment to aid bleeding control and observation for 30–60 min.

3.6.1.3.5 | *Bone lesions (including fractures and dislocations)*

In cattle older than 6 months, the bony horn core has to be cut during dehorning. Dehorning of adult cattle leads to the opening of the frontal sinuses to the external environment. This carries the risk of sinus infection, requiring the use of cleaned and sterile surgical and non-surgical instruments (Jesse et al., 2016). The wound needs to be covered with gauze or cotton to prevent feed or litter particles or insects from entering the sinus. Chronic sinusitis is a frequent complication of dehorning (Ward & Rebhun, 1992). If not properly treated, sinus infection can lead to skull bone damage. Furthermore, bone injuries and fractures to limbs and ribs may result from animals' panic reactions during the handling and restraint for the dehorning procedure. Comparing different dehorning methods, the risk of crushing or cracking of the skull bones, e.g. caused by a sudden defence reaction of the animal during dehorning, is increased when using stiff blades rather than wire saws and infection is more likely to occur after fractures (Parsons & Jensen, 2006).

3.6.1.4 | *Conclusions on disbudding and dehorning*

1. Disbudding, i.e. the destruction or removal of the free-floating horn buds in the skin above the skull of calves, is a common practice in beef cattle.
2. Dehorning, i.e. the surgical removal of grown horns in calves over 2 months of age and in adult cattle, is a less frequent practice, which is banned in some MSs as routine mutilation.
3. Both disbudding and dehorning of cattle aim to reduce animal injuries and damage to hides under constrained housing or transport conditions, improve human safety, reduce damage to facilities and ease cattle handling.
4. The WCs selected as highly relevant for cattle due to disbudding or dehorning are soft tissue lesions and integument damage, bone lesions (including fractures and dislocations), handling stress, eye disorders, separation stress, inability to perform sucking behaviour and inability to perform comfort behaviour.
5. Regardless of the method, both disbudding and dehorning are painful practices and are associated with handling stress due to the restraint required to perform them properly.
6. Dehorning carries considerably higher welfare risks (such as bleeding, sinus infections or bone fractures) than disbudding, and is related to more handling stress and longer wound healing times (certainty > 90%).
7. Properly administered local anaesthesia and post-surgical analgesia reduce pain around the procedure in all disbudding and dehorning methods (certainty > 90%).
8. Even if applying local anaesthesia and post-surgical analgesia, long-lasting pain develops (for several weeks) (certainty > 66%).
9. Signs of persistent sensitisation towards mechanical stimulation or pressure near the site of the procedure have been reported in calves, potentially worse for calves disbudded at a very young age (e.g. at 3 days (certainty > 66%). Research is needed to clarify this.
10. Legal requirements, type of drugs available and common practices regarding the application of local anaesthesia and analgesia vary widely within the EU.
11. Procaine seems to be less effective than lidocaine for local anaesthesia.
12. Sedation reduces overt signs of handling stress during disbudding and dehorning (certainty > 90%). Insufficient research is available on possible negative welfare effects of sedation, including increased stress due to sedative effects.
13. Surgical disbudding carries higher welfare risks, such as bleeding or infection, than hot-iron and caustic paste disbudding and elicits more responses indicative of pain (certainty > 90%).
14. Caustic paste disbudding carries further welfare risks, such as unintentional caustic burns of the eye or other body parts, than hot-iron disbudding (certainty > 90%). Caustic paste elicits substantial pain and is associated with prolonged healing times (e.g. 18 weeks) due to deeper wounds than those caused by thermocautery (certainty > 90%). Moreover, in contrast to hot-iron disbudding, it requires the separation from the cow and from other calves to avoid burning them. For hot-iron disbudding, there are numerous brands of disbudders on the market, but there is insufficient information on the welfare consequences of different heat capacities, tip sizes and application times.
15. Stress during handling and restraint is greater in extensively raised cattle due to them being less used to contact with people and farming facilities.
16. Better adapting housing, management and transport conditions to horned animals allows to refrain from disbudding and dehorning. An alternative is to keep genetically hornless (polled) cattle.

3.6.1.5 | *Recommendations on disbudding and dehorning*

1. If possible, disbudding and dehorning should be avoided.
2. Dehorning should not be conducted unless justified by veterinary indication on an individual animal.
3. Legal requirements for disbudding should be harmonised across the EU, promoting standardised protocols that include the mandatory use of local anaesthesia and analgesia.
4. To mitigate the pain induced by disbudding or dehorning, local anaesthesia and analgesia should be properly applied. Criteria of proper application relate to the choice of medication, appropriate volumes, correct application sites, timing of anaesthetic and analgesic treatment, and control of efficacy before disbudding or dehorning starts as well as after the procedure.
5. Surgical disbudding should be avoided because of the higher risks of bleeding or infection in comparison to other disbudding methods.
6. Caustic paste disbudding should be avoided because of the higher welfare risks than hot-iron disbudding, such as longer healing times, unintentional caustic burns of the eye or other body parts and because it requires separation from other animals including the dam to avoid udder burns when nursing the calf.
7. Guidelines on correct use of the numerous different brands of disbudding irons on the market should be made available and followed due to their impact on induced pain and ease of healing.
8. More research is needed on the potential increase of long-term pain sensitivity in calves disbudded a few days after birth. As a precaution, disbudding very early after birth is not recommended.
9. For any method of horn removal, and particularly for extensively raised cattle, safe, non-damaging and low-stress handling methods and facilities for animal restraint should be used to alleviate handling stress, but also to improve the safety of the personnel.
10. Sedation prior to disbudding should be carried out, but further research should investigate the possible negative welfare effects of sedation.
11. Further research is recommended on possible negative long-term effects of disbudding, such as persistent increase in sensitivity towards mechanical stimulation and/or pressure.
12. The need for disbudding should be prevented by adapting housing, handling and transport conditions to horned animals, or by rearing genetically hornless (polled) cattle.

3.6.2 | Castration

3.6.2.1 | *Current practices*

Castration, i.e. the procedure involving the physical removal or inactivation of a bull's testicles, serves multiple purposes within the context of cattle management. The main purpose of castration is to improve meat quality by increasing the intramuscular fat content. Also, it is employed to diminish aggressive and sexual behaviour and mitigate the occurrence of meat quality issues, specifically dark cutting beef. Castration may result in an alteration of the position in the social hierarchy within the herd.

There are various methods for castrating cattle, including surgical removal of the testes, commonly executed with tools such as an emasculator or a Newberry knife; the use of a Burdizzo clamp (emasculatome), which crushes the spermatic cords; or the application of rubber rings or bands around the neck of the scrotum. Compared to other castration methods, the Burdizzo carries a risk of incomplete castrations (Thüer, Doherr, et al., 2007), even more so for older animals (Mach et al., 2009). The rubber ring or elastic band induces ischaemia and subsequent necrosis of tissues distal to the ring. Small rubber rings are used for calves less than 1 month of age (Becker et al., 2012). For older cattle, heavy wall latex bands are used along with a grommet to securely fasten the mechanically tightened tubing at the appropriate tension (Fisher et al., 2001; Pang et al., 2008). Chemical and immunological castration methods have been reported (Cohen et al., 1990, as cited in Stafford & Mellor, 2005a, p. 272) but are not used in Europe (Marquette et al., 2023a). Immunocastration is based on a vaccine against gonadotropins thereby disrupting the normal function of the hypothalamus, which then results in a lack of luteinising hormone and follicle-stimulating hormone release and subsequently a reduction of testosterone and sperm synthesis in males (Amatayakul-Chantler et al., 2013). In the context of this Scientific opinion, 'physical' castration methods refer to surgical castration, Burdizzo castration, and rubber ring or band castration.

The decision whether to castrate or not depends on the husbandry system, market conditions and consumer expectations, among other factors. There are countries such as the Netherlands, Italy, Austria, Germany and Spain, where castration is not common for conventional beef.

The age at which physical castration is carried out and pain management strategies vary depending on the method (Coetzee, 2011; Marquette et al., 2023a) and the MS. According to the recommendations of Council of Europe (1988) it is generally recommended that physical castration occurs before 4 weeks of age, the latest at 3 months or at the earliest handling opportunity beyond this age (Council of Europe, 1988). In Ireland, the recommended maximum castration age varies from 8 days when using a rubber ring or latex band to 6 months when using a Burdizzo clamp. Above 6 months of age, castration must be conducted by a veterinarian using appropriate anaesthesia and/or analgesia (Teagasc, 2020). In Austria, physical castration is only allowed with anaesthesia and post-surgical analgesia and by a veterinarian or a specially trained person, and in Germany anaesthesia is required for physical castration carried out above 4 weeks of age. Rubber rings are forbidden in Austria and Germany. Late castration at 18 months has been described but is not economically advantageous (Micol et al., 2009, as cited in Marquette et al., 2023a, p. 709) although it may be performed in certain bulls with a potential for high-quality meat.

The application of analgesia and anaesthesia is usually done intramuscularly or subcutaneously and, in some cases, intravenously. The process of puncturing and administering the drug can be painful in itself. Other routes of administration of analgesia evaluated are oral (Coetzee, 2011; Meléndez et al., 2019; Olson et al., 2016) and topical administrations (Kleinhenz et al., 2018; Lomax & Windsor, 2013; Mancke et al., 2025). Although the literature refers to a range of drugs tested in the context of castration, in this Scientific Opinion the most relevant in an EU context are discussed.

3.6.2.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of castration are **'soft tissue lesions and integument damage'**, **'handling stress'**, **'resting problems'**, **'restriction of movement'** and **'separation stress'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3.

3.6.2.3 | *Preventive and mitigating measures*

This section aims at discussing the highly relevant consequences of castration with a view of providing reccomendations on welfare mitigation measures. In this context, an exhaustive review of the all the castration literature was not intended but rather a discussion of the key findings relevant for providing reccomendations on mitigation measures for the welfare consequences considered highly relevant by the EFSA experts. In light of this, the literature was searched to identify relevant original research as well as narrative reviews (Bretschneider, 2005; Coetzee, 2011; Marquette et al., 2023a; Stafford & Mellor, 2005a; Tschoner, 2021) or systematic reviews (Canozzi et al., 2017) on the topic. The experimental studies reviewed have mostly focused on the evaluation of welfare implications depending on castration method, calf age, and effects of pain mitigation drugs, or a mixture of these factors, and for this reason, direct comparisons of outcomes across experimental studies is often difficult, but conclusions and recommendations are drawn when sufficient evidence is available.

3.6.2.3.1 | *Soft tissue lesions and integument damage*

3.6.2.3.1.1 | Cortisol and substance P

Cortisol has been widely used in research papers to quantify acute distress associated with nociception in calves because its response is reportedly associated with the noxiousness of the mutilation (Bergamasco et al., 2021). Several studies have looked at the effect of age at castration cortisol concentrations. Most studies evaluating cortisol response in castrated calves report a lower response in younger compared to older cattle. Calves of 6 weeks castrated without pain mitigation drugs showed lower cortisol concentrations than 3 and 6 month animals (Bergamasco et al., 2021), though no differences were observed for 'area under the curve' nor for 'time to maximum concentration'. Serum cortisol and substance P was evaluated in calves of 8 weeks and 6 months castrated with surgical and band castration; regardless of treatment, concentrations of cortisol and plasma substance P were greater in 6 month old calves compared to their younger counterparts (Dockweiler et al., 2013). However, a meta-analysis assessing 22 publications and involving 162 trials with beef cattle up to 12 months of age concluded that differences in cortisol levels in surgical and non-surgical castration without drug administration compared to uncastrated animals were not statistically significant (Canozzi et al., 2017). This may be due to the fact that increased cortisol levels may be seen in response to handling alone (Coetzee et al., 2007) making results difficult to interpret.

Regarding substance P, lower values in younger calves post-castration compared to older calves were reported (Bergamasco et al., 2021). Dockweiler et al. (2013) observed lower peak changes in younger (8 weeks) calves compared to older calves (6 months), while Marti et al. (2017) found no differences among ages. Variation in substance P concentrations following unmitigated surgical castration were observed in a study looking at the effects of unmitigated castration in 6 weeks, 3 months and 6 months calves, with the authors concluding that such responses may be age specific.

3.6.2.3.1.2 | Indicators of integument damage and soft tissue lesions

The age of castration also has an influence on the extent of soft tissue lesions and integument damage and an impact on the degree of inflammation, swelling, healing scores, and wound and scrotal temperature (Marti et al., 2017; Mintline et al., 2014). Inflammation evaluated with a swelling score lasted for 7 days when surgical castration was carried out in 1 week to 8 week old calves, and up to 14 days when it was carried out in 4-month-old calves (Marti et al., 2017). Calves of 1.5 months showed less swelling compared with 5.5 month old calves due to the less developed testicular and scrotal tissue present in younger calves (Ting et al., 2005). Faster healing times in younger animals were also reported by Norring et al. (2017). They evaluated the parameters incision closure, skin temperature, and tissue swelling, pain sensitivity (evaluated by applying increasing force with von Frey hairs at the castration wound) and weight gain in surgically castrated calves at 3 (range 0–8) or 75 (range 69–80) days of age (Norring et al., 2017). The authors concluded that calves castrated at around 3 days of age showed more swelling and more signs of pain, but the castration incisions healed sooner, and their weight gain was less affected, when compared to animals castrated at 75 days of age indicating mixed effects of age on castration (Norring et al., 2017).

The influence of the method of castration on indicators of inflammation has also been evaluated in research. In Burdizzo castration, the spermatic cord and the blood vessels supplying the testicles are crushed, which is followed by oedema and increased temperature in the affected tissue due to the trauma; which resulted in an increase of scrotal circumference for 7 days after Burdizzo castration in all age groups tested (1.5, 2.5, 3.5, 4.5 and 5.5 month old) (Ting et al., 2005). When inflammation was evaluated after castration with rubber rings in 1 week to 2 month old calves or with band castration in 4 month old calves, swelling lasted from 21 to 28 days and 35 days, respectively (Marti et al., 2017). In rubber ring or band castration the process of healing may be further extended if the tension exerted to constrict the scrotum is insufficient, and thus it takes longer to slough off (Marti et al., 2017). Overall, these studies indicate that healing and tissue regeneration following castration are generally faster in surgical castration and Burdizzo compared to rubber rings or elastic bands, and that castrating at an early age is associated with a faster healing process.

Measures to mitigate pain resulting from castration is the use of pain management drugs; this is discussed below.

3.6.2.3.1.3 | Effect of anaesthetics to mitigate pain around castration

Local anaesthetics are prescribed as pre-emptive and are administered directly to the scrotum (as a ring block at the neck of the scrotum, in each testicle or a combination of them) or into the epidural space (Coetzee, 2011; Muir et al., 1995). One of the most researched compounds in this context is lidocaine, administered as local aesthetic. Other drugs less frequently evaluated are bupivacaine administered as local anaesthetic and xylazine administered epidurally. Lidocaine has a fast onset of action (5–10 min), low toxicity and has an effective time of approximately 2 h (Boesch et al., 2008). Bupivacaine has an effective time of 4 h (Boesch et al., 2008). Xylazine has primarily sedative and depressive effects (in terms of reduction in heart rate and breathing rate) and only limited analgetic properties in cattle (González et al., 2013; Ting, Earley, Hughes, & Crowe, 2003). It becomes fully effective 15–20 min after intramuscular injection and the effect lasts for about 30–60 min. In the EU the use of bupivacaine and lidocaine in cattle are restricted and maximum residue limits have been set (EMA, online).

Regarding lidocaine, a study investigating the anaesthetic effects of administration of lidocaine before Burdizzo or rubber ring castration in 1 month old calves (n = 10–15 calves) reported that compared with calves castrated without local anaesthesia, calves castrated with lidocaine showed lower serum cortisol levels, less active behaviours (e.g. foot stamping, kicking or wound licking) and abnormal postures (e.g. standing or waking unsteadily, standing with a hunched back or lying with partially or full extended hind legs) for about 2 h. However, lidocaine administration did not result in a fully painless castration (Thüer, Mellema, et al., 2007).

The effect of lidocaine was also investigated in a study where 2–4 months old calves (n = 7–13 calves) were castrated with either Burdizzo clamp, rubber rings, bands or surgical castration with or without the anaesthetic drug (Stafford et al., 2002). Although band castration caused a greater cortisol response than ring castration, the anaesthesia was effective in eliminating the cortisol response in both types of castrations. In contrast, lidocaine anaesthesia was not effective in eliminating a cortisol response in surgical castration and was only partially effective in Burdizzo castration. In the case of Burdizzo castration, the reduction of plasma cortisol through local anaesthesia with lidocaine only lasted between 0.5 and 1 h after the procedure; for surgically castrated calves, plasma cortisol did not differ or was even greater compared to calves without pain control (Stafford et al., 2002). Similar results were observed in a separate study where the use of lidocaine as local anaesthesia applied 20 min before castration in surgically castrated calves of 5.5 month of age (n = 8) failed to reduce the area under the curve of cortisol and the concentrations of fibrinogen and haptoglobin (acute phase proteins indicators of inflammation and tissue damage) 24 h after castration compared to calves surgically castrated without local anaesthesia (Earley & Crowe, 2002). In younger calves (1 week old; n = 10) castrated with Burdizzo clamp, when lidocaine or bupivacaine were applied 20 min before castration to each spermatic cord and scrotal neck, serum cortisol increased in all groups immediately after the procedure, but the total cumulative serum cortisol concentration for the 3 h after castration was lowest for calves anaesthetised with lidocaine followed by application of bupivacaine and non-medicated calves (Boesch et al., 2008).

Topical administration of anaesthetics before calf castration has also been evaluated. In 3 to 4 month old calves, a combination of lidocaine, bupivacaine, adrenalin and cetrimide applied topically to the spermatic cords (n = 6–9 calves) was associated with less pain-related behaviours (e.g. ventral recumbency with partially or totally extended legs, statue standing with head down, high frequency of postural change from lying to kneeling, etc) up to 3.5 h after castration and a lower mean response to von Frey stimulation compared to no pain mitigation (Lomax & Windsor, 2013). A separate study reported that when anaesthesia in the form of a lidocaine-infused band was applied to 2 week old calves (n = 13), they showed more lying bouts at 35–41 days post-castration and an overall reduction of wound licking behaviour compared to calves castrated with normal (non-lidocaine infused) bands (Mancke et al., 2025).

To sum up, these studies indicate that using anaesthesia alone during castration is associated with pain reduction around the procedure but this occurs only to some extent (Coetzee, 2011). A better strategy is using combined anaesthesia and analgesia; results of studies regarding these aspects are discussed below.

3.6.2.3.1.4 | Analgesics

The NSAIDs produce analgesia and anti-inflammatory effects to some degree by reducing prostaglandin synthesis through inhibition of the enzyme cyclo-oxygenase (Ochroch et al., 2003), and their effects on the peripheral and central prostaglandins show their important role in multimodal analgesic protocols (Coetzee, 2011). The type of NSAIDs, its dose, pharmacokinetics and the time of administration influence their mitigation action. The most common NSAID used during castration are ketoprofen administered intravenously (Earley & Crowe, 2002; Stafford et al., 2002; Ting, Earley, & Crowe, 2003) with a mean half-life of 0.42 h; flunixin meglumine intravenously (Cull et al., 2022; Webster et al., 2013), subcutaneously (Nordi et al., 2019; Stilwell et al., 2008) or topical (Kleinhenz et al., 2018) with a mean half-life of 3.4 ± 1.0 h for intravenous, 5.4 ± 2.5 h for subcutaneous administration (Kissell et al., 2012) and 6.4 h for topical (Kleinhenz et al., 2018); carprofen administered intravenously (Pang et al., 2006) or subcutaneously (Stilwell et al., 2008) with an mean half-life of 37–49 h (Coetzee, 2012); and meloxicam administered subcutaneous (Gellatly et al., 2021; Meléndez et al., 2019; Meléndez, Marti, Pajor, Moya, et al., 2018; Meléndez, Marti, Pajor, Moya, Gellatly, et al., 2017) or orally (Meléndez, Marti, Pajor, Moya, Gellatly, et al., 2017; Meléndez, Marti, Pajor, Sidhu, et al., 2018; Olson et al., 2016; Roberts et al., 2015) with a mean half-life of 16.4 h and 27.5 h respectively (Coetzee et al., 2009).

A few studies investigated the effect of an NSAID administered as single dose around castration. In 5.5 month old calves (*n* = 8), administration of ketoprofen alone 20 min prior to surgical castration resulted in a lower cortisol peak 15 min after the procedure, a reduced cortisol area under the curve and lower plasma concentrations of fibrinogen and haptoglobin 24 h post-castration, compared to calves castrated without pain mitigation (Earley & Crowe, 2002). When carprofen (1.4 mg/kg BW, intravenous) was administered 20 min prior to band or Burdizzo castration in 5.5 month old calves (*n* = 10), no significant differences in cortisol response were observed from 2 h before to 12 h after castration, compared to calves castrated without pain mitigation (Pang et al., 2011). These findings suggest that, at the tested doses, ketoprofen and carprofen are not effective in mitigating inflammatory markers or cortisol responses associated with castration in calves. There were also no differences total blood cell count or interleukin-6 concentration in calves administered oral meloxicam alone and surgically castrated within the first 48 h after birth (Brown et al., 2015).

In a study involving 4 to 5 month old calves (*n* = 15), oral meloxicam administered 2 h prior to surgical or band castration was associated with a lower heart rate from 2 to 10 h post-castration, reduced plasma cortisol concentrations 5 h after surgical castration and during 24 h following band castration, and decreased substance P levels at 24 and 48 h in both castration methods, compared to control calves (Olson et al., 2016). In the same study, calves band castrated with oral meloxicam also showed lower lying bouts and lying time, and a greater overall activity (motion index) for 3 days, compared to non-medicated animals (Olson et al., 2016). A study comparing different timings of subcutaneous meloxicam administration (6 h, 3 h and immediately prior to castration) in 6-month-old surgically castrated calves (*n* = 11–12) reported that only administration at the time of castration significantly reduced substance P concentrations 24 h post-procedure, compared with administration 3 or 6 h prior to castration (Meléndez, Marti, Pajor, Moya, Gellatly, et al., 2017). These results suggest that immediate pre-castration administration may be the optimal timing for meloxicam administration.

Further studies evaluated the potential impact of NSAID use on inflammatory response reduction and healing process. No changes in the inflammatory response and healing were observed in 1 week old (*n* = 12) nor 2 month old (*n* = 21–22) rubber ring or surgical castrated calves using meloxicam administered subcutaneous immediately before castration (Marti et al., 2018). Other NSAIDs such as flunixin meglumine applied intravenous alone also did not show a reduction of inflammation or wound healing after castration in 25 day old calves (*n* = 24) compared with calves castrated without pain management (Mintline et al., 2014). However, when subcutaneous meloxicam was combined with lidocaine applied as local anaesthesia prior to castration in 7–8 month old calves (*n* = 12), scrotal circumferences (measured as a proxy of inflammation in weaned calves) were reduced compared to calves that did not use the combination of local anaesthesia and NSAID (Meléndez, Marti, Pajor, Sidhu, et al., 2018). A further study concluded that 10 day old calves (*n* = 19–21 calves) castrated after administration of lidocaine as local anaesthetic and subcutaneous injection of the NSAID meloxicam showed fewer tail flicks and foot stamping, and increased lying time during the first hour post-procedure, compared to calves castrated after injection of meloxicam only (Bernier et al., 2025). Overall, the reviewed studies indicate that NSAIDs administered as a single dose have limited effect in reducing inflammation from castration, but, if combined with lidocaine, a reduction of scrotal circumference and pain-related behaviours seem to occur.

3.6.2.3.2 | *Separation stress and handling stress*

Castrated beef calves need to be separated from the dam to carry out the procedure and this results in handling and separation stress. However, the behavioural and physiological responses to separation and handling stress are linked and are difficult to disentangle in young beef calves and often include vocalisations (Schnaider et al., 2022) and increased cortisol levels (Dockweiler et al., 2013; Meléndez, Marti, Pajor, Moya, Heuston, et al., 2017).

Different studies investigated cortisol levels depending on age at castration to evaluate potential effects of handling and, in the case of beef calves, separation stress. Baseline levels of salivary cortisol – after separation from the dam and restraint but before castration – were greater in 1 week old beef calves than in 2 month and 4 month old beef calves, indicating that calves separated at a younger age experience higher levels of stress (Meléndez, Marti, Pajor, Moya, Heuston, et al., 2017). No statistically significant differences on salivary cortisol concentrations at 60 and 120 min were observed between sham-castrated and castrated calves with band and surgical castration in 1 week old calves, but all groups showed an increase in concentrations compared to baseline levels. Statistically significant differences in cortisol concentrations between sham castration and castrated calves were observed only in 2–4 months calves. This suggests that in young calves the effects of handling and separation seem to have a higher impact on cortisol levels than the potential effect of pain from castration. When interpreting these results it is also important to note that calves' cortisol levels baseline levels in the first weeks of life have been reported to be very high decreasing to the levels expected in adult cattle by 27 days of age (Knowles et al., 2000). Other indicators assessed in the same study were lying and standing behaviours, tail flicks and foot stamps which also suggested a lower pain experience in the 1-week calves compared to the older age categories evaluated. Another study on dairy calves reported that 6 week old calves had a lower cortisol concentration than 3 and 6 month old calves in both sham and castration treatments, and that cortisol levels decreased faster in 6 week old calves than in the older calves (Bergamasco et al., 2021). Consistent findings were reported by Dockweiler et al. (2013), where sham-castrated calves at 8 weeks showed lower heart rate variability and a reduced cortisol area under the curve compared to sham-castrated calves at 6 months. Taken together, these results suggest that compared to dairy calves, beef calves may experience an additional stressor resulting from separation from the dam.

Research studies have also looked at the effect of age on separation stress. Young calves seem to show greater motivation to re-establish contact with their dams as observed in a study where greater levels of restlessness were observed in calves castrated at 3 month old compared to 6 month old (Petherick et al., 2015). However, the pain from castration may supress the demonstration of behavioural expressions of separation stress. During separation from their dams, fewer vocalisations at 4–7 h post-castration compared to non-castrated calves were observed (Petherick et al., 2015). These authors suggested that non-castrated calves acted in a 'normal' way and therefore vocalised to establish contact with their dams because they were not experiencing pain, while calves in pain did not vocalise as much (Petherick et al., 2015). It is interesting to note that cow-calf proximity the following 2 days after castration did not differ between castration method (band or surgical) or compared with non-castrated calves in 2 month old calves (Gellatly et al., 2021). This contrasts with observations from other species (ewe-lambs) where an increase of maternal care (licking, sniffing and vigilance behaviour) has been observed when lambs expressed pain-related behaviours (Futro et al., 2015). In sum, these results indicate that younger (< 8 weeks) calves are likely to experience higher levels of separation stress compared to 3 and 6-month calves, but the behavioural demonstrations of such separation may be suppressed by pain-related behaviours experienced. There is very limited evidence on the effects of castration in calves younger than 1 week.

3.6.2.3.3 | *Resting problems and restriction of movement*

The method of castration affects calves' resting behaviour and activity, likely due to their attempts to avoid exposing the affected area to friction or mechanical stimulation. Age at castration is also likely to play a role on the severity of these welfare consequences due to a higher extension of affected tissue in older animals.

Several studies investigated the influence of method of castration on resting behaviour. Calves castrated with rubber ring or bands at the age of 4 weeks spent more time standing compared to those that underwent surgical castration (Nogues et al., 2021). This is in line with results from a study where calves castrated at 4 month old with bands showed more standing and fewer lying bouts than calves knife or sham castrated 8 weeks after the procedure (Marti et al., 2017) indicating longer term effects of the rubber rings or elastic bands. These resting problems are associated with the inflammatory response and integument damage caused by the application of the rubber ring or band. However, there seems to be an effect of calves' age on the severity of the resting problems caused by rubber rings or bands. Difference in lying times among rubber-ring or band castrated and non-castrated calves were observed when calves were castrated at the age of 4 months but such difference was not observed in calves castrated at 1 week or 2 months (Meléndez, Marti, Pajor, Moya, Gellatly, et al., 2017). This may be due to a more developed scrotum and testicular tissue suggesting higher resting problems linked with elastic bands or rubber rings in older animals. This is in line with the observations from Gonzalez who reported that castrated calves older than 6 months showed more lying bouts and less lying time compared to non-castrated calves (González et al., 2013; Meléndez, Marti, Pajor, Moya, Heuston, et al., 2017). Castrated calves tend to stand or lie still and avoid walking to minimise the stimulation of the mutilated area. This was observed in a study evaluating the frequency of abnormal postures depending on the castration method used (Burdizzo, surgical, rubber ring and sham castration) and depending on age (6, 21 and 42 days). Surgical castration was associated with a significant increase in abnormal standing (defined as standing stationary with no movement of the legs or body, standing with hunched back or trembling, standing with persistent kicking or foot stamping or waking backwards) especially in the first 30 min after castration. The rubber ring method was associated with significantly higher abnormal postures in the first 2 h than those observed in sham castrated, Burdizzo and surgically castrated calves (Robertson et al., 1994). Another study reported a higher number of tail flicks and a lower walking time in the first 3 days after castration in calves castrated with rubber ring compared to surgically calves. This effect was observed for calves castrated at 3 and at 6 months old (Petherick et al., 2015). A lower impact on walking behaviour of surgical castration compared to band castration was also observed in 2 month old calves during the first 2 days after castration (Gellatly et al., 2021). In summary, the existing evidence indicates that all physical castration methods are associated with resting problems and restriction of movement. These effects are more pronounced following surgical, rubber rings or elastic bands castration than when the Burdizzo method is used. Furthermore, these welfare impairments tend to persist longer when older calves – over two to 3 months of age – are castrated using rubber rings or elastic bands.

The use of pain mitigation strategies around the time of castration is expected to reduce the severity of resting problems and movement restriction. This has been demonstrated in calves treated with a single oral dose of meloxicam, which showed fewer pain-related behaviours and less scrotal inflammation following both band and surgical castration compared to untreated controls (Olson et al., 2016). In a separate study, calves castrated at 6 months of age and treated with an epidural administration of xylazine combined with intravenous flunixin exhibited significantly higher lying times on the day of castration, as well as at 48 h and 14 days post-procedure, compared to calves that did not receive pain relief (González et al., 2013). It is worth noting however that xylazine causes sedative effects and this may result in adverse experiences during reversal; for a discussion of the limitations of xylazine in this context, see Section 3.6.2.3.1.3.

Importantly, the restraint method can also have an impact on the overall handling stress. Handling methods include a tip-table (often used for calves below 3 months) and a chute for older calves where they are restrained while standing (Meléndez, Marti, Pajor, Moya, Heuston, et al., 2017). The horizontal position of the tip table may cause additional handling stress compared to when calves are kept standing. This is suggested by the observation of increased levels of salivary cortisol in 1 week and 2 month old non-castrated calves 60 min after being restrained in horizontal position compared to 4 month old calves that were sham castrated standing in a chute (Meléndez, Marti, Pajor, Moya, Heuston, et al., 2017). However, caution should be taken when interpreting the effects of the handling method on handling stress in very young calves that are kept with their dams because stress during handling could be confounded with separation stress or be additional to separation stress.

In summary, castration invariably involves handling and separation from the dam, making it impossible to fully prevent these welfare consequences. As mentioned in the handling stress discussion of the 'disbudding and dehorning section' (see Section 3.6.1.3.2), mitigation strategies for handling stress include application of principles of low-stress handling (Grandin, 2021), alongside the application of correct protocols of pain mitigation drugs.

3.6.2.3.4 | *Pain mitigation: main messages*

Current evidence generally indicates that castrated calves exhibit higher cortisol responses to castration compared to sham castrated calves, but this was not confirmed in a meta-analysis specifically investigating this issue. Although it is commonly assumed that young calves experience less pain resulting from castration compared to older calves, an assessment of the available data does not allow to conclusively demonstrate age-related differences in the intensity of pain perception during the mutilation procedure and the possibility of an age-dependent cortisol response to castration cannot be excluded. Nevertheless, if castration is to be performed, conducting it at an early age – preferably before 8 weeks – is recommended because this is associated with smaller wound size and faster healing. However, there are very limited data on the effects of the castration in neonatal calves (below 1 week old) and hence recommendations cannot be drawn for this age group. To the EFSA experts' knowledge, no studies have specifically evaluated the effects of early castration on the possible development of sensitisation, indicating a need for research in this area.

A review of results from experimental studies indicates that combining local anaesthesia with NSAIDs is more effective in reducing pain associated with castration than using a single analgesic agent. Nevertheless, there is no combination of pain mitigation drugs that is likely to be fully effective when physical castration is carried out, particularly for castrations carried out under field conditions. Best practices on pain mitigation include consideration of time for the medication to take effect when planning the castration procedures (Neves et al., 2017), or the pain mitigation strategy not being applied in a timely manner to avoid long handling and restraint times (Stafford et al., 2002). Furthermore, while most of the literature published regarding castration in cattle focuses on alleviating pain during and the hours after the procedure, there is sufficient evidence that castration causes long-lasting pain (i.e. for several weeks after the procedure) (Small et al., 2020; Thüer, Mellema, et al., 2007) and hence ideally pain mitigation should be applied for as long as the pain is likely to last. Sedation prior to castration should be carried out especially when calves are unused to handling but further research should be carried out on its possible negative welfare effects.

In addition, provision of clean bedding material will reduce the likelihood of lesion infection (Marti et al., 2017; Marti et al., 2018). Furthermore, regardless of the method used, castration should be performed by a veterinary surgeon or trained operator who is competent in the chosen procedure and can recognise signs of complications (WOAH, online). Finally, the most effective method to prevent pain and soft tissue lesions and integument damage resulting from castration would be the use of immunocastration (Marti et al., 2015) but the vaccine is currently not approved in the EU for cattle.

3.6.2.4 | *Conclusions on castration*

1. Castration is a mutilation procedure involving the physical removal or inactivation of testes. Physical castration methods are surgical, rubber ring, band or Burdizzo castration. All of them cause severe pain when performed without the use of drugs for pain mitigation. The use of some castration methods is banned in some MSs (e.g. rubber rings in Austria).
2. Rubber ring and band castration are often performed without anaesthesia. Surgical and Burdizzo castration are usually used with pain mitigation.
3. Highly relevant welfare consequences of the physical methods of castration are soft tissue lesions and integument damage, handling stress, separation stress, resting problems and restriction of movement.
4. All methods of castration (including immunocastration) have the aim to improve meat quality by increasing intramuscular fat and reducing dark cutting beef, and to reduce sexual and aggressive behaviours.

5. It is not completely clear whether there are differences in the intensity of pain perception around the procedure depending on age at castration but, due to the smaller size of the wound, healing is quicker in younger animals (certainty >90%).
6. Castration carried out between 1 and 8 weeks of age is associated with a faster healing of the wound compared to older ages (certainty >90%). Very limited research is available on the welfare consequences of castration in neonatal (<1 week) calves, so conclusions cannot be drawn for this age group.
7. When very young animals experience pain, there is a risk for central sensitisation (certainty >50%).
8. Castration at an early age (first weeks of age) is associated with a higher separation stress in beef calves.
9. There is no conclusive evidence that a short-term application of NSAIDs significantly reduces inflammation or healing time.
10. The use of anaesthesia mitigates the pain around the procedure (i.e. for a few hours). However, in practice, full pain relief is rarely achieved.
11. Depending on the method of castration, pain is shown at different times. Surgical and Burdizzo castrations are characterised by a high frequency of behaviours indicative of pain around the procedure, followed by a lower frequency of such pain behaviours during healing over 4–9 weeks (certainty >90%). Rubber ring and band castration are characterised by pain around the time of the procedure, followed by prolonged pain over 6–9 weeks (certainty >90%).
12. The use of pharmacological pain mitigation (NSAIDs and anaesthesia) reduces the frequency of behavioural responses indicative of pain around castration (certainty >90%). Despite pain mitigation, these behaviours can be observed more frequently in calves older than 6 months of age than in younger calves (certainty >90%).
13. The combination of local anaesthesia and NSAIDs leads to a higher reduction of behaviours indicative of pain than using anaesthesia or NSAIDs alone (certainty >90%).
14. Research indicates that lidocaine leads to a higher reduction of behaviours indicative of pain than other local anaesthetics, and that meloxicam reduces post-surgical inflammation. There is a lack of studies directly comparing modes, timing of administration and duration of treatment at different ages (certainty >90%).
15. The choice of drug, time and method of administration of the anaesthesia and NSAIDs impacts the mitigation of pain.
16. Immunocastration prevents the pain associated with integument and soft tissue damage and physical removal of the testicles, but this method is currently not approved in the EU for cattle.

3.6.2.5 | *Recommendations on castration*

1. The need for castration should be reconsidered and if possible castration should be avoided.
2. If carried out, castration should be performed before 8 weeks of age to promote faster healing of the wound. However, research is needed on the potential effects on central sensitisation of very early castration (within days after birth).
3. Band castration and rubber ring castration should be avoided due to the longer time needed to heal and the prolonged pain associated with these methods.
4. Care should be taken to avoid incomplete castrations when using the Burdizzo method.
5. To mitigate the pain induced by all methods of castration, regardless of the age of the animals, a combination of anaesthesia and analgesia should be properly applied and continued as long as pain is likely to be experienced. Criteria for proper application relate to the choice of medication, appropriate volumes, correct application sites, timing of anaesthetic and analgesic treatment, and control of local anaesthesia efficacy before castration starts.
6. It is recommended to promote standardised protocols for the use of local anaesthesia and analgesia around castration to improve the pain mitigation in commercial practice.
7. Facilities have to be adapted to perform castration procedures minimising handling stress and pain. Particularly for extensively raised cattle, safe, non-damaging and low-stress handling methods and facilities for animal restraint should be used to alleviate handling stress, but also to improve the safety of the personnel.
8. During and after castration, calves should be in a clean and comfortable space to avoid infections and promote resting.
9. The authorisation of immunocastration as an alternative to physical castration in the EU should be considered.

3.6.3 | Tail docking

3.6.3.1 | *Current practices*

Tail docking entails the removal of a portion of the tail, either through amputation or other means. The primary rationale behind tail docking in beef cattle is to prevent tail-tip injuries and necrosis caused by trampling on the tail tip, which occurs mostly when animals are kept on hard CSFs at high stocking density (e.g. Rouha-Muelleder et al., 2012; Schrader et al., 2001) (see also Section 3.2.2.3.2.1 on the relationship between hard flooring and tail tip lesions).

Already in 1988 the Council of Europe recommended that tail docking should be forbidden (Council of Europe, 1988) and most EU MSs prohibited this practice (Spoolder et al., 2016). In cases of severe tail injury, tail docking can be carried out in individual animals for medical reasons, and tail docking is still permitted in two EU MSs for animal welfare reasons (Spoolder et al., 2016). For example, in Austria removing a maximum of 5 cm, i.e. the tendinous part of the tail, is allowed in calves, but only if necessary to avoid lesions and if the risk of lesions cannot be reduced through other preventive measures. Similarly, in Germany authorisation from the competent authority can be granted to dock the tip of the tail of male calves under 3 months of age using elastic rings if other preventive measures to reduce tail lesions have not been successful. Although the extent to which this practice is implemented is unknown, it is expected to be rare.

Tail docking methods in cattle include surgical docking, elastic banding and hot docking (Sutherland & Tucker, 2011). Surgical docking entails cutting a portion of the tail using sharp surgical instruments, elastic banding involves the application of an elastic ring and hot docking utilises a heated docking iron.

Administration of analgesia and anaesthesia during the procedure is recommended to minimise pain and discomfort; in some MSs, e.g. Austria, anaesthesia and post-surgical analgesia are mandatory, and the procedure must be carried out by a veterinarian.

3.6.3.2 | *Welfare consequences*

The WCs selected as highly relevant for cattle as a result of tail docking are **'handling stress'**, **'soft tissue lesions and integument damage'** and **'resting problems'**. **'Inability to perform comfort behaviour'** was identified as a welfare consequence linked with soft tissue lesions and integument damage. The definition of each WC is available in Section 2.3.

3.6.3.3 | *Preventive and mitigating measures*

3.6.3.3.1 | *Handling stress*

Handling and restraint are necessary to perform all tail-docking procedures. There are no studies comparing different handling methods with regard to tail docking, but it can be assumed that the effects as regards e.g. separation and constraint of the animals described for other mutilations apply (see Sections 3.6.1.3.2 and 3.6.2.3.2).

3.6.3.3.2 | *Soft tissue lesions and integument damage and resting problems*

All tail docking methods lead to soft tissue lesions and integument damage. In the case of surgical removal or hot docking the lesions result immediately from the procedure itself, while elastic banding initially causes a cessation of blood flow, which is followed by necrotisation of the tissue distal from the band and loss of the necrotic tissue after about 3 weeks.

There are only few studies on the effects of tail docking in cattle and most studies were carried out in dairy calves and heifers, primarily using elastic banding in more proximal parts of the tail, thus resulting in short tail stumps (e.g. ending one hand width below the level of the vulva). Research on tail docking of female dairy calves and heifers is due to the fact that tail docking of dairy cattle was frequently practiced in e.g. North America and New Zealand (Sutherland & Tucker, 2011). However, this type of mutilation has nowadays been banned or is employed less in these regions. Studies on the effects of removal of the tail tip only are lacking.

Rubber band docked calves increased tail grooming and the number of standing and lying bouts on day 0 while the total lying time remained unchanged thus indicating restlessness (Tom et al., 2002). Similarly, more head movements directed towards the tail and time spent standing following band tail docking have been observed by Eicher and Dailey (2002). No significant differences in behaviour were observed between control calves and calves docked using a hot-iron (Tom et al., 2002). Surgical tail docking of cattle weighing between 255 and 370 kg with a pruning shear followed by administration of an elastrator band for haemostasis (under peridural anaesthesia and postoperative intravenous application of flunixin meglumine) resulted in shorter lying times and an increased number of rear foot stomps than in control animals during the first 3 days. Step counts and motion index were increased in docked animals compared to controls for 2 weeks after the procedure (Kroll et al., 2014).

In fattening bulls with a mean weight of about 280 kg, Winterling and Graf (1994) observed that animals whose tail tip had been docked at calf age (exact age not provided) showed significantly more (82%) 'protected' positions of the tail when lying, i.e. on the body or in proximity to the body than undocked animals (72%). The authors assumed that the docked tail is more sensitive to mechanical stimuli even when fully healed.

Physiological responses to tail docking vary. An increase in cortisol has been found in hot-iron docked calves, and the response was independent from the application of an epidural local anaesthetic (Petrie et al., 1996b). No such changes were found in calves tail docked using rubber rings (Petrie et al., 1996b). However, Tom et al. (2002) did not find significant differences in plasma cortisol concentrations between control and hot-iron docked calves, whereas the rubber ring group exhibited a significantly higher concentration for 60 min after treatment. Other studies have not found evidence for changes in cortisol following tail docking in calves (Schreiner & Ruegg, 2002) or pre-parturient heifers (Eicher et al., 2000). Similarly, no effects were described for heart and respiration rate (Schreiner & Ruegg, 2002).

As outlined above, the occurrence of tail-tip injuries is mainly determined by the combination of housing system and the associated stocking density. In an on-farm study with 10 farms per housing system, Schrader et al. (2001) found tail-tip injuries in 32% of fattening bulls kept in fully slatted floor pens (2.15 m^2 per animal), while only 3% of the animals in straw bedded pens (3.73 m^2 per animal) were affected ($p < 0.001$). In animals kept in fully slatted floor pens, the incidence of tail tip lesions increased with increasing stocking density.

3.6.3.3.3 | *Linked welfare consequences*

Removal of large parts of the tail, including the tail tuft, impairs effective fly removal from the rear body parts, thus leading to **'inability to perform comfort behaviour'** (dairy cattle: Eicher et al. (2001).

Short tail stumps have been shown to be more sensitive to heat and cold than when the tail remains intact, and neuromas can form in the scar tissue (Eicher et al., 2006), but the implications of this sensitivity are unclear.

3.6.3.4 | *Conclusions on tail docking*

1. Surgical removal, hot docking and elastic banding are the methods used for tail docking of cattle.
2. The highly relevant welfare consequences of all tail docking methods are handling stress, soft tissue lesions and integument damage, and resting problems.
3. Most scientific evidence refers to practices through which up to two-thirds of the tail is removed. Currently, if tail docking is allowed according to national legislation, removal of the tail tip is most common, but the effect of this method on animal welfare has not been investigated.
4. Band/rubber ring tail docking results in behaviours indicative of pain, such as head movements directed towards the tail, and more and shorter resting bouts (certainty > 90%).
5. Hot-iron docking leads to less intense reactions indicative of pain than band/rubber ring tail docking (certainty > 66%).
6. There is less evidence for changes in physiological measures such as blood cortisol or heart rate following tail docking compared to changes in behaviour.
7. The evidence for the effectiveness of epidural local anaesthesia is inconclusive, but due to the smaller lesion inflicted and the lesser innervation, docking of the tendinous tail tip leads to less severe welfare impairments than docking of parts of the tail with vertebrae (certainty > 90%).
8. The primary rationale for tail docking in beef cattle is to prevent tail-tip injuries and necrosis, but these problems can be mitigated by management measures such as adequate space allowance and floor conditions (certainty > 90%) (see Sections 3.3 and 3.2.2 respectively).

3.6.3.5 | *Recommendations on tail docking*

1. Tail docking should not be carried out routinely.
2. The need for tail docking can and should be prevented by the provision of sufficient space and appropriate floor conditions (see Sections 3.3 and 3.2.2 for more specific recommendations on these aspects).
3. Facilities have to be adapted to perform tail docking procedures minimising handling stress and pain. Particularly for extensively raised cattle, safe, non-damaging and low-stress handling methods and facilities for animal restraint should be used to alleviate handling stress, but also to improve the safety of the personnel.

3.7 | The risk to welfare associated with breeding practices

3.7.1 | General description of the current breeding practices

The goal of beef cattle breeding is often to enhance traits related to meat production, with different objectives among breeds. In existing beef production systems, there might be significant potential to improve animal welfare traits.

Traits influencing animal welfare such as maternal ability (see Section 3.7.6) are, like other traits, often influenced by genetic and non-genetic factors, typically through the complex interaction of multiple genes. Genes can also have pleiotropic effects, whereby a single gene can impact various phenotypic traits that may seem unrelated (Jensen, 2010). The evidence suggesting that welfare traits are partly genetically determined by numerous genes with pleiotropic effects or linked with other genes carries two significant implications. Firstly, that breeding for a particular production trait, like growth rate, may result in favourable and/or unfavourable genetic alterations in welfare-related traits, such as calving difficulty. Secondly, that welfare enhancement through breeding should be combined with data collection on potential consequences of the genetic changes. Additionally, due to low heritability of functional traits, breeding should be combined with improved management practices to achieve welfare improvements (Turner et al., 2024). The rate of genetic improvement depends on the heritability the trait and the number of traits considered within a subpopulation. As the intercrossing and multiplication process takes time, there may be a delay of years before the initial effects of genetic selection on commercial production can be observed.

Integrating breeding strategies with practical management interventions could help address some of the most prevalent WCs in commercial farming such as reproductive disorders (e.g. dystocia), handling stress or soft tissue lesions (e.g. resulting from disbudding). However, it is essential to consider the potential broader impact of selection on phenotype including effects on affective states.

3.7.2 | Polledness

3.7.2.1 | *Description of the trait*

Horns are permanent bony protrusions stemming from the frontal bone of the skull. They comprise a bony core ensheathed in cornified epithelium. Tissue differentiation begins during embryogenesis, with physical growth starting during the first weeks after birth. Initially free-floating in the skin layer above the skull, the horn buds later attach to the frontal bones (Aldersey et al., 2020); pneumatisation starts at the age of about 6 to 8 months so that the frontal sinuses are directly connected with the horn cores. Typically pointed and curved, horns serve several functions such as communication, defence and thermal regulation (Aldersey et al., 2020; Schafberg & Swalve, 2015).

Polled cattle do not develop horns. In naturally polled cattle, polledness arises from a genetic mutation, primarily driven by a dominant allele (P, POLLED) located on bovine chromosome 1 (Aldersey et al., 2020; Schafberg & Swalve, 2015). Thus, if an animal is heterozygous (Pp) it will show a polled phenotype. This makes it relatively easy to breed for polledness (Windig et al., 2015), although there are four different dominant DNA sequence variants that result in polled animals: Celtic POLLED (Medugorac et al., 2012), Friesian POLLED (Allais-Bonnet et al., 2013), Mongolian POLLED (Medugorac et al., 2017) and Guarani POLLED (Drögemüller et al., 2005; Georges et al., 1993).

The possible occurrence of scurs complicates the selection for polledness. Scurs are incompletely developed horn-like structures that consist of fibrous tissue covered by a layer of keratin, are of smaller size, have an irregular shape and lack attachment to the skull (Capitan et al., 2011; Grobler et al., 2021). Like horns, scurs begin to develop and differentiate during the fetal stage, and their early postnatal development is difficult to distinguish from horns. Because both scurs and early-stage horns are free-floating formations (Randhawa et al., 2020) in young calves scurs can be easily mistaken for horns (Grobler et al., 2021). Horns and scurs are governed by distinct genetic mechanisms (Aldersey et al., 2020). The genetic causes of scurs are still challenging to comprehend due to the variability of loci found in different cattle populations and the effects that sex hormones and epistasis have on the expression of scurs (Grobler et al., 2021).

The expression of scurs in cattle has been categorised into Type I and Type II scurs. Type I scurs are epistatic to POLLED and appear to be influenced by sex (Grobler et al., 2021). Studies have suggested the existence of a Type I SCURS locus on bovine chromosomes 19 (Asai et al., 2004), 2, 9 and 10 (Tetens et al., 2015). Type I SCURS can only appear when males are heterozygous for the POLLED locus and homozygous or heterozygous for the presence of scurs in the SCURS locus, or when females heterozygous for the POLLED locus have a homozygous SCURS locus (Grobler et al., 2021). For instance, in French Charolais cattle, Type II scurs were observed, which result from a mutation on the Twist Family basic helix–loop–helix Transcription Factor 1 (TWIST1) gene (Capitan et al., 2011). Type II scurs are dominant over horns but not over the polledness allele. No study has found homozygous animals for the TWIST1 locus, indicating that this variant may be lethal during embryonic stages (Grobler et al., 2021).

3.7.2.2 | *Animal categories*

The polledness trait can be expressed in all types of cattle categories and both males and females.

3.7.2.3 | *Current breeding practices*

Certain beef breeds, like Aberdeen Angus or Irish Moiled, exhibit genetic polledness, while other breeds largely lack this trait. Currently, there are breeding programmes aimed at selecting polled animals in various beef breeds, including Hereford, Limousine, Charolais and Simmental (ICBF, 2019). A rising proportion of homozygous or heterozygous polled animals were confirmed from information sent through the Public call for evidence (EFSA Public call for evidence, 2024 – PC-0742 19 – Landwirtschaftskammer Nordrhein-Westfalen). This increase is attributed to the widespread genotyping of beef cattle bulls, with a homozygous POLLED genotype featured in bull catalogues for farmers' selection of semen from polled bulls.

Polled bulls can be selected as sires in most beef cattle breeds due to the successful introgression of the POLLED allele through various breeding programmes worldwide and the proportions of polled beef cattle have largely increased. However, the frequency of polledness remains low or not present at all in some breeds. For example, while Aberdeen Angus are all polled, and polled animals are present in Limousine, Charolais, Hereford and Blonde d'Aquitaine, other breeds are typically horned, such as Chianina, Romagnola and other autochthonous beef breeds.

In some dairy cattle breeds, dynamics towards polledness are less marked depending on breeding policies of breeding associations (Scheper, 2018), and sometimes it may prove challenging to increase the frequency of the POLLED allele, even with genomic selection (Scheper et al., 2016 retrieved from EFSA Public call for evidence 2024 - PC-0742 19 - EFFAB- FABRE TP; Mueller et al., 2021 retrieved from EFSA Public call for evidence 2024 - PC-0742 19 - EFFAB- FABRE TP). Some authors reported that historically, farmers were hesitant to use semen from these bulls due to their lower rankings for other breeding values, such as production, despite their potential for introducing polledness (Randhawa et al., 2021).

3.7.2.4 | *Welfare consequences*

The general decision whether to keep horned or hornless beef cattle may lead to differing WCs in relation to **'soft tissue lesions and integument damage'**, **'bone lesions (including fractures and dislocations)'**, **'group stress'**, **'predation**

stress', **'heat stress'** and **'inability to perform comfort behaviour'** as explained below. The selection for genetic polledness in beef cattle prevents certain negative WCs of disbudding and dehorning which relate to **'soft tissue lesions and integument damage'**, **'bone lesions (including fractures and dislocations)'**, **'handling stress'**, **'eye disorders'**, **'separation stress'** and **'inability to perform sucking behaviour'** (see Section 3.6.1). The definition of each WC is available in Section 2.3. The WCs of not having horns vs. having horns, e.g. through the establishment of genetic polledness in beef cattle populations, are discussed below.

3.7.2.4.1 | *Soft tissue lesion and integument damage and bone lesions (including fractures and dislocations)*

If physical agonistic interactions occur, polled cattle is at a lower risk that skin lesions are caused. On the other hand, in dairy cows it has been found that hornless cows show a greater proportion of physical agonistic interactions than horned cows in the housing period (review in Knierim et al., 2015; Lutz et al., 2019) which could lead to bruises that are difficult to detect in living animals. During transport and lairage the risk of horn-related injuries is particularly high, and polled animals have been found to have half the number of bruises on their carcasses compared to horned cattle after road and partly rail transport in two Australian studies (Meischke et al., 1974; Shaw et al., 1976). However, a more recent US study evaluating presence of bruises on carcasses ($n = 4287$) originating from 13 different feedlots found a high proportion of bruises due to other causes than horn thrusts and no significant relationship between the number of horned feedlot cattle in a slaughter group and the prevalence of bruises (Youngers et al., 2017). Similar recent European studies are not available, but in general it can be expected that handling, loading, transport and lairage conditions that increase the risk of social conflict without adequate opportunities for retreat will disproportionately increase the risk of bruising in horned cattle.

In most of the cases, injuries caused by horns are superficial scratches and bruises (Menke et al., 1999; Schneider, 2011). However, injuries caused by horns may also affect sensitive areas such as udder and genitals and can sometimes even lead to abdominal rupture and abortion (Knierim et al., 2015). Other risks associated with the presence of horns are the risk of injury to the horns themselves (Knierim et al., 2015). Inadequate housing and management conditions greatly increase (a) the risk that agonistic interactions related to competition for resources lead to an increase in horn injuries and (b) the risk that horned individuals injure their horns, for example by getting stuck in housing facilities (Lutz et al., 2019).

3.7.2.4.2 | *Group stress*

Polled animals may have greater difficulties in establishing stable social dominance relationships and may engage in more physical agonistic interactions (Knierim et al., 2015; Menke et al., 1999). One study compared agonistic interactions in groups of horned and hornless dairy cows while they were kept in an outdoor exercise yard for 1 h per day, and confirmed that dehorned dairy cows showed a higher proportion of agonistic interactions with body contact than horned cows while the level of total agonistic interactions did not differ according to horn status (Lutz et al., 2019). When it comes to assessing social interactions and hierarchies in mixed herds of horned and dehorned cattle, study results are not clear-cut (Knierim et al., 2015). Horned cows often have an advantage in terms of rank in the social hierarchy, but not always (Beilharz & Zeeb, 1982). Other factors such as weight, age and social experience may override the effect of the presence of horns, especially in established herds. During establishment of the hierarchy in groups of five heifers, Bouissou (1972) found that animals without horns had a lower rank than horned animals. Furthermore, within pairs of animals, lighter animals (weight difference 50 kg) with horns dominated heavier disbudded ones in 75 per cent of the cases while bodyweight did not affect the dominance-submission relationship when both animals had been disbudded. A more recent study compared activity levels and behavioural responses to a novel object and food competition tests of 81 young fattening bulls (up to 12 months old), kept in two horned, two disbudded or two mixed groups, and of 71 heifers up to 11 months of age, kept in two horned and two disbudded groups under slightly different husbandry conditions (Reiche et al., 2020). No conspicuous problems were found in the mixed groups. In general, test results were inconsistent between repetitions and inconclusive with indications of more expression of fear in the novel object tests in disbudded bulls, but also in horned heifers, and more physical agonistic interactions in the food competition test in horned bulls, but less in horned heifers. The authors state that the effects were small and highly context dependent. Thus, as reviewed by Knierim et al. (2015), effects of horns on cattle social interactions are still not fully understood. Firstly, there is a lack of recent studies, and existing studies sometimes lack details. Moreover, it is difficult to compare the behaviour of animals reared in different environmental conditions and farms, as other factors such as herd size, housing conditions including space allowance per animal, farm management and human handling experience largely influence social interactions in the herd (Knierim et al., 2015). Recommendations to reduce harmful agonistic interactions in horned dairy herds target low levels of competition for resources, the opportunity to avoid dominant conspecifics and facilitation of stable social relationships (Johns et al., 2019). It can be expected that the same applies to beef cattle. Important measures to achieve this include a generous space allowance in total and in specific functional barn areas such as the outdoor loafing area (Lutz et al., 2019), the avoidance of areas where cattle may have difficulties to retreat, a generous ratio of lying, drinking feeding resources per animal (Collings et al., 2011; Krawczel et al., 2012), and in terms of management, the avoidance of regrouping (Raussi et al., 2005; von Keyserlingk et al., 2008) and continuous availability of feed (Collings et al., 2011). In general, group stress in polled cattle is more difficult to detect than in horned cattle where horn-related injuries are an overt indicator of physical agonistic interactions. Nevertheless, the measures mentioned for reducing harmful agonistic interactions (Johns et al., 2019) also reduce group stress in polled cattle (Baars et al., 2019). Ebinghaus et al. (2025) found that housing and management conditions better complied with recommendations to reduce agonistic interactions in 12 German dairy farms with horned cows than in 13 with hornless cows. However, they did not find significant differences in faecal cortisol levels between horned and hornless herds, indicating similar stress levels.

3.7.2.4.3 | *Predation stress*

Horns can be effective as part of defence against predators (Schafberg & Swalve, 2015), and polled animals or their calves may in principle be at higher risk of predation when reared in open environments (e.g. animals kept at grass in rural areas) where they can come into contact with predators. No studies addressing this were found.

3.7.2.4.4 | *Heat stress*

Horns may also play a role in thermal regulation in hot environments by increasing radiation surface and selectively cooling the brain (Taylor, 1966). In a study that compared superficial skin temperatures in horned and dehorned cattle, the horned cattle showed a rise of 0.18°C in superficial horn temperature per unit of heat load index while their eye temperature remained significantly lower than that of dehorned cattle (Algra et al., 2023). In agreement with the hypothesis of thermal dissipation from horns, Baars et al. (2019) compared milk samples from horned and hornless dairy cows within a mixed herd during ambient temperatures of −6 to 2°C. The study observed differences in milk fatty acid composition, which were attributed by the authors to an increased energy demand due to greater heat dissipation in the horned cows during cold environmental conditions. However, differences in feed intake could not be included. The results regarding the role of horns in heat dissipation should be considered with caution because at present the number of studies and the sample sizes studied (e.g. in Algra et al. (2023) are low. Îf supported by future research, the role of horns for thermal dissipation should be taken into consideration, in particular when dealing with individuals kept in environments with high temperatures.

3.7.2.4.5 | *Inability to perform comfort behaviour*

If horns are genetically absent or removed, cattle are no longer able to use them for self-grooming of body regions which are otherwise out of reach. Taschke (1995) observed six adult horned dairy cows kept in tie-stalls for 24 h and found that about 28% of all self-grooming occurrences involved the horns. No investigations are available whether horned cattle use brushes differently than hornless cattle, but it is conceivable that brushes are particularly important for hornless cattle to compensate for the lack of horns.

3.7.2.4.6 | *Other considerations*

Rapidly increasing the frequency of the POLLED allele in breeds where it sporadically occurs may lead to certain undesirable outcomes, e.g. due to inbreeding, which can result from high selection intensity for the polled trait in populations with a limited number of POLLED sires (Randhawa et al., 2021). The establishment of genetic polledness in beef cattle populations may also lead to WCs due to a loss of desirable genetic traits that may affect aspects such as disease resistance or adaptability. However, knowledge on this is lacking.

In addition, even if this point is out of the scope of the mandate, it has been reported that many farmers feel safer with hornless cattle from the risk of horn-gore injuries (Titterington, Knox, Buijs, et al., 2022). Records on farmers' accidents do not currently allow comparisons to be made between the incidence and severity of accidents involving horned or hornless cattle, as the necessary information on the proportion of horned and hornless cattle in the population is not available. Injury risks with hornless cattle may sometimes be underestimated, as also pushes of hornless cattle can lead to fatalities (Knierim et al., 2015).

On the other hand, dehorning practices itself may also increase the risk of injuries in handlers, especially in free-ranging systems where dehorning is applied to calves older than 2 months of age, which poses a greater risk to the health and safety of handlers (Bortolussi et al., 2005).

3.7.2.5 | *Enhancing polledness frequency through breeding practices*

The POLLED genetic variant allows for the use of polled bulls as breeding stock, and the proportions of polled beef cattle have largely increased. In small populations of rare breeds where introgression of the POLLED trait can only be achieved by crossing with other breeds, this is commonly avoided and sometimes the horns are a distinct trait of certain breeds (e.g. Highland cattle). Better understanding of the loci behind polledness and scurs may make genetic selection of polled individuals more effective. However, as insufficient knowledge is available about the functions of horns for cattle, e.g. regarding heat dissipation and about possible genetic correlations with other significant traits, a loss of the horn allele would not only mean a reduction of phenotypic and genetic diversity, but also traits important for disease resistance and other welfare aspects may get lost. Some authors reported the developing of gene editing outside EU for inserting the POLLED variant into a breed (Mueller et al., 2021; Schuster et al., 2020). It cannot be excluded that this technique has WCs but the technique is not currently permitted in the EU, and its consideration is out of the scope of the present mandate.

Another way to increase the frequency of polledness is to avoid breeding horned breeds in favour of naturally polled breeds. While in some EU member states this already seems to be the case (i.e. Eastern EU, EFSA Public call for evidence, 2024 – PC-0742 19 – Czech Beef Cattle Association, EFSA Public call for evidence, 2024 – PC-0742 19 – Deutscher Tierschutzbund e.V.), in other countries the native beef cattle breeds are horned. In the latter case, the abandonment of some breeds in favour of polled breeds would lead to a loss of genetic diversity and variability. This latter strategy may also raise productive and economic concerns, which however are out of the scope of the present mandate.

3.7.2.6 | *Conclusions on polledness*

1. The introgression of polledness in horned cattle breeds is an alternative to disbudding and dehorning procedures to mitigate soft tissue lesions and integument damage (certainty >90%) (for more details, see Section 3.6.1).
2. In some breeds, introgression of the polled variant has already been achieved with a rather high frequency, whereas in other breeds introgression is more difficult due to the lower frequency of the POLLED allele, especially in small populations of rare breeds, or it is sometimes not wanted, because the horns are considered a distinct trait of the breed.
3. Genomic selection represents a useful tool for increasing the frequency of the POLLED allele in cattle breeds.
4. As genetic polledness is inherited as a dominant trait, intensive selection for polledness can lead to the complete loss of the horn trait.
5. Horns play a role in thermal regulation (certainty >66%) and protection against predators (certainty >66%), and they are used for comfort behaviour (self-scratching). Their functional importance depends on specific husbandry conditions (e.g. high/low environmental temperatures, indoor/outdoor conditions, presence of brushes).
6. Evidence of a lower proportion of physical interactions in horned cattle herds indicates that the presence of horns also facilitates a more effective social communication within the herd.
7. When physical agonistic interactions occur, the presence of horns increases the risk of injuries (certainty >90%). However, conditions leading to reduced competition for resources, that enable cattle to avoid dominant conspecifics and provide for stable social relationships, have been demonstrated to reduce group stress and decrease agonistic interactions and related injuries in herds of horned cattle (certainty >90%).
8. Soft tissue lesions resulting from agonistic interactions are often not as visible in polled cattle compared to horned cattle (certainty >90%). However, this does not mean than they do not occur. For this reason, polled cattle will also benefit from housing conditions leading to reduced competition (certainty >90%).
9. Genetic associations of polledness with other traits are largely unknown. The establishment of genetic polledness in beef cattle populations carries a risk of losing desirable genetic traits such as disease resistance or adaptability (certainty >50%).

3.7.2.7 | *Recommendations on polledness*

1. The function of horns (e.g. establishing and maintaining stable social dominance relationships, self-grooming, defence against predators, thermal regulation) should be taken into account when deciding whether to keep polled or horned beef cattle.
2. The decision whether to keep polled or horned beef cattle should be based on the specific housing and management conditions. The more the housing system minimises competition for resources, enables cattle to avoid dominant conspecifics, facilitates stable social relationships and thus provides for low group stress and low number of physical agonistic interactions and related injuries, the less it is indicated to select for polled cattle.
3. If hornless cattle shall be kept, selection for genetic polledness is to be preferred to disbudding/dehorning to avoid their negative welfare consequences of pain and associated stress. However, the potential negative long-term consequences of polledness on the genetic capacity for disease resistance and other welfare-related traits resulting from loss of genetic variability should be also considered. Further research is recommended.

3.7.3 | Temperament

3.7.3.1 | *Description of the trait*

In beef cattle, temperament can be defined as the animals' persistent behavioural and emotional responses to various stimuli, including human interaction, handling and environmental factors (Sant'Anna et al., 2015). Persistent responses towards external stimuli indicate the animal's predisposition to react, rather than a momentary emotional state. The term temperament has been used in different ways in various studies. It was initially used in animal husbandry to describe an animal's response to handling or forced movement by humans (Burrow, 1997). This definition is human-centred and is commonly used in beef cattle, where it is also referred to as 'disposition' or 'docility' in the animal breeding and genetics field. Previous studies have used various other terms for describing the assessment of temperament, such as 'handling temperament', 'maternal temperament', 'aggressive temperament' or more general terms like 'aggression' and 'sociability' (Brown Jr, 1974; Gibbons et al., 2009, 2010; Gutiérrez-Gil et al., 2008; Réale et al., 2007). The latter were used in studies that examine the animal's response in contexts beyond human handling.

Temperament encompasses a range of traits, from docile and calm to aggressive and excitable, with individual animals exhibiting varying degrees of reactivity. Researchers commonly assess temperament using standardised behavioural tests, such as crush (or chute) scoring, flight speed (also named exit speed), temperament score or docility test. These tests evaluate cattle's reactions to restraint, handling and novel stimuli, providing quantitative or semiquantitative data on their temperament traits. A list of the behavioural tests most used to define temperament in genetics studies is reported in Table 10.

Temperament is a multidimensional trait influenced by genetic and environmental factors. It has mostly low-to-moderate heritability estimates, making this trait amenable for selection. However, the genetic basis of temperament is complex, involving multiple genes and gene–environment interactions. Cattle temperament is shaped by physiological (i.e. age and sex) and other factors, such as previous experiences, handling and maternal effects (Mormède, 2005). Some of the variability in heritability estimates presented in Table 10 can also be attributed to differences in temperament among breeds. For example, breeds derived from *Bos indicus* are generally known to have a more excitable or flighty temperament than *Bos taurus* breeds (Burrow, 2001). Large differences exist also when comparing the heritability estimated for temperament assessed through different behavioural tests. This last point is important because different behavioural tests might measure slightly different behavioural responses, which therefore also have genetic bases that do not completely overlap (reviewed in Haskell et al., 2014). In addition, the statistical characteristics of scores and values assigned to individuals following behavioural assessments can significantly impact heritability estimates.

TABLE 10 Behavioural tests used to define beef cattle temperament in different genetic studies and the relative heritability estimates. Heritability estimates are expressed as mean ± standard error.

Measure used to assess/ evaluate temperament	Description	Heritability estimates in different beef cattle breeds
Movement score (or crush score or chute score)	Assessment of the movement of the animals inside the squeeze chute (crush) for 4 s, just after the animal enters (a scale from 1 – no movement, to 5 – continuous vigorous movement). In Kadel et al. this was adapted with more subcategories and a final score from 1 to 15 (Kadel et al., 2006)	0.10 ± 0.03 in Nellore (Sant'Anna et al., 2015) 0.15 ± 0.06 in German Angus (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.17 ± 0.07 in Charolais (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.33 ± 0.10 in Hereford (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.11 ± 0.08 in Limousine (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.18 ± 0.07 in German Simmental (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.19 ± 0.02 in Brahmans, Santa Gertrudis and Belmond Red at weaning (Kadel et al., 2006) 0.15 ± 0.03 in Brahmans, Santa Gertrudis and Belmond Red in finishing period (Kadel et al., 2006)
Crush score	Assessment of body position and overall reactivity of cattle inside the squeeze chute (crush) for 4 s, just after the animal entrance (a scale from 1 – animal does not offer resistance, remains with head, ears and tail relaxed, to 5 – animal offers great resistance, sclera of the eye is always visible and has a 'freezing' reaction). This protocol is similar to the movement score reported above (Sant'Anna et al., 2013) but with some additional observations concerning body posture.	0.07 ± 0.04 in Nellore (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen; Sant'Anna et al., 2015)
Temperament Score or Docility test	Assessment of the reaction of an animal that is separated from its conspecifics in a pen and is approached by an operator that tries to drive the animal to a corner of this pen and hold it there for a predetermined period of time without physical aids (responses to all parts of the test are scored independently and then integrated into a single score from 1 to 5).	0.21 ± 0.03 in Nellore (Barrozo et al., 2012; Le Neindre et al., 1995; Phocas et al., 2006; Sant'Anna et al., 2015) 0.18 ± 0.02 in Nellore (Barrozo et al., 2012) 0.14 ± 0.11 in tropical breeds at weaning (Fordyce et al., 1996) 0.12 ± 0.11 in tropical breeds at 1 year of age (Fordyce et al., 1996) 0.08 ± 0.10 in tropical breeds at 2 years of age (Fordyce et al., 1996) 0.19 ± 0.03 in Pirenaica (Varona et al., 2012)

(Continues)

TABLE 10 (Continued)

Measure used to assess/ evaluate temperament	Description	Heritability estimates in different beef cattle breeds
Flight speed score	Score of the flight speed from the chute with 1 = walk; 2 = trot; 3 = run; and 4 = jumping out (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) In Kadel et al. this was adapted with more subcategories and a final score from 1 to 10 (Kadel et al., 2006)	0.20 ± 0.08 in German Angus (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 - PC-0742 21 - Landwirtschaftskammer Nordrhein-Westfalen) 0.25 ± 0.10 in Charolais (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.36 ± 0.06 in Hereford (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.11 ± 0.07 in Limousine (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.28 ± 0.07 in German Simmental (Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) 0.21 ± 0.02 in Brahmans, Santa Gertrudis and Belmond Red at weaning (Kadel et al., 2006)
Flight speed	Measurement of the time taken for an animal to break two infrared sensors placed 1.7 m apart after the animal leaves a crush (Kadel et al., 2006).	0.28 ± 0.05 in Nellore (Kadel et al., 2006; Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen; Rolfe et al., 2011; Sant'Anna et al., 2015; Paredes-Sánchez et al., 2023) 0.30 ± 0.02 in Brahmans, Santa Gertrudis and Belmond Red at weaning (Kadel et al., 2006) 0.34 ± 0.03 in Brahmans, Santa Gertrudis and Belmond Red in finishing period (Kadel et al., 2006) 0.34 ± 0.11 in a population of Hereford, Angus, Simmental, Limousine, Charolais, Gelbvieh, Red Angus and MARC III crosses (¼ Hereford, ¼ Angus, ¼ Pinzgauer, ¼ Red Poll) during finishing phase (Rolfe et al., 2011)
Flight distance	Assessment of the distance at which an animal starts to move away from an approaching human (Fordyce et al., 1996).	0.40 ± 0.15 in tropical breeds at weaning (Fordyce et al., 1996) 0.32 ± 0.14 in tropical breeds at 1 year of age (Fordyce et al., 1996) 0.70 ± 0.23 in tropical breeds at 2 years of age (Fordyce et al., 1996)
Aggressiveness score	Measurement of whether or not the animal showed signs of aggressiveness towards the handler in tests (Phocas et al., 2006)	0.08 ± 0.02 in Limousine heifers (Phocas et al., 2006)
Running time 1	Percentage of seconds passed running on a total of 60 s during which: an animal is isolated from herd mates and left alone in a pen for 30 s and then in the presence of a motionless handler for another 30 s (Phocas et al., 2006).	0.24 ± 0.02 in Limousine heifers (Phocas et al., 2006)
Running time 2	Percentage of time spent running during a test in which the handler attempts to contain an animal for 30 s in the corner of a pen with two solid walls. The test stops after the animal spent 30 s in the corner or a total test duration of 2 min is reached (Phocas et al., 2006)	0.22 ± 0.02 in Limousine heifers (Phocas et al., 2006)
Number of escapes 1	Number of escapes performed by the animal during the test described for running time 1 (Phocas et al., 2006).	0.10 ± 0.02 in Limousine heifers (Phocas et al., 2006)
Number of escapes 2	Number of escapes performed by the animal during the test described for running time 2 (Phocas et al., 2006).	0.25 ± 0.02 in Limousine heifers (Phocas et al., 2006)
Docility score	A linear combination of the results from the behavioural tests performed by (Phocas et al., 2006) described above. The individual docility scores vary from 6.5 (most aggressive animal) to 17 (most docile animal) (Phocas et al., 2006).	0.18 in Limousine heifers (Phocas et al., 2006)

Behavioural tests that involve quantitative measurements tend to yield larger heritability estimates. This is because the continuous nature of these measured values provides a more variable measure of the assessment of temperament traits. In contrast, scores that are based on qualitative assessments result in lower heritability estimates due to the reduced variability in the outcome measures, especially if there is a low number of score categories.

In summary, genetic studies have revealed that temperament traits in beef cattle exhibit a degree of heritability, suggesting the possibility of breeding to enhance temperament characteristics. However, several limitations exist, primarily stemming from the diverse array of behavioural tests used to assess temperament.

3.7.3.2 | *Animal categories*

Temperament is a trait observed across all animal categories. It is also crucial in animals that interact with handlers. Temperament can be assessed from an early age, including young calves from 2 months old (Webb et al., 2015). Numerous scientific studies measure temperament in beef calves post-weaning, starting from around 5 months of age (e.g. Kadel et al., 2006; Hoppe et al., 2010 retrieved from EFSA Public call for evidence 2024 - PC-0742 21 - Landwirtschaftskammer Nordrhein-Westfalen; Venot et al., 2015).

3.7.3.3 | *Current breeding practices*

Temperament, often referred to as docility in genetics, is included among the traits for which beef cattle sires are already being selected (Norris et al., 2014). Depending on the EU Member State, docility can be assessed and recorded by farmers, such as in Ireland (EFSA Public call for evidence, 2024 – PC-0742 21 – IFA), or by genetic centres, such as in Italy and France (ANABORAPI I-BEEF, online; Limousine, online). Normally bulls kept as candidate sires are tested with behavioural tests at different life stages, and aggressive or excitable individuals are discarded from the selection schemes.

For example, candidate sires of Piedmontese sires are tested for their temperament at their entrance to the genetic centre, and at the end of the testing period at the genetic centre (ANABORAPI I-BEEF, online). The first test is performed when the calves are 5 months old and consists of the observations of the calves during five phases (observation of the calf's behaviour in absence of the handler, in presence of the handler, with attempts of physical contact, during the movement to the weighting crush and in the weighting crush). The second test is conducted when the animals are 12 months old and is conducted during body measurements. The evaluator observes the animal's behaviour, as well as the stimuli and movements required by the operator to maintain control.

For each phase of both tests, a score ranging from 1 to 4 is assigned to indicate the observed behaviour of the animal. These scores reflect the animal's response to various stimuli and interactions with the operator, providing insight into the docility level. Despite the temperament assessments being performed at 5 and 12 months of age, currently the Docility Index used to select the candidate sires is calculated based on the results of the second test (ANABORAPI I-BEEF, online).

Docility indices are also used for other European beef cattle breeds. For example, Limousine candidate sires are assessed using two behavioural tests, whose results are translated into two genetic indices, named COMPsev and REACsev (Venot et al., 2015). These two indices are based on the behavioural tests named COMP and REAC. The REAC measure is taken under restraint conditions and involves counting the number of movements of the animal (head, feet) during the first 10 s of weighing on the scale. This observation is assessed between 4 and 10 months of age, and the score for REAC ranges from 1 to 10, with a value of 10 corresponding to 10 movements or more. For the second measure, COMP, the performance control technician assigns a behaviour assessment score during the body measurements performed on the individual between 5 and 12 months of age. The COMP assessment ends with a score from 1 (friendly) to 7 (aggressive, tries to charge) (Venot et al., 2015).

3.7.3.4 | *Welfare consequences*

The interaction between cattle temperament and housing practices plays a pivotal role in their overall welfare, and undesirable temperament is one of the reasons cattle are culled (Hidano & Gates, 2019). Temperament can lead primarily to the welfare consequence **'handling stress'**. No linked welfare consequences were identified in this context. The definition of this WC is available in Section 2.3.

3.7.3.4.1 | *Handling stress*

Temperament plays a role in animals' reactions to handling, their behaviours in response to challenges such as human approach or intervention during calving, and their interactions with other cattle. These behaviours also affect its adaptability to routine farm practices (Norris et al., 2014). Cattle that are docile and calm are easier to move and handle, and exhibit less signs of fear, resulting in fewer attempts to run away or make sudden movements.

The response of cattle to human intervention, especially in stressful situations such as calving, is another critical aspect of their temperament. Animals that remain calm and cooperative during human approach or assistance around parturition are likely to experience less stress, contributing to a more positive outcome for both the cow, the calf and the handler (Turner & Lawrence, 2007).

Animals with a more excitable temperament have been found to have impaired growth and productive performance (Sant'Anna et al., 2015), which may be a result of reduced time spent eating and decreased DMI (Nkrumah et al., 2007). However, this negative association between excitable/fearful temperament and growth was not consistently found in other studies, suggesting that variability may exist within and between different populations (Rolfe et al., 2011).

A negative association has been observed between excitable or fearful temperament and reproductive performance in beef cattle. The negative effects that excitable or fearful temperaments appear to have on reproductive and growth in beef cattle have been explained by the fact that these individuals may show higher stress responses. Baseline serum cortisol levels were significantly higher in excitable than in calm or intermediate temperament animals in both *Bos indicus* (Cooke et al., 2017; Cooke et al., 2019; Stahringer et al., 1990) and *Bos taurus* (Cooke et al., 2012; Fell et al., 1999; King et al., 2006). The cortisol levels of the more excitable or fearful animals were on average +25% to +60% higher than the cortisol levels observed in the calmer animals, while levels of cortisol in hair from the tail switch, reflecting the cortisol secretion over a longer period of time (Tallo-Parra et al., 2015) but sometimes only moderate correlations with faecal glucocorticoid concentrations (Moya et al., 2013), did not differ between calm and more excitable individuals (Cooke et al., 2017).

Although the relationship between stress response and immunity in other species is well-known (Burdick et al., 2011), little research has been conducted on the effects of different temperaments on beef cattle immunity and health. However, one study reported a negative correlation between flight time speed and total mononuclear cells in blood at 5 days after arrival of beef cattle steers at the feedlot (Fell et al., 1999).

The nature of interactions between conspecifics is a crucial aspect of herd dynamics and individual welfare in cattle. Positive social interactions can lead to a herd that appears more cohesive and less stressed. On the other hand, negative interactions, such as bullying or excessive competition, can increase stress levels and lead to injuries. However, no studies have yet established a link between the temperament of beef cattle and how they respond to human handling and their interaction with other members of the herd or the environment. Further research is required to determine whether the more excitable or fearful temperament of certain individuals has any adverse effects on social interactions within the herd.

3.7.3.5 | *Enhancing temperament traits through genetics and breeding practices*

As reported in the current breeding practices paragraph, several selection schemes are already testing docility in the candidate sires and discard the animals that show aggressive or excitable responses to the behavioural tests. However, there are some constraints that have delayed the genetic improvement of beef cattle breeds for temperament traits.

Firstly, the behavioural tests used to assess temperament are often inconsistent among studies and selection programmes, and sometimes rely on farmers' definitions of temperament, which are often based on subjective experience (Estévez-Moreno et al., 2021). Often, different behavioural tests are used in different EU MS or breeding centres for different breeds. This makes it difficult to assess and compare the genetic value for docility between different breeds. In addition, a study highlighted the importance of defining the human environment in handling test procedures (Grignard et al., 2001). The reactions across test situations (docility test and crush test) were only highly correlated ($r > 0.8$) when a human was present, while this did not depend on whether the human was motionless or stroked the animals (Grignard et al., 2001).

In pigs and mice, maternal defensiveness is exhibited most strongly by the least fearful animals (Marchant, 2002; Parmigiani et al., 1999) but it is unknown whether the same pattern is seen in cattle. In beef cattle, where cows stay with calves, a maternal aggressive behaviour can make farmer interventions difficult when necessary and also injure the calf. Thus, selecting cattle for reduced fear of humans during routine husbandry tasks may improve routine procedure efficiency but at the same time could lead to exacerbated handling problems, hazards and stress of animals in the postpartum period (Turner & Lawrence, 2007). Therefore, it may be important to assess not only the temperament of bull candidates, but also their daughters and their maternal temperament, so that selection indices can take into account the propensity to develop aggressive maternal defensive behaviour (Turner & Lawrence, 2007).

Another point that has been recently raised is the need to further validate new behavioural tests that could be used to assess different aspects of temperament in cattle. One approach supports the use of methods within the framework of Pavlov's classical studies on higher nervous activity and conditioned reflex-driven behaviour (Danchuk et al., 2020; Parshutin & Ippolitova, 1973). According to this approach, which emphasises the role of the cerebral cortex in shaping behaviour, the primary nervous processes governing behaviour are defined by three key indices: intensity (strength), balance and mobility. Cows with a strong and balanced temperament, characterised by higher nervous activity, display energetic behaviour, curiosity towards their surroundings and determination in achieving goals. They can quickly adapt to changes in environmental conditions and exhibit relative resistance to stress-inducing stimuli. Conversely, cows with a strong and balanced but inert temperament exhibit calmer behaviour, show less interest in environmental changes and demonstrate stress resistance, albeit with slower adaptation to new conditions. These findings support the need to identify behavioural tests that could evaluate also the ability to cope with novelty, expressing curiosity and not only inert temperament (Danchuk et al., 2020; Forss et al., 2024).

Moreover, researchers are actively pursuing the identification of genes and genetic variants associated with heightened docility in animals (Paredes-Sánchez et al., 2023). Identifying genetic mutations directly linked to docile or calm temperaments could enable the selection of the less fearful or less aggressive individuals without negatively affecting other traits related to growth or production (Adamczyk et al., 2013). The candidate loci associated with temperament in cattle are diverse and located on different chromosomes. Among them, the gene Solute Carrier Family 6 Member 2 (SLC6A2) which controls the action of norepinephrine and supports arousal, mood, attention and reactions to stress, has been indicated as a candidate gene involved in cattle temperament (Paredes-Sánchez et al., 2023). Other candidates reported in the literature are Solute Carrier Family 18 Member A2 (SLC18A2) and Pro-opiomelanocortin (POMC) genes (Garza-Brenner et al., 2017). The first participates in the transport of dopamine, preventing its accumulation, while the second is the precursor for corticotropic hormone (ACTH), which increases the expression of brain-derived neurotrophic factors responsible for neuron proliferation, differentiation and survival. Another recent study performed on Brahman and Yunlin cattle identified Sortilin Related VPS10 Domain Containing Receptor 3 (SORCS3) as a candidate locus associated with temperamental personality dimensions (novelty seeking, harm avoidance, reward dependence and persistence) (Shen et al., 2022). In humans, diseases associated with SORCS3 include attention deficit-hyperactivity, suggesting that this gene may be a candidate for identifying variants associated with cattle temperament. However, the number of candidate loci associated with cattle temperament is quite high and distributed across the entire genome of cattle. Therefore, further research is deemed necessary to identify a set of mutations that could aid in the selection of beef cattle that are less fearful and less aggressive. The precision of heritability estimates derived from genomic studies is currently hindered by the difficulty of standardised testing for temperament in a large number of animals. Behavioural tests are often time-consuming and resource-intensive (Titterington, Knox, Morrison, & Shirali, 2022).

The development of new technologies for automated temperament assessment holds promise in expanding the availability of temperament data for genomic studies in beef cattle. These advancements enable the efficient and standardised evaluation of temperament traits across larger numbers of animals (Chen et al., 2021), facilitating the collection of extensive datasets for genetic analysis. Automated systems, such as computer vision and machine learning algorithms, offer non-invasive and objective methods for assessing temperament-related behaviours (Cakmakci et al., 2023; Chen et al., 2021), including fearfulness, aggressiveness and sociability. By leveraging these technologies, researchers can overcome limitations associated with manual assessment methods, such as subjectivity, lack of validated protocols and time-consuming processes. Ultimately, the integration of automated temperament assessment tools into genomic studies enhances the accuracy and reliability of genetic evaluations, paving the way for targeted breeding strategies aimed at improving temperament traits in beef cattle populations.

3.7.3.6 | *Conclusions on temperament*

1. Efforts to select beef cattle displaying less fearful and aggressive temperament mitigate welfare issues resulting from flightiness and aggression (certainty > 90%).
2. Selection for calmer temperament (in terms of reduced flightiness) and simultaneously for increased maternal ability may also cause an increase in maternal defensiveness due to reduced fearfulness towards humans, which leads to increased difficulty in assisting the calf (certainty > 66%).
3. Current breeding practices for improving beef cattle temperament include the assessment of the candidate sires with behavioural tests. Individuals showing aggressive responses towards humans are discarded from the selection schemes.
4. Identification of genes and genomic regions is useful for enhancing selection for docile and calm temperament in beef cattle (certainty > 66%).
5. The behavioural methods to assess these traits are quite variable and, in some cases, rely on farmers' definitions of temperament, which are often based on subjective experience.
6. Outcomes of behavioural tests to assess temperament are not consistent across studies (certainty > 90%).

3.7.3.7 | *Recommendations on temperament*

1. The daughters of the sire candidates should be assessed to take into account the link between temperament and maternal ability.
2. Behavioural tests used in selection programmes to assess temperament should be harmonised. The human environment should be better defined in handling tests before they are used as a selection criterion.
3. Consensus among researchers on behavioural tests needs to be reached to develop more efficient selection schemes addressing cattle temperament.
4. New behavioural tests to assess different aspects of temperament should be identified and validated, especially those focusing on the ability to cope with novelty expressing curiosity.
5. The selection process could be improved by further research focusing on mutations directly associated with less fearful and excitable temperaments.
6. New technologies and automated systems should be used to assess temperament traits across a larger number of animals, to assess temperament-related behaviour (including fearfulness, aggressiveness and sociability), and to enhance the accuracy and reliability of genetic evaluations.

3.7.4 | Hypermuscularity

3.7.4.1 | *Description of the trait*

Hypermuscularity, is a well-documented trait in beef cattle characterised by an increase in muscle mass by on average 20%, leading to significantly higher meat yields. This condition is valued in the beef industry due to its association with higher meat yield and leaner mass, particularly in the hindquarters, shoulders and back. The increase in muscle mass ranges from 8% to 51% in the forequarters and from 9 to 34% in the hindquarters (Ansay & Hanset, 1979; Fiems, 2012). It results from an increase in the number of muscle fibres (hyperplasia) rather than an increase in the size of existing fibres (hypertrophy) (Grobet et al., 1997).

This trait is associated with the mh (muscle hypertrophy) locus on *Bos taurus* chromosome 2, as reported in Online Mendelian Inheritance in Animals database (OMIA:000683–9913) (OMIA, online). The effect of the mh locus on the presence of double-muscling trait is determined by mutations in the myostatin (MSTN) gene (also known as growth differentiation factor 8 – GDF8). This gene encodes myostatin protein, which negatively regulates muscle growth. In hypermuscular cattle, mutations in MSTN lead to reduced or absent myostatin activity, resulting in uncontrolled muscle growth. Specifically, the most common mutation is a deletion in the MSTN gene (MSTN c.821_831del), which has been extensively studied in Belgian Blue and Piedmontese breeds, but is also present in other breeds (OMIA, online). Beef cattle display the double-muscled (DM) phenotype only when they are homozygous for the mutated allele with the deletion MSTN c.821_831del (autosomal recessive inheritance). However, there are several types of mutations located on the MSTN gene that can alter the functionality of the encoded protein, including missense mutations, nonsense mutations and deletions/insertions, as summarised in OMIA (OMIA, online). The missense mutation MSTN c.282C>A (alias F94L) has been shown to have an additive effect that produces in heterozygosis an intermediate hypermuscular non-double-muscled (non-DM) phenotype (Sellick et al., 2007). Similarly, an additive effect has also been observed for the nonsense mutation MSTN c.1004G>T (alias E291*) in the Marchigiana breed (Sarti et al., 2019). There is an appreciable difference between hypermuscular non-DM and DM individuals. Furthermore, while mutations in the myostatin gene are acknowledged in the scientific literature as the primary cause of the DM phenotype, additional mutations in other genes can further enhance muscle mass even in DM animals (Druet et al., 2014).

In the context of this Scientific opinion, subjects homozygous for these variants, such as Belgian Blue cattle, will be referred to as DM and animals heterozygous for MSTN variants with an additive effect will be referred to as hypermuscular non-DM. Hypermuscular animals include both DM and non-DM.

3.7.4.2 | *Animal categories*

Double-muscling is expressed in all categories of beef cattle and it holds particular significance in suckler heifers/cows due to its close relationship with calving difficulties and dystocia. Already in the third trimester of pregnancy, the muscle mass of fetuses from DM cows, is significantly heavier and more pronounced than that of fetuses of the same age from other breeds (Mao et al., 2008).

3.7.4.3 | *Current breeding practices*

Double-muscling in cattle has been documented for over a century, but the number of DM individuals was low due to complications during parturition. The prevalence only increased with advanced surgical techniques for caesarean sections (C-sections) and the advent of antibiotics and anaesthesia used in the course of C-sections (Fiems, 2012). Over the years, the genetic selection schemes employed in several European cattle breeds have increasingly focused on *MSTN* (alias *GDF8*) mutations due to their significant impact on muscle development and meat production. Double-muscling has been identified and extensively studied in various cattle breeds, including the Belgian Blue, Piedmontese and Limousine, each exhibiting varying degrees of double-muscling and associated phenotypic characteristics.

In Belgian Blue cattle, the myostatin gene mutation MSTN c.821_831del is particularly prominent and has been systematically selected for. The selection schemes for Belgian Blue cattle have prioritised this mutation because of its substantial economic benefits, including higher meat yield and improved meat quality. The emphasis on the MSTN mutated allele has been so significant that it has reached fixation in almost all Belgian Blue herds, meaning almost all animals exhibit the mutated allele in homozygosity. In order to reduce the WCs resulting from double-muscling, Belgian Blue sires are now selected for calving ease (CRV, 2022) and for leg conformation (EFFAB confirmed this by email on 31 January 2024) (EFFAB, 2024). By 2014, the mutated allele responsible for double-muscling was only absent in a small population of about 3400 Blancs Bleus Mixtes, the ancestral dual-purpose counterpart of Belgian Blue cattle (Druet et al., 2014) which may serve in future as a source of genetic diversity.

The myostatin gene mutation MSTN c.821_831del has also been identified in the Spanish cattle breed Asturiana de los Valles (Grobet et al., 1997). Asturiana de los Valles bulls are evaluated as candidate sires for two distinct purposes: as terminal sires producing offspring intended for fattening and subsequent slaughter, and as sires of future suckler cows. In both cases, bulls are selected for their muscular conformation and the expression of the double-muscling phenotype, locally referred to as 'cularidad' (ASEAVA, 2024a). However, a notable difference exists between sires selected for the two lines. Sires selected for suckler cow breeding are also selected for calving ease to mitigate the negative effects of hypermuscularity during calving. Additionally, the Asturiana de los Valles breeders' association (ASEAVA) maintains some breeding bulls that do not carry the myostatin gene mutation responsible for double-muscling, designated as 'toros libres del gen culón' (ASEAVA, 2024b).

The Piedmontese beef cattle breed, originating from Italy, exhibits a double-muscling phenotype locally known as 'doppia groppa'. This phenotype is caused by a single nucleotide polymorphism in exon 3 of the *MSTN* gene, resulting in an amino acid change that disrupts the normal conformation of the myostatin protein (Kambadur et al., 1997). This genetic mutation leads to increased muscle mass and reduced fat content, traits highly valued in meat production. Similar to Belgian Blue cattle, the MSTN mutated allele is nearly fixed in the Piedmontese breed, with over 96% of the herds in the Piedmont region exhibiting the mutation in homozygosity (Miretti et al., 2013).

The Marchigiana breed, originating from Central Italy, is known for its large body size and high weight gain. In 2003, a missense mutation in the MSTN gene causing a double-muscling phenotype was identified in this breed (Marchitelli et al., 2003). However, the negative health and survival effects observed in homozygous individuals prompted the Marchigiana breeders association (ANABIC) to exclude all DM homozygous animals from their selective breeding programmes, opting to retain only heterozygous bulls. Unlike breeds with other myostatin gene mutations, heterozygous sires in Marchigiana cattle exhibit superior lean mass deposition characteristics without the adverse effects associated with double-muscling, resulting in hypermuscular, non-DM sires (Aiello et al., 2018; Ceccobelli et al., 2022).

The Irish Limousine Cattle Society has adopted a similar approach to ensure informed mating decisions. The Limousine breed showed different mutations in the myostatin gene (Cortés-Lacruz et al., 2017; Dominguez-Castaño et al., 2021), some of which are causative of the hypermuscular DM phenotype and others are associated with hypermuscular non-DM animals. In a document published in July 2021, the Irish Limousine Cattle Society summarised the different MSTN mutations that can be found in Limousine breeding animals, and suggested which matings are discouraged due to calving difficulty and possible health problems encountered in the offspring (ILCS, online).

3.7.4.4 | *Welfare consequences*

Double-muscling not only leads to increased muscle mass but also significantly alters skeletal conformation and reduces the size of internal organs relative to body mass. The welfare implications of double-muscling are therefore multifaceted and have been scientifically reviewed (Bellinge et al., 2005; Fiems, 2012). The general decision whether to keep DM cattle may lead to differing WCs in relation to are **'reproductive disorders'**, **'handling stress'**, **'heat stress'**, **'respiratory disorders'**, **'locomotory disorders (including lameness)'**, **'bone lesions (including fractures and dislocations)'**, **'muscle disorders'** and **'metabolic disorders'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3.

3.7.4.4.1 | *Reproductive disorders*

The reduction in skeletal structure, particularly the underdeveloped hip bones in DM animals, negatively impacts calving ease and cows' longevity. Studies indicate that the inclusion of the MSTN allele in Piedmontese cattle results in a significantly reduced pelvic opening area. The pelvic opening in DM dams is 10% smaller than in non-DM Charolais (Vissac et al., 1973) and 6% smaller than in crossbred cows, leading to higher incidences of dystocia and perinatal mortality (Arthur et al., 1988). DM cattle, such as the Belgian Blue breed, have heavier fetal weights, with calves weighing up to 50 kg at birth (Fiems et al., 2001). The percentage of calf birth weight to dam weight is 9.0% for primiparous Belgian Blue cows (Fiems & De Brabander, 2009) and 8.3% for multiparous Belgian Blue cows (Fiems, 2012), compared to 7.5% and 6.5% for primiparous and multiparous Holstein cows, respectively (Johanson & Berger, 2003). This disparity between the reduced pelvic opening and increased calf birth weight necessitates C-sections, which have become routine for DM breeds. DM breeds such as the Belgian Blue and Piedmontese exhibit high incidences of dystocia and need elective C-sections in most of the calvings (> 90% for DM Belgian Blue) (Tuska et al., 2021) and 9% in primiparous Piedmontese (Biagini & Lazzaroni, 2019). Furthermore, C-sections significantly reduce subsequent pregnancy rates, because of health implications of the surgery. For a further discussion on the consequences of C-section, see Section 3.7.5.

3.7.4.4.2 | *Handling stress*

C-sections and dystocia resulting from hypermuscularity cause pain and handling stress in the dam, may increase the risk of delayed colostrum intake and onset of maternal behaviours (see Maternal ability, Section 3.7.6), and impair the production and quality of colostrum (Tuska et al., 2021).

3.7.4.4.3 | *Heat stress and respiratory disorders*

DM cattle are more prone to heat stress compared to non-DM cattle. A study from 1970's observed that as ambient temperatures rise, rectal temperatures of DM cattle increase more than those of non-DM animals (+2.24°C in DM vs. +1.25°C in non-DM cattle) (Halipré, 1973), but no recent data on this aspect were found. This heightened sensitivity is due to several physiological factors. Firstly, DM cattle have a larger muscle mass and a smaller body surface area relative to their body mass, which limits their capacity for heat dissipation. Heat generation is proportional to muscle mass, while heat dissipation depends on body surface area (Taylor et al., 2024). Additionally, DM cattle exhibit lower capillary density, which affects their ability to regulate body temperature (Stavaux et al., 1994). Blood flow to the skin, which is crucial for sweating and heat dissipation (Blazquez et al., 1994), is directly linked to capillary density, and lower capillary density in DM cattle (Stavaux et al., 1994) impairs their ability to transfer metabolic heat from the body core to the skin. Furthermore, approximately 15% of endogenous heat is lost through the respiratory tract in cattle (Finch, 1986). However, DM cattle have reduced lung capacity, which further hampers their ability to dissipate heat. Moreover, DM cattle are more susceptible to severe respiratory disorders like bronchopneumonia (Gustin et al., 1987), which can further diminish their heat regulation abilities. These factors collectively make DM cattle more vulnerable to heat stress, potentially exacerbating other health issues and impacting their overall welfare.

3.7.4.4.4 | *Locomotory disorders (including lameness), bone lesions (including fractures and dislocations)*

According to Wolff's law, bones adapt to the loads placed on them by remodelling and becoming stronger to resist extra load (Fiems, 2012; Rasch et al., 1989). However, the smaller bone content in DM cattle (Ansay & Hanset, 1979) means that their bones are more challenged due to the increased body weight. This additional load on a reduced skeletal structure can lead to various locomotory disorders (Fiems, 2012). Hendricks et al. (1973) found that 13–15 months old Angus DM bulls had shorter metacarpal bones and thinner cortices compared to non-DM animals. Further studies showed that humerus and femur lengths are significantly reduced by 4%–5% in DM Charolais bulls compared to non-DM bulls, and that their femur circumference was reduced by 7%–10% (Vissac & Perreau, 1968). Shahin et al. (1991) reported that DM cows have a lower proportion of bone in their carcasses, particularly in the forelimb and hind limb, with humerus, carpus and os coxa percentages of total bone weight being significantly lower in DM cows than in non-DM animals. In addition to bone structure, muscle and tendon properties also contribute to locomotory issues. Research on *MSTN* null mutant mice, which are used as animal models for the double-muscling trait, revealed decreased force generation in muscles and increased degenerative changes in the intervertebral discs (Hamrick et al., 2003). Mendias et al. (2006) found that while *MSTN* null mice had significantly larger muscles (tibialis anterior and soleus muscles were 72% and 82% greater, respectively, than in wild-type mice), their tendons were much smaller (40%–44% smaller in mass), resulting in a significantly decreased tendon/muscle mass ratio and a 50% smaller cross-sectional area of tibialis anterior tendons. The tendons also exhibited a 14-fold increase in stiffness, which is critical as stiffer tendons can cause greater damage to muscle fibres during contractions (Mendias et al., 2006). These anatomical and physiological discrepancies could make DM cattle more susceptible to locomotory disorders, but it should be considered that these conclusions are based on a mice model. The smaller, more heavily loaded bones, combined with less robust tendon structures, lead to higher risks of skeletal and muscular injuries, reduced mobility and overall poorer locomotion capabilities and fatigue. DM cattle may thus be at greater risk of leg injuries and lameness compared to other beef cattle. For instance, 50% of the DM Piedmontese bulls kept in concrete fully slatted floor pens showed swollen carpal and tarsal joints between 233 and 273 days of life (Schiavon et al., 2010) and even higher rates have been reported for Belgian Blue bulls (De Campeneere et al., 2002; Ruis-Heutnick et al., 2000). It should however be considered that prevalences for other breeds under similar housing conditions are not available.

3.7.4.4.5 | *Muscle disorders*

DM cattle have been reported to be more prone to muscle disorders such as white muscle disease and muscular dystrophy (Allen, 1977). Animals with these muscle disorders have an increased need for selenium, and correspondingly, Belgian Blue DM cattle have been shown to require increased dietary selenium levels when compared with other beef cattle breeds (Guyot et al., 2007). Higher creatine phosphokinase activity, a marker of muscle degeneration, has been observed in DM Belgian Blue bulls compared to Belgian Blue bulls with normal conformation, suggesting more muscle degenerative processes in DM cattle (Uytterhaegen et al., 1994).

3.7.4.4.6 | *Metabolic disorders*

The anatomical and physiological features of DM cattle can also increase the risk of metabolic disorders in these animals (Fiems, 2012). The larger muscle mass requires more energy at maintenance level, whereas several internal organs are relatively smaller in DM cattle (Ansay & Hanset, 1979; Vissac & Perreau, 1968), thereby decreasing the feed intake capacity. Their reduced DMI combined with the lower energy content per kilogramme dry matter in low-quality diets results in significantly decreased overall energy supply (Fiems, 2012). Consequently, DM animals are often provided with high-energy diets to meet their nutritional needs (Fiems, 2012). Furthermore, several studies found that DM cattle have higher phosphorus, calcium (Fiems, 2012; Meschy, 2002) and selenium (Guyot et al., 2007) requirements than non-DM animals, indicating that DM cattle should be provided diets with increased macro and micro-nutrient density (Fiems, 2012). High-energy and high-protein diets have, however, been found to increase the risks of metabolic and locomotory disorders (Schiavon et al., 2010), suggesting that nutritional requirements in DM cattle should be addressed carefully.

3.7.4.4.7 | *Further considerations*

Double-muscling in cattle is not only associated with increased muscle mass but also with several genetic abnormalities. For instance, DM animals, particularly in the Marchigiana breed, frequently exhibit macroglossia, which is an abnormally large tongue that can lead to difficulties in nursing and feeding (Aiello et al., 2018). Additionally, there is a notable prevalence of arthrogryposis, a congenital condition characterised by joint contractures that impair movement (Anderson et al., 2008). Belgian Blue cattle also show increased frequency of alleles causing several genetic abnormalities, such as congenital muscular dystonia, crooked tail syndrome, dwarfism, prolonged gestation, SNAPC4, hemartoma and arthrogryposis (EFFAB confirmed this by email on 31 January 2024) (EFFAB, 2024). For this reason, artificial insemination candidates that carry genetic mutations for these conditions have been rejected since 2017. These genetic anomalies further complicate the health and welfare management of DM cattle, underscoring the need for careful breeding and management practices to mitigate these adverse effects.

A smaller heart and smaller lungs found in DM animals (Vissac & Perreau, 1968) may also contribute to an increased risk of fatigue and increased susceptibility to stress. Exercise has been found to lead to exhaustion more rapidly in DM than in non-DM cattle (Holmes et al., 1973). In addition, psoroptic mange has been reported to be prevalent in Belgian Blue cattle in Flanders (Sarre et al., 2012), while *Psoroptes ovis* infestations are rare or absent in other cattle breeds (Losson et al., 1999). It remains however unclear, whether the increased susceptibility to mange in Belgian Blue can be considered an effect of the double-muscling genotype.

3.7.4.5 | *Preventive and mitigating measures*

To limit the WCs associated with double-muscling in cattle, several genetic selection strategies can be implemented. One approach is to exclude all DM homozygous animals from the breeding programmes, opting to retain only heterozygous bulls. This strategy has been chosen by the Italian National Breeders Association for Marchigiana beef cattle breed. Furthermore, matings between heterozygous individuals can be prevented. To avoid matings of Marchigiana bulls and cows carrying the *MSTN* exon 3 mutation, ANABIC has implemented an online platform that allows breeders to search for the genotype of potential sires by ear tag, ensuring informed mating decisions (ANABIC, 2024). By doing so, breeders can achieve a balance between muscle growth and skeletal robustness, thereby reducing the incidence of dystocia and other related welfare issues. Selection strategies for the Piedmontese breed are designed to maximise the advantages of the double-muscling while trying to address the reproductive challenges associated with double-muscling (see Section 3.7.5).

Another strategy involves crossbreeding DM cattle with non-DM breeds to combine desirable traits from both. This may result in offspring that maintain some of the enhanced muscle characteristics while benefiting from improved calving ease and overall health (Arthur, 1995). For example, semen coming from Belgian Blue sires is often used on multiparous dairy cows in order to obtain dairy-beef cross calves with good muscle mass deposition but reduced risk of calving difficulties when compared with beef breeds (EFSA Public call for evidence, 2024 – PC-0742 17 – Deutscher Tierschutzbund e.V).

Additionally, selecting for calving ease and improved anatomical features (such as pelvic dimensions and internal organ size) in DM breeds may address some of the challenges associated with DM cattle, but further research is needed (see Section 3.7.5).

3.7.4.6 | *Conclusions on hypermuscularity*

1. Double-muscled (DM) animals experience high rates of dystocia due to a mismatch between calf size and the pelvic conformation of dams, necessitating C-sections (certainty > 90%). For example, elective C-sections are carried out in approximately 90% of calvings in DM Belgian Blue cows.
2. Double-muscled animals are at greater risk of heat stress, locomotory disorders (including lameness), metabolic disorders and fatigue resulting from a smaller heart and smaller lungs compared to non-DM animals (certainty > 90%).
3. Double muscling in beef cattle is predominantly caused by mutations in the myostatin (MSTN) gene, the most impactful being MSTN c.821_831del, leading to reduced or absent myostatin activity and thus hyperplasia of muscle fibres, especially in hindquarters and shoulders.
4. Double muscling has a prevalence above 90% in some beef cattle breeds, such as Belgian Blue and, to a lower extent, the Piedmontese breed.
5. Banning homozygous DM animals as sires and keeping only heterozygous hypermuscular bulls that show intermediate phenotypes mitigates WCs due to hypermuscularity.
6. Avoiding mating hypermuscular sires homozygous for certain MSTN gene mutations with heifers and hypermuscular dams prevents the occurrence of WCs due to dystocia.
7. Welfare consequences of hypermuscularity are mitigated by selecting for improved anatomical features such as pelvic conformation and internal organ size (certainty > 50%).

3.7.4.7 | *Recommendations on hypermuscularity*

1. For welfare reasons, homozygous double-muscled animals should not be used, and heterozygous hypermuscular genotypes that show intermediate phenotypes should be preferred.
2. Breeding bulls that do not carry myostatin gene mutations responsible for double muscling should be used.
3. Selection strategies should also include traits for improved anatomical features, accounting for e.g. pelvic conformation for calving ease, although the implications of the low calf weight part of the 'birthing ease' trait are unknown.
4. Informed mating decisions should be promoted, e.g. by implementing online platforms that allow breeders to search for the genotype of potential sires.

3.7.5 | Dystocia and caesarean section

3.7.5.1 | *Description of the traits*

Dystocia is a painful condition characterised by prolonged or difficult labour that necessitates human intervention and can be attributed to factors such as calf size, pelvic conformation of the dam, a mismatch between dam's pelvic conformation and calf muscular mass, and calf malpresentations (as reviewed in Boakari & Ali, 2021). Dystocia, and the necessity for C-sections are significant welfare concerns in beef cattle. In the context of this Scientific Opinion, the terms dystocia and C-section are considered in relation to their association with some traits that are objectives of genetic selection, such as conformation traits in certain breeds of beef cattle.

The frequency of dystocia varies among beef cattle breeds and across different countries. Smaller breeds, such as Canadian Simmental, have lower dystocia frequencies, with approximately 3.7% on more than 1 million calvings (Jamrozik & Miller, 2014). In contrast, larger breeds show higher incidences with French Charolais having around 8% (Phocas & Laloë, 2004) and Swedish Charolais and Hereford primiparous cows exhibiting 6% of dystocia (Eriksson et al., 2004). Belgian Blue cattle are particularly prone to dystocia, leading to nearly 90% of C-sections being elective (Tuska et al., 2021). In hypermuscular DM cattle, dystocia is primarily due to the larger birth weight and muscular hypertrophy of the calves, resulting in calves that are too large to pass through the pelvic opening of the dam. Gestation length has also been associated with increased risk of dystocia, as calves tend to be heavier in cases of prolonged gestation length. Furthermore, in hypermuscular DM dams, skeletal underdevelopment relative to increased muscle mass may complicate calf passage in the birth canal. For a complete review of the implications of hypermuscularity on the welfare of beef cattle see Section 3.7.4.

C-sections can be routinely performed with an elective C-section procedure, or performed in emergency when labour becomes too delayed, and the dam and calf health are at risk. Elective C-sections are more commonly performed in cases where natural delivery is expected to be not possible or difficult.

Most of the beef cattle breeds are already selected for the traits 'calving ease' and 'birthing ease' to reduce the risk of dystocia and C-sections. These two traits are used to estimate the genetic merit of potential sires, but they do so from different perspectives. 'Birthing ease' evaluates how the conformation of the calf at birth affects calving problems, estimating the candidate sire's ability to produce offspring with a smaller body size and lighter weight at birth. This trait focuses on minimising the physical challenges caused by the calf during delivery. In contrast, 'calving ease' assesses the conformation of the dam's birth canal and the overall suitability for unproblematic calving. It estimates the genetic merit of the sire of the dam regarding an optimal pelvic structure and rear body conformation that enhances her ability to deliver calves without difficulties. Calving ease and birthing ease traits can be obtained using measures such as calving ease score, calf weight, prevalence of twins, calf size, calf condition after birth and liveability. The explanation of the traits and how they are assessed is reported in Table 11.

TABLE 11 Measures included in calving ease and birthing ease traits.

Measure used to assess/ evaluate calving ease and birthing ease	Description	Literature
Calving ease score	A scale from 1 to 5 to describe how difficult the birth was and how much human intervention was needed. The used scale is: 1-no problem; 2-slight problem; 3-needed assistance; 4-considerable force needed to help getting out the calf; 5-extreme difficulty, needed C-section. This scale has been changed in some studies into a 4-point scale, with 3 used to indicate calvings that needed hard assistance and 4 the calving that needed C-section (Cervantes et al., 2010).	First established for dairy cattle by Berger (Berger, 1994). Used to estimate the impact of beef sires on beef × dairy matings (Basiel et al., 2024). Heritability of 0.325 ± 0.022 in Asturiana de los Valles (Cervantes et al., 2010). Heritability of direct (calf) effect of 0.135 in Charolais and 0.145 in Hereford (Eriksson et al., 2004). Heritability of maternal (dam) effect of 0.073 in Charolais and 0.113 in Hereford (Eriksson et al., 2004). Heritability of direct calving ease = 0.15 (Beef cow), 0.16 (Beef heifer), Maternal calving ease = 0.08 (Beef cow + Beef Heifer) in Aberdeen Angus (Interbull Centre, online).
Calf size at birth	A 5-point scale, with 1 being very small, 2-small, 3-average, 4-large, 5-very large (Berger, 1994). Another variant of this trait is the calf birth weight (Eriksson et al., 2004).	First established for dairy cattle by Berger (Berger, 1994). Heritability of direct (calf) effect of 0.481 in Charolais and 0.509 in Hereford (Eriksson et al., 2004). Heritability of maternal (dam) effect of 0.109 in Charolais and 0.062 in Hereford (Eriksson et al., 2004). Heritability of Direct Birth size = 0.22, Maternal Birth size = 0.05, Direct Birth weight = 0.33, Maternal birth weight = 0.07 in Aberdeen Angus (Interbull Centre, online).
Calf liveability (or calf survival)	A scale with three steps: 1-alive; 2-dead at birth; 3-dead by 48 h post-natal.	First established for dairy cattle by Berger (Berger, 1994). Heritability of 0.226 ± 0.018 in Asturiana de los Valles (Cervantes et al., 2010).
Stillbirths	Recording of stillbirth calves.	Heritability of Stillbirth = 0.038 in Aberdeen Angus (Interbull Centre, online).

TABLE 11 (Continued)

Measure used to assess/ evaluate calving ease and birthing ease	Description	Literature
Calf condition	A scale with 3 steps: 1-normal; 2-weak; 3-deformed.	First established for dairy cattle by Berger (Berger, 1994)
Multiple pregnancy	A scale with 3 steps: 1-single; 2-twin; 3-triplets.	First established for dairy cattle by Berger (Berger, 1994)
Gestation length	The interval, in days, from the last mating date to calving.	Heritability of 0.331 ± 0.026 in Asturiana de los Valles (Cervantes et al., 2010). Heritability of Gestation length = 0.35 in Aberdeen Angus (Interbull Centre, online).

Heritability estimates for calving ease, calf survival and gestation length are generally low to moderate, with variability across different studies (Cervantes et al., 2010; Eriksson et al., 2004). This variability is largely attributed to differences in the statistical models used for estimation of heritability (Tomka, 2018). Nevertheless, selection programmes for these traits have been shown to produce significant improvements in future generations (Bennett et al., 2021). In addition, the genetic variability at the basis of traits such as calving ease, calf size at birth and gestation length is influenced by both the genetic variability of the calf (direct effect) and the genetic variability of the dam (maternal effect). Genetic correlations are approximately 0.30 between calving ease and gestation length (considering both maternal and direct effects), and around 0.70 between calving ease and calf survival (for both maternal and direct effects), suggesting that selecting for calving ease would produce benefits also for the other traits (Cervantes et al., 2010). However, some studies have found negative genetic correlations between the direct and the maternal effects of calving and birthing, implying that sires with excellent genetic merits for both calving and birthing ease could be hard to find (McHugh et al., 2014 retrieved from EFSA Public call for evidence 2024 - PC-0742 17 - IFA). The dual genetic influence of these traits underscores the importance of selective breeding in managing and improving these traits selecting for both the direct and maternal effects.

To the EFSA experts' knowledge, there are no published studies specifically looking at the risks or welfare consequences of repeated C-sections in cattle. Some authors recommend avoiding repeating C-sections on the same animal and suggest focusing on selecting for ease of calving instead (Hoeben et al., 1997). Studies on humans found that repeated caesarean births are associated with increased risk of complications such as bleeding, infection, damage to the bladder and bowel, and deep venous thrombosis (as reviewed by Dodd et al., 2017). As the number of caesarean sections a woman underwent increased, the risk of adhesions also increased (as reviewed by Rashid & Rashid, 2004; Uygur et al., 2005; Dodd et al., 2017). Comparing groups of women who had only one caesarean birth with women who had multiple caesarean births, the presence of dense adhesions and bladder injury were higher in women who had multiple C-sections (Choudhary et al., 2015; Sobande & Eskandar, 2006; Uygur et al., 2005). In sum, repeated C-sections carry risks for the health of the cow, inferring from literature available on humans.

3.7.5.2 | *Animal categories*

Dystocia and C-section affect suckler heifers/cows and calves, influencing their welfare and survival. The traits used to reduce the incidence of dystocia and C-section and mitigate their welfare effects are also used for sire selection.

3.7.5.3 | *Current breeding practices*

Genetic selection strategies to reduce calving difficulty focus on selecting sires using traits such as calving ease and birthing ease, calf birth weight and size, stillbirth, calf survival and calf weaning weight. The goal is to enhance calving ease by breeding dams with improved rear body and pelvic conformation and by producing calves that are smaller at birth but exhibit substantial growth during the post-natal period. These selection strategies become even more important in beef compared to dairy cows, because surveillance of calving may be more difficult when the cows are kept in extensive conditions.

For the main beef cattle breeds reared in the EU, the traits' selection objectives, their assessment, statistical modelling and some genetic parameters have been publicly shared for Ireland, Estonia, Germany, Sweden, UK, France, Slovenia and Czechia through Interbull webpage (Interbull Centre, online).

Selection for calving ease is a major objective for some European autochthonous breeds. For example, the selective breeding programme for the Piedmontese breed developed by the Italian National Association of Piedmontese Breeders has developed two distinct indices: the Meat Index ('Indice Carne'), focused on selecting breeding stock that produces offspring intended for fattening and slaughter, and the Breeding Index ('Indice Allevamento'), aimed at selecting breeding stock for female replacements (ANABORAPI, online a). Both indices attribute equal importance to growth potential and muscularity, contributing 20% and 25% to the total value of the Meat Index and Breeding Index, respectively. However, the indices differ in the weight assigned to birthing ease and calving ease traits. The Meat Index places a higher emphasis on birthing ease, which accounts for 36% of the total index value and calving ease accounts for 12%. Conversely, the Breeding Index assigns 18% of its total value to birthing ease and 30% to calving ease.

Similarly, Belgian Blue herds are currently selected for calving ease, and in particular some associations and companies, such as the CRV, have created genetic indexes to estimate the percentage of problem births when a Belgian Blue sire is mated with Holstein cows (CRV, 2022). According to a 2019 report from Wageningen University, genetic selection is projected to increase the rate of natural births to 50% in selected Red and White Belgian cows and 60% in selected Belgian Blue cows by 2035 (EFSA Public call for evidence, 2024 – PC-0742 18 – Netherlands Food and Consumer Product Safety Authority). Furthermore, following a public debate in the late 90ies, the Danish Blue White Belgian association (in the meantime the breed has been renamed to Danish Blue) was able to reduce the reported rate of C-sections of more than 50% to slightly less than 10%. This was achieved by selecting sires known for less birth difficulties in their offspring and adaption of the diets of in-calf animals to be leaner at parturition (Sandøe et al., 2018).

The improvements in the ease of calving and calf survival through genetic selection have been documented in a recent study by Bennett et al. (2021). In this study, heifers with higher breeding values for calving ease were compared with control heifers selected for average birth weights across seven populations (Angus, Charolais, Gelbvieh, Hereford and three composite crossbreed populations). Heifers selected for calving ease belonging to these seven populations had lighter calf weight at birth by 2.6 kg when compared to control heifers belonging to the same breeds, though calves' weights were not significantly different from control heifers at weaning. These select line heifers exhibited significantly shorter hip height, lighter mature weights and greater calving success by the second parity. Their calves were born earlier, with lighter weights and required less assistance. Furthermore, the study found that select line heifers had fewer assisted calvings (7 percentage points) and higher calf survival rates to weaning (1.3 percentage points) during their first parity, with negligible differences compared to control lines in later parities. Over their herd life, select line cows weaned more calves, had fewer calving assists and their calves exhibited greater weight gain to weaning. Although select line cows were lighter at maturity, their marketable cow weight was nearly identical to control lines, indicating no significant unfavourable effects. The select heifer system resulted in significantly greater weaned calf weight per heifer of about 55 kg (due to higher calf survival and greater calving success by the second parity. The authors strengthened how these results support the positive outcomes of genetic selection for calving ease in beef cattle, demonstrating improvements in both calving ease and overall productivity without detrimental effects on other performance traits (Bennett et al., 2021).

3.7.5.4 | *Welfare consequences*

Dystocia can significantly impact the health and welfare of both the suckler cow and calf, potentially endangering their lives (Boakari & Ali, 2021). A C-section is a surgical intervention employed to mitigate the risks associated with dystocia. However, it carries its own welfare implications on the suckler cow, especially when performed as an emergency procedure (Newman & Anderson, 2004). As reported for the welfare consequences of poor maternal ability (Section 3.7.6.4), most publications on the negative effects of difficult calving and poor maternal ability studied dairy breeds. However, given the common physiological basis, it is reasonable to consider the welfare consequences identified in dairy cows and calves as comparable to those in beef cattle breeds. The general decision whether to carry out dystocia and C-sections may lead to differing WCs in relation to **'handling stress'**, **'soft tissue lesions and integument damage'**, **'muscle disorders'**, **'prolonged hunger'**, **'prolonged thirst'** and **'reproductive disorders'** for suckler cows and in relation to **'gastro-enteric disorders'** and **'respiratory disorders'** for calves. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3.

3.7.5.4.1 | *Welfare consequences of dystocia and C-sections in suckler cows*

Dystocia is recognised as one of the most painful conditions for cows, causing intense pain, potentially leading to suffering (Barrier et al., 2012; Kielland et al., 2009). In addition to the pain during the active labour phase, the physical trauma to the reproductive organs during a difficult birth, as well as the surgical intervention of a C-section, can lead to severe pain. Pain in particular can occur during and after dystocia and when C-section is performed in emergency (EFFAB confirmed this by email on 31 January 2024) (EFFAB, 2024). Emergency C-sections are at risk of being more painful than planned ones due to the urgency of the situation, which can limit pain management and lead to greater tissue trauma and subsequent pain. Cows can be already in labour, leading also to higher stress and pain. Based on surveys performed in 2021 on US veterinaries, 76% of them declared to use analgesia (Non-Steroidal Anti-Inflammatory Drugs) when performing C-sections (Robles et al., 2021). However, several publications suggest that analgesia should be administered approximately 10 min before C-section, as cows that are not treated with analgesia show behavioural patterns indicating pain after surgery (Kolkman et al., 2010 retrieved from EFSA Public call for evidence 2024 – PC-0742 18 – Compassion in World Farming Brussels (CIWF EU); Barrier et al., 2014 retrieved from EFSA Public call for evidence 2024 – PC-0742 18 – Compassion in World Farming Brussels (CIWF EU); Mauffré et al., 2021). The practice of routine C- sections is also associated with the use of antibiotics in order to limit the risk of post-surgical infection leading to further health issues (De Coensel et al., 2020 retrieved from EFSA Public call for evidence 2024 – PC-0742 18 – Compassion in World Farming Brussels (CIWF EU)).

In case of human intervention, the increased handling necessary for ensuring cows' and calves' survival during dystocia and C-sections, can be a substantial source of stress for cows, causing 'handling stress' (Barrier et al., 2012). Dystocic calvings and C-sections cause 'soft tissue lesions and integument damage' resulting in pain. Injuries to the pelvic region or limbs during difficult calvings, as well as post-surgical pain, can significantly impair mobility in cows. The injuries and physical exhaustion accompanying difficult calvings can cause 'muscle disorders', interfering with the cow's ability to eat and drink normally, determining 'prolonged hunger' and 'prolonged thirst'. It is likely that such effects can be mitigated with post-surgical pain management. Dystocia and emergency C-sections increase the risk of infections, including metritis and peritonitis, and long-term reproductive disorders, potentially affecting future fertility and calving performance (Svensson et al., 2006; Lyons et al., 2013 retrieved from EFSA Public call for evidence 2024 – PC-0742 18 – Compassion in World Farming Brussels (CIWF EU)). Other reproductive issues that can result from C-sections include reduced fertility due to uterine adhesions affecting the ovary or uterine tube, hindering uterine involution (Vermunt, 2008). Scar tissue formation within the uterine wall can increase the risk of abortion in subsequent pregnancies by limiting uterine expansion and/or hindering fetal nutrition.

3.7.5.4.2 | *Welfare consequences of Dystocia and C-sections on calves*

Dystocia and C-sections also have profound welfare consequences for calves, influencing their immediate survival and long-term health. Most of these welfare consequences have been discussed in Section 3.7.6.4 on welfare consequences of poor maternal ability.

Calves born through distocya or C-sections can experience significant pain due to physical trauma during delivery and the handling involved in surgical procedures. In the worst cases, distocya may also result in the death of the calf (Boakari & Ali, 2021). Furthermore, long, difficult calvings and C-sections are predisposing factors for poor maternal ability (see Section 3.7.6.4 on WCs of poor maternal ability) and lower quality colostrum (Tuska et al., 2021). Belgian blue cows undergoing longer duration C-sections were found to produce colostrum in lower quantities and poorer in nutrients (Tuska et al., 2021). This could potentially impact calf survival rate and growth, predisposing the calves to greater risks of **'gastro-enteric disorders'** and **'respiratory disorders'**.

3.7.5.5 | *Preventive and mitigating measures*

Calving ease traits are currently a focus of genetic selection in breeds known for high muscle development. This has been effective in reducing the incidence of dystocia in some populations (Bennett et al., 2021). However, there is a lack of recent data on the trends of dystocia and C-sections in breeds with high incidences of dystocia, such as the Belgian Blue.

Given the association between dystocia and hypermuscularity in DM breeds, measures to mitigate WCs of hypermuscularity (see Section 3.7.4.5) can also be relevant in reducing the need for C-sections.

Selection for appropriate pelvic dimensions could further accelerate the genetic progress for calving ease, and this trait has been found to have moderate to high heritability estimates in beef cattle breeds (Kolkman et al., 2012 retrieved from EFSA Public call for evidence 2024 – PC-0742 18 – Belbeef).

The accuracy of the estimation of genetic merit of sires and dams may be further improved with the application of sensors and precision livestock farming tools to record calving duration and difficulty also in animals kept on pasture (Aquilani et al., 2022).

Another way to enable a faster improvement of calving ease would be to identify at DNA level the gene variants that regulate the development of the maternal birth canal, and those that lead to lower birth weights in calves without impairing their subsequent growth. However, there is little evidence on the extent that selection for lower birth weights may affect the vitality of the calves. A genome-wide association study (GWAS) performed by Pausch et al. (2011) provided evidence for two significant quantitative trait loci (QTLs) on bovine chromosomes 14 and 21 that collectively explain at least 10% of the genetic variation in calving ease in the German Fleckvieh breed. These QTLs also influence stillbirth rates and postnatal growth traits, such as daily gain and body size. The genomic region on chromosome 14 identified by Pausch et al. (2011) corresponded with the results reported in other studies (Kneeland et al., 2004). In particular, Pausch et al. (2011) identified an association peak for calving ease in a mutation on gene *Ribosomal protein S20* (*RPS20*). This mutation is located in a polyadenylation site, potentially altering mRNA stability and expression, leading to differences in fetal growth rates. This QTL region on chromosome 14 has been reported in other studies for its association with the growth hormone and insulin receptor signalling pathways (Mota et al., 2020). The other QTL on chromosome 21 also involved genes related to ribosomal assembly, suggesting a possible common mechanism influencing fetal growth (Pausch et al., 2011).

The integration of genomic selection with the use of GWAS with traditional breeding approaches holds promise for mitigating dystocia in beef cattle (Purfield et al., 2015; Institut de l'élevage et al., 2024). The identification of genetic markers can accelerate the selection process by providing a more precise estimation of the genetic merit of heifers and young bulls for calving ease (Silva et al., 2020). This advancement would eliminate the necessity to wait for calving difficulty records from their daughters or through subsequent parities, thereby enhancing the efficiency and effectiveness of breeding programmes.

3.7.5.6 | *Conclusions on dystocia and C-section*

1. Dystocia may have serious consequences on cow welfare (e.g. soft tissue lesions and integument damage, handling stress, prolonged hunger) (certainty >90%) and calf welfare (e.g. increased mortality rate, gastro-enteric disorders, respiratory disorders) (certainty >90%).
2. Planned C-section is a commonly used surgery to minimise the risks of dystocia and its effects on cows and calves. This procedure is associated with negative welfare consequences for cows (certainty >90%).
3. It is likely that repeated C-sections lead to a higher risk of bleeding, infection and adhesions based on findings from human studies (certainty >50%).

4. Selection for calving ease, reduced calf size and weight, and reduced stillbirths is currently implemented in beef cattle. Genetic improvement has been achieved by these selection strategies in most breeds (certainty > 90%).
5. Including heifers' and dams' pelvic conformation in the selection traits leads to a faster genetic improvement (certainty > 66%).
6. The identification of candidate genes and markers associated with calving ease and dam pelvis morphology allows for a more accurate estimation of breeding values in beef cattle sires and dams.

3.7.5.7 | *Recommendations on dystocia and C-section*

1. To avoid the welfare consequences of dystocia and C-section, animals that carry the DM homozygous genotype should not be breds.
2. Selection of beef cattle breeds for calving and birthing ease, and reduced stillbirths should be further promoted.
3. Inclusion of the heifers' and dams' pelvic conformation in the selection traits should be emphasised to achieve a faster genetic improvement.
4. It is recommended to improve estimation of breeding values in beef cattle sires and dams by identifying candidate genes and markers associated with calving ease and dam pelvis morphology.

3.7.6 | Maternal ability

3.7.6.1 | *Description of the trait*

'Maternal ability' in beef cattle refers to the suite of multiple traits that influence a dam's capacity to successfully form a cow-calf bond, including the nurturing and rearing of the offspring, directly impacting the welfare of both dam and calf. The cow cares for her calf through social interactions, nurturing and sucking, calf-directed behaviours (e.g. licking and sniffing, as well as other contact behaviours), and protection from danger or predation (Nevard et al., 2023). These behaviours and provisions depend on the cow's capacity and motivation to devote adequate time, energy, and resources to protecting and rearing her offspring.

Maternal ability is currently composed of a set of traits that includes calving ease, maternal behaviours, milk production and other traits indicating the reproductive efficiency of the dam. These traits can be assessed using indicators such as calving ease score, calf birth weight, calf weaning weight, cow weight at weaning and survival rate of the calves born from a dam (Mwansa et al., 2002). Some of the indicators are time-consuming to record (e.g. observing maternal behaviour to score calving ease), making them difficult to implement for genetic selection. Some of the traits included in maternal ability can be assessed indirectly through other measures that are strongly correlated with the trait of interest. For example, the selection schemes are currently using calving ease, birth weight and weaning weight to compose the traits 'calving ease' and 'birthing ease'. As described in the section 'dystocia and caesarean section', 'Birthing ease' evaluates how the conformation of the calf at birth affects calving problems; in contrast, 'calving ease' assesses the conformation of the dam's birth canal and the overall suitability for unproblematic calving. In fact, although calving ease is more closely related to the incidence of calving assistance, dystocia and C-sections, the current selection for calving ease also has a direct effect on the dams' maternal ability. The selection for calving ease can mitigate negative consequences for both the mother and

TABLE 12 List of the suite of multiple traits commonly included in the term 'maternal ability' and their indicators used in studies considering beef cattle breeds.

Trait	Description	Indicator
Calving ease (see Section 3.7.5).	The ability of a dam to calve without assistance from veterinarians or operators.	Direct indicator: Calving ease score (from 1 or 0-no assistance needed and fast birth, to 4 or 5- C-section and abnormal presentation of the calf) (Saad et al., 2020). Indirect indicator: Calf birth weight (Saad et al., 2020), also used for 'birthing ease' trait (see Section 3.7.5).
Maternal behaviours	The expression of maternal behaviours, consisting of prepartum behaviours, placentophagia, cow-calf bonding behaviours, protective and udder display behaviours.	Direct indicators: observational studies, proximity loggers (Kour et al., 2021; Sandelin et al., 2005). Indirect indicators: calf survival rate, calf weaning weight.
Milking ability	The ability of a cow to properly nurture the calf.	Direct indicators: Udder and teat morphology and functionality, colostrum quality and milk production (Cortés-Lacruz et al., 2017; Paranhos da Costa et al., 2023). Indirect indicators: calf weaning weight, calf survival rate (Cortés-Lacruz et al., 2017).
Maternal reproductive efficiency	The ability of a cow to keep good reproductive efficiency without compromising her health and longevity.	Direct indicators: age at first calving, calving interval, dam weight at weaning (MacGregor & Casey, 1999).

calf, such as pain, lacerations, prolapses, haemorrhages and lack of maternal behaviours in cows (Bennett et al., 2021). For instance, beef cattle breeds in Ireland selected for maternal ability resulted in the reduction of dystocia and calving interval (Twomey et al., 2020). For a review of dystocia and C-section, see Section 3.7.5.

A list of the traits included in maternal ability and the relative indicators is reported in Table 12.

At present, maternal ability is mainly targeted through phenotypes that are only in part determined by the mother (and thus related to maternal ability). For example, the weaning weight of the calves has two main genetic (in addition to environmental) determinants: the genetics of the calf (e.g. the growth potential that largely depend on the sire) and the maternal ability of the dam (e.g. how much the mother's care of the calf and milk production allow the calf to grow). Part of the strategy for more efficient selection is to estimate the proportion of phenotypic variability that is determined by maternal genetics (McHugh et al., 2014; Mwansa et al., 2002; Phocas & Laloë, 2004; Roughsedge et al., 2005).

Maternal ability is therefore a complex trait (Walmsley et al., 2016), determined by many *loci* (Purfield et al., 2015) and whose expression depends on environmental factors. Bovine maternal behaviour is indeed influenced by various factors that are not genetic, including age, experience, parity and general management practices (reviewed in Nevard et al., 2023), or a mix of both genetic and management factors (e.g. dam's and calf general body condition) (Stěhulová et al., 2013). For example, calves born from primiparous dairy cows are at a significantly higher risk of mortality during the first 5 months of age compared to calves born from multiparous dairy cows (Mõtus et al., 2018). Possible factors associated with this effect in primiparous cows include lower milk production during the first lactation (Mummed, 2012), lower levels of maternal antibodies in colostrum (Conneely et al., 2013) and less experience as a mother (Nevard et al., 2023). Lower levels of maternal antibodies in the colostrum of primiparous cows were reported by Conneely et al. (2013) in dairy cows, yet it can be assumed that a similar association exists in beef cattle as well.

Despite the complexity of the trait, the genetic basis of maternal ability has been demonstrated in Gasconne cows (Stěhulová et al., 2013), where maternal behaviour, from day 3 to day 30 post-natal was consistent across different parities. However, variations were observed due to the body and health condition of both the mother and calf, as well as the sex of the calf (Stěhulová et al., 2013). Nevertheless, it is considered that direct comparison between different studies is difficult due to the different approaches to measure maternal ability.

The heritability estimates for different components of maternal ability vary widely. While traits like milk production and calving ease typically exhibit moderate to high heritability (ranging from 0.30 to 0.60), estimates for maternal behaviour are considerably lower in recent studies, around 0.10 (Michenet, Saintilan, et al., 2016). This lower heritability of maternal behaviour and the problems involved in its measurement, represent challenges for its inclusion in the selection schemes.

3.7.6.2 | *Animal categories*

Maternal ability is a trait of suckler cows, but the WCs primarily affect calves and to a lesser extent the suckler cows themselves.

3.7.6.3 | *Current breeding practices*

In most beef cattle breeds bred in the EU, selection for maternal ability is carried out by considering indices consisting of several traits to which different weights are associated. However, most beef cattle selection schemes only indirectly select for dams' maternal ability by genetically selecting for higher pre-weaning daily weight gain of calves (Lopes et al., 2017) and calf weaning weight (Cortés-Lacruz et al., 2017; Dominguez-Castaño et al., 2021). Some selection schemes are also using calving ease score additionally to birth weight to compose the trait 'calving ease'.

For example, according to EFFAB (European Forum of Farm Animal Breeders) (2024), in France various beef cattle breeds (e.g. Aubrac, Salers, Bazadaise, Limousine, Charolaise, Rouge de Prés, Parthenaise, Gasconne des Pyrénées and Blonde d'Aquitaine) are selected according to composite indices including calving ease, calf weight at weaning, calf muscular development at weaning, calf bone development at weaning, calf bone density at weaning (EFSA Public call for evidence, 2024 – PC-0742 20 – EFFAB FABRE-TB). Sires and dams belonging to other European beef breeds, such as the Piedmontese breed, are also selected for calving ease and calf growth (ANABORAPI, online b).

3.7.6.4 | *Welfare consequences*

At birth, the calf relies on the cow for survival, especially in free-range farming systems where human supervision and intervention may be limited. Immediately after birth, it is crucial for the newborn to be cleaned from amniotic fluid and fetal membranes by the cow, and be stimulated to stand up and start to suckle to ingest colostrum (reviewed in Nevard et al., 2023). Delaying calf colostrum ingestion for 6 h after birth can reduce the effectiveness of passive immunity transfer from the dam to the calf (Godden, 2008; Svensson et al., 2006). Although direct studies linking low maternal ability with calf dehydration and related WCs are lacking specifically in beef cattle (McGee & Earley, 2019), it can be assumed that delayed or inadequate colostrum and milk intake can lead to the same significant welfare consequences as in dairy calves (McGee & Earley, 2019). A meta-analysis of over 10 studies has identified passive immunity transfer failure as a significant risk factor for mortality, bovine respiratory disease, diarrhoea, and overall morbidity in dairy and beef calves (Raboisson et al., 2016). Poor maternal ability can lead to the welfare consequences **'gastro-enteric disorders'**, **'respiratory disorders'**, **'metabolic disorders'**, **'umbelical disorders and hernias'**, **'prolonged hunger'**, **'prolonged thirst'**, **'predation stress'**, **'inability to**

perform sucking behaviour', **'separation stress'**, **'soft tissue lesions and integument damage'**, **'bone lesions (including fractures and dislocations)'** and **'cold stress'**. No linked welfare consequences were identified in this context. The definition of each WC is available in Section 2.3.

Most evidence on links between lower beef cattle maternal ability and increased welfare issues in their calves comes from studies on dairy calves. However, studies on dairy calves can be informative, as the physiological basis is expected to be similar (McGee & Earley, 2019).

3.7.6.4.1 | *Gastro-enteric disorders and respiratory disorders*

Although insufficient passive immunity through low antibody levels in colostrum has been linked to respiratory tract disorders (Wittum & Perino, 1995) there is little evidence of a direct relationship between inadequate passive immunity transfer and the risk of diarrhoea without comorbidity (Mõtus et al., 2018). However, dairy calves with diarrhoea are more likely to develop respiratory disorders, suggesting the presence of common predisposing factors between respiratory and gastro-enteric disorders such as inadequate passive immunity transfer (Svensson et al., 2006). Additionally, the importance of timely colostrum intake for the development of the gastro-intestinal tract in calves is well known, as reviewed by Ontsouka et al. (2016). It is therefore highly likely that delayed colostrum intake or poor-quality colostrum intake predisposes calves to dysbiosis and diarrhoea. A study on dairy calves found that inadequate immunity transfer increased the predicted risk of morbidity by 30% compared to calves with excellent immunity transfer (Urie et al., 2018).

3.7.6.4.2 | *Metabolic disorders*

Along with gastro-enteric and respiratory disorders, metabolic disorders are listed by farmers as one of the primary causes of mortality in dairy calves aged between 4 and 10 days (Mõtus et al., 2018). Delays in colostrum intake affect the metabolic status of the calves (Rauprich et al., 2000), as colostrum composition changes greatly during the first hours, and as time passes, udder secretion tends to become more and more similar to milk (McGrath et al., 2016). Dairy calves that are fed high-quality colostrum, or colostrum secreted within the first day after calving, have been found to exhibit a body temperature in the upper normal range (De Paula et al., 2019; Rauprich et al., 2000). Additionally, they have higher plasma concentrations of proteins, urea, γ-glutamyl transferase, triglycerides, cholesterol and phospholipids (Rauprich et al., 2000), all of which are associated with a more active metabolism and a healthier calf.

3.7.6.4.3 | *Umbilical disorders and hernias*

Prompt intake of high-quality colostrum is crucial to reduce the risk of mortality and infections (Raboisson et al., 2016), including navel infections (omphalitis) in calves during their first week of life. Untreated navel infections can lead to sepsis and death. Omphalitis diagnoses in dairy breeds are more common in males than in females (Cuttance et al., 2017; Dachrodt et al., 2021), especially during the summer months (Dachrodt et al., 2021) and often coincide with diarrhoea and respiratory disorders (Dachrodt et al., 2021). Prolonged and painful calving is a known risk factor for poor maternal behaviour and delayed cow-calf bonding (Barrier et al., 2012).

3.7.6.4.4 | *Prolonged hunger and prolonged thirst*

Delayed or inadequate colostrum and milk intake can cause nutrient deficiencies, dehydration and weakness. Dehydration and malnutrition can, in some cases, lead to the death of calves, especially in farming conditions where animal inspection is less frequent and animal handling opportunities are limited.

3.7.6.4.5 | *Predation stress*

Mismothering and abandoning calves are risk factors for calf mortality (Brown et al., 2003; Bunter et al., 2014), in particular in harsh environments (hot or cold). When herds coexist in an environment with predators, temporary abandonment of calves by the mothers can more easily occur as reported in a study with extensively managed Herd of Brahman heifers with an increase of calves' deaths due to delayed colostrum intake (Brown et al., 2003). A temporary abandonment may increase the risk of predation for calves born in extensively-managed herds.

3.7.6.4.6 | *Inability to perform sucklng behaviour*

It is important to consider that during the first week of life, calves left with their mother will consume between 7 and 12 L of milk per day, depending on their breed and weight at birth (Daros et al., 2014; Santo et al., 2020; Waiblinger et al., 2020) and the milk yield of the mother cow. Delaying the calf's access to milk from the dam can result in frustration due to the inability to express natural sucking behaviour as well as hunger and dehydration.

3.7.6.4.7 | *Separation stress*

Abandonment by the mother or irregular maternal behaviours can cause separation stress in calves, as they strongly depend on contact with the mother for survival. Gene expression measured in blood gathered from calves from birth to 7 days of age also suggests that separation from the mother and isolation can activate a molecular response in the genes involved in inflammatory processes (Surlis et al., 2018).

3.7.6.4.8 | *Soft tissue lesions and integument damage and bone lesions (including fractures and dislocations)*

Trauma or bone fractures can occur for various reasons (Gangl et al., 2006), such as distress or sudden movements in cows trying to escape from human handling or kicking to avoid contact with the calf. Calves born from dams with poor mothering ability may be more prone to soft tissue lesions and bruises. In addition, aggressive behaviours in dams may lead also to bone fractures in such calves.

3.7.6.4.9 | *Cold stress*

After calving, the mother licks away the membranes and allows the calf to rest close to her. Depending on the weather conditions, lack of motherhood might result in cold stress for the calf.

3.7.6.5 | *Preventive and mitigating measures*

Genetic selection and breeding schemes aimed at enhancing traits associated with maternal ability in beef cattle are effective tools to prevent or mitigate the WCs for calves that result from dams with poor or lacking maternal ability. Due to the multifactorial and complex nature of the traits that define maternal ability in cows (Nevard et al., 2023), selecting for improvements in all aspects of calving, lactation and behaviour before, during and after calving that foster calf health, survival and growth can be challenging. As with other traits that are already subject to selection in livestock, there are direct and indirect strategies that can be employed to improve maternal ability. Direct strategies aim to improve the trait of interest, such as the udder and teat conformation or the expression of maternal behaviours; indirect strategies aim to improve traits that can influence the establishment of poor maternal behaviour, such as calving ease (see Section 3.7.5).

Udder and teat morphology directly influence calf sucking behaviour and milk production, ultimately influencing also calf growth and survival (McGee & Earley, 2019; Wittum & Perino, 1995). These traits have been selected for improving milking operations in dairy cows for many years, favoured by their moderate to high heritability values. Similarly, the morphology of udders and teats in beef cattle breeds also has moderate heritability estimates, ranging from 0.14 to 0.49 (Bradford et al., 2015; Bunter & Johnston, 2013; Devani et al., 2019). Moreover, it can be objectively measured (Devani et al., 2019). However, from the information retrieved, at present schemes including this trait for the selection of beef cattle breeds were not found.

It has been suggested that selecting for behaviours associated with enhanced maternal ability could be beneficial, but it has not been implemented. Maternal ability and its associated behaviours have a genetic component, albeit low (around 0.10) heritability (Michenet, Saintilan, et al., 2016). Additionally, objectively and efficiently measuring such behaviours is challenging. Currently, these behaviours are typically measured through direct observation. However, this method is not feasible for large-scale measurements required to improve this trait. Additionally, beef cattle breeds are often raised on pasture and calving often occurs on pasture where it is challenging to be observed. However, a more feasible approach may involve the use of precision livestock farming technologies, such as proximity loggers and other sensors (Handcock et al., 2009). These sensors can measure the frequency and duration of contacts between the mother and the calf, even in free-ranging farming systems. This would make it possible to record traits associated with maternal behaviours on a large number of dams and implement selection schemes also for these traits.

Selecting for traits linked to maternal ability could also lead to an increase in the expression of maternal defensive aggression towards handlers and operators (Turner & Lawrence, 2007). Maternal defensive aggression is a heritable trait, with partly low heritability. Values from 0.06 (Turner & Lawrence, 2007), 0.09 (Morris et al., 1994) and 0.42 in Simmental (Hoppe et al., 2008 retrieved from EFSA Public call for evidence 2024 – PC-0742 21 – Landwirtschaftskammer Nordrhein-Westfalen) have been reported. The variability in heritability is linked to the populations studied and the lack of consistency in evaluation protocols. Environmental factors strongly influence the trait, as evidenced by the low repeatability of the trait among subsequent parities for the same dams (ranging from 0.09 in Turner and Lawrence (2007) to 0.20 in Morris et al. (1994)). Nevertheless, Turner and Lawrence (2007) postulate that its heritability is sufficiently high to justify the development of a protocol for evaluating this behaviour and to include it in selection schemes. This would allow for the selection of animals that maintain good maternal ability without exhibiting aggression towards humans.

Currently, most beef cattle selection schemes indirectly select for dams' maternal ability by genetically selecting for higher calf weaning weight (Cortés-Lacruz et al., 2017; Dominguez-Castaño et al., 2021) and pre-weaning daily weight gain (Lopes et al., 2017). Calves that reach a higher live weight at weaning are assumed to have been raised by mothers with better maternal ability. However, selection for weaning weight without considering the maternal and calf genetic components may have unintended consequences. Direct weaning weight mainly represents the genetic merit of the calf to achieve a good weaning weight, while the maternal component of weaning weight represents the genetic merit of the dam to facilitate the calf in achieving a good weaning weight, and it reflects also cow's milk yield (McHugh et al., 2014). Therefore, selecting for weaning weight without considering the maternal components of this trait may slow the improvement in cows' maternal ability. Cortés-Lacruz et al. (2017) pointed at unintended consequences when only using weaning weight for selection for maternal ability and suggested to also include milk yield measured by milking at 150 days after parturition in a combined breeding index.

It should also be considered that negative genetic correlations between some of the traits of interest and production related traits exist. The results reported by Twomey et al. (2020) and by Berry et al. (2016) indicated that the selection of sires and dams for productive performances would decrease the reproductive efficiency and maternal traits (Berry et al., 2016; Twomey et al., 2020). This effect is caused by the adverse associations between many of the female-specific traits and the productive traits included in breeding indices (Twomey et al., 2020). However, genomic selection is seen as a solution that could avoid the negative effects of genetic correlations existing among traits. Similarly to what happened in dairy cattle (Weller et al., 2017), so far there has been a growing trend of studies aimed at identifying genes and mutations associated with maternal ability at the DNA level in order to implement genomic selection schemes in beef cattle breeds. The ultimate goal of these studies is to identify a panel of molecular markers that can be used to select animals with the most favourable combinations of variants for maternal ability. Once DNA variants associated with maternal ability traits have been identified, breeders can select animals with favourable genetic markers to propagate traits related to calving ease, maternal behaviours and milk production. This approach accelerates genetic progress in maternal ability, ensuring that future generations of beef cattle exhibit improved maternal traits without compromising other economically relevant traits.

One of the genomic regions identified so far from GWASs is a region on bovine chromosome 22 (*BTA22*), which contains genes associated with milk production and resistance to mastitis (Carvalho et al., 2020; Grigoletto et al., 2019). Other candidate genes associated with composition and production of milk, and ability to produce heavier calves were also found on bovine chromosomes 6, 14, 16, 21 and 26 (Carvalho et al., 2020; Michenet, Barbat, et al., 2016; Michenet, Saintilan, et al., 2016). These regions include genes encoding proteins that directly affect milk synthesis (such as the *SLC44A5* and *GBA3* genes) or that may have an effect on fetal growth (the *SLC13A4* gene, which expresses a protein that acts as sulfate carrier to the fetus during pregnancy) (Carvalho et al., 2020; Grigoletto et al., 2019). These regions harbour also genes that classified to be involved in chemical stimulus detection. Genes included in this group are many olfactory receptor genes (Carvalho et al., 2020; Michenet, Barbat, et al., 2016; Michenet, Saintilan, et al., 2016). These genes may be of particular interest because variations in their DNA sequence could affect the perception of odours. This is important because odours play a crucial role in cow-calf bonding and calf recognition, and therefore variation in odour perception may also affect cow-calf bonding (Griffith & Williams, 1996). Additionally, other genes associated with beef cattle maternal ability were identified as genes coding for cholinergic receptors (Carvalho et al., 2020). These genes respond to chemical or mechanical signals, enabling the transmembrane transfer of a cation through a channel that opens upon binding acetylcholine. Acetylcholine is a neurotransmitter that is activated in many situations, but it also plays a crucial role in establishing behaviours associated with maternal care in ruminants. In ewes, there is an increase in the release of acetylcholine and norepinephrine within the olfactory bulb at the time of parturition which appears to be more pronounced in multiparous mothers (Lévy et al., 1993).

The genetic schemes have allowed for an overall improvement of maternal ability and calf growth potential at weaning (Carvalho et al., 2020). Although the identification of genomic regions to be implemented in selection schemes is less developed in beef cattle breeds than in dairy cattle breeds, promising results have been obtained to date in GWASs. These results hold promise for the future implementation of genomic selection for maternal ability traits in beef cattle while overcoming current limitations of measurement of certain behavioural traits related to maternal ability.

3.7.6.6 | *Conclusions on maternal ability*

1. Maternal ability is a multifaceted trait that includes temperament (see Section 3.7.3), calving ease (see Section 3.7.5), maternal behaviours, milking ability and maternal reproductive efficiency.
2. Breeding for maternal ability mitigates the welfare consequences of poor maternal care or inadequate milk production (certainty > 90%).
3. Selection for maternal ability can lead to inadvertently selecting for increased maternal aggressive temperament, a trait with potentially negative implications for handler and calf safety (certainty > 50%).
4. Maternal ability includes several traits with a highly variable heritability, making selection challenging in case of low heritability. In addition, large-scale phenotypic assessment is poorly feasible, especially for behavioural measures.
5. Udder and teat morphology are associated with calf survival and growth rates. Even though these are moderately heritable traits, they have not been included in beef cattle selection schemes yet.

3.7.6.7 | *Recommendations on maternal ability*

1. Traits associated with maternal ability in beef cattle should be enhanced by selection schemes, using direct and indirect strategies. Direct strategies aim to improve the trait of interest, such as the udder and teat conformation or the expression of maternal behaviours. Indirect strategies aim to improve traits, such as calving ease, that can influence normal maternal ability and cow-calf bond.
2. The use of Precision Livestock Farming technologies to record traits associated with maternal behaviours should be considered in order to improve the implementation of these traits in the selection schemes.
3. A harmonised protocol for evaluating maternal defensive behaviour should be developed.
4. Identification of molecular markers that can be used in genomic selection to improve maternal ability traits in beef cattle is recommended.

3.8 | Decision-making criteria for the euthanasia of cull cows kept for the production of beef

This chapter addresses a request received to identify decision-making criteria relevant for the euthanasia of cull cows kept for the production of beef. Thus, key decision criteria involved in culling decisions were delineated, without conducting a comprehensive risk assessment of the animal welfare implications associated with each step (for further information on the interpretation of this request, see Section 1.1.3 - Interpretation of the Terms of Reference).

In this opinion the term 'euthanasia' is not further used because an unanimous definition of euthanasia is lacking. The word 'euthanasia' originates from the Greek terms 'eu' (meaning 'good' or 'well') and 'thanatos' (meaning 'death') (AVMA, 2020). The American Veterinary Medical Association (AVMA) does not directly define euthanasia but states that 'the term is usually used to describe ending the life of an individual animal in a way that minimises or eliminates pain and distress. A good death is tantamount to the humane termination of an animal's life' (AVMA, 2020). According to the WOAH, euthanasia is 'the act of inducing death using a method that causes a rapid and irreversible loss of consciousness and death with minimum pain and distress to the animal' (WOAH, 2018). Other authors emphasise that euthanasia refer to ending suffering (Rollin, 2006). In this opinion the more general term 'killing' will be used. This is in line with the approach taken in previous EFSA scientific opinions (EFSA AHAW Panel, 2020, 2025). Killing also includes 'slaughter' which refers to killing for human consumption which can be carried out in the abattoir or on-farm. It also includes 'emergency killing' which is regulated by 'Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing' and refers to the 'killing of animals which are injured or have a disease associated with severe pain or suffering and where there is no other practical possibility to alleviate this pain or suffering'. In these instances, killing should be done as soon as possible.

It is important to emphasise that this phase of life of cows – after they are removed from the productive herd – is associated with particular and important welfare risks related to factors such as pre-existing health and welfare issues, WCs of transport (EFSA AHAW Panel, 2022b), WCs of keeping a cow for fattening, Wcs of emergency killing, or delays between decision making and taking actions. The extent of these risks for welfare is often largely unknown and this constitutes an important knowledge gap requiring further research. Resources related to these aspects known to the EFSA experts are listed here, but an appraisal of the extent to which they are based on scientific evidence was not carried out.

3.8.1 | Culling reasons

In this Scientific Opinion the term 'cull cow' refers to dairy and suckler cows which are no longer considered fit for their primary production purpose (milk, calves). As a consequence, these animals may be sent to slaughter, kept for fattening or killed. Although it is acknowledged that in some instances cows may be culled for involuntary reasons (as discussed in more detail below), only cows intentionally removed from the productive herd were considered in the context of this assessment. Culling reasons vary and more than one can be present at the same time. The reasons for culling dairy or suckler cows can be referred to as voluntary or involuntary (Cockram, 2021; Fetrow et al., 2006 ; Hadley et al., 2006). Voluntary culling reasons are due to economic and managerial decisions, and include low milk production, cow aggression and advanced age; involuntary culling reasons are due to unplanned events related to the health status of the cow, and include injury and health issues such as lameness, mastitis and other udder problems (Cockram, 2021; Fetrow et al., 2006; Hadley et al., 2006). In the scientific literature, infertility can be considered both as a voluntary (Cockram, 2021) and as an involuntary reason to cull (Fetrow et al., 2006; Hadley et al., 2006). However, this distinction between voluntary and involuntary culling does not always occur. The main culling reasons reported voluntary by farmers to the Danish Cattle Database for cows transported to slaughter, containing data about Danish dairy cows culled in 2020 and 2021, were reduced milk production (29%), reproductive issues (25%) and udder health (16%), while mentioned reasons for on-farm euthanasia were accidents (29%), locomotor disorders (18%) and metabolic/digestive disorders (17%) (Thomsen & Houe, 2023). Infertility and reproductive problems were also the most prevalent (40%) culling reasons in 2015 mentioned in a dataset from the Polish Federation of Cattle Breeders and Dairy Farmers (Adamczyk et al., 2018). According to data collected from Spanish dairy farms between 2006 and 2016, reproductive problems were the most frequent cause of culling (30%), followed by low production (23%) (Armengol & Fraile, 2018). No specific data on culling reasons of suckler cows were found; however these are probably similar to those for dairy cows, except that mastitis and lameness tend to be more common in dairy cows as reasons to cull (EFSA, 2025).

Following the decision to remove the cow from the productive herd, the farmer may opt to sell the cull cows immediately to a slaughterhouse or to auction markets (given the cow's fitness for transport (Cockram, 2021)), or they can opt for drying off or reducing milking frequency and fattening the cows (Teagasc, 2022). Feeding cows for 60 days and drying them off following the decision to remove them from the productive herd, improved BCS, hock lesions and udder problems, and increased body weight, making the cows better fit for transport compared to cull cows sent directly to slaughter (Berdusco et al., 2024).

Transport of cull cows to slaughterhouses or markets can lead to various welfare consequences. Weak animals are at risk of falling and may struggle to regain footing, while those in poor body condition are more susceptible to fasting and cold exposure (EFSA AHAW Panel, 2022b). Transport up to 8 h worsened the conditions of cull cows in 411 cull cows transported to a slaughterhouse by truck in Denmark. The cows showed more or worse lameness, milk leakage and wounds than before being transported (Dahl-Pedersen et al., 2018). If these animals are not fit for transport and are without the prospect of recovery in a reasonable period of time, they should be killed on-farm as soon as possible (EFSA AHAW Panel, 2022b).

3.8.2 | Decision tree for cull cows used for the production of beef

The EFSA experts created a decision tree reflecting the relevant decision-making steps to consider in this context (Figure 9). The decision tree consists of five key questions that can guide the decision around the most appropriate course of action for each animal (indicated by red arrows in the decision trees of the examples provided below). The assumptions of the decision tree are that the cow must leave the productive herd and that the cow will be used for beef if possible, i.e. she will not be used for another purpose than beef on the home farm or a different farm, such as a nurse cow for dairy calves.

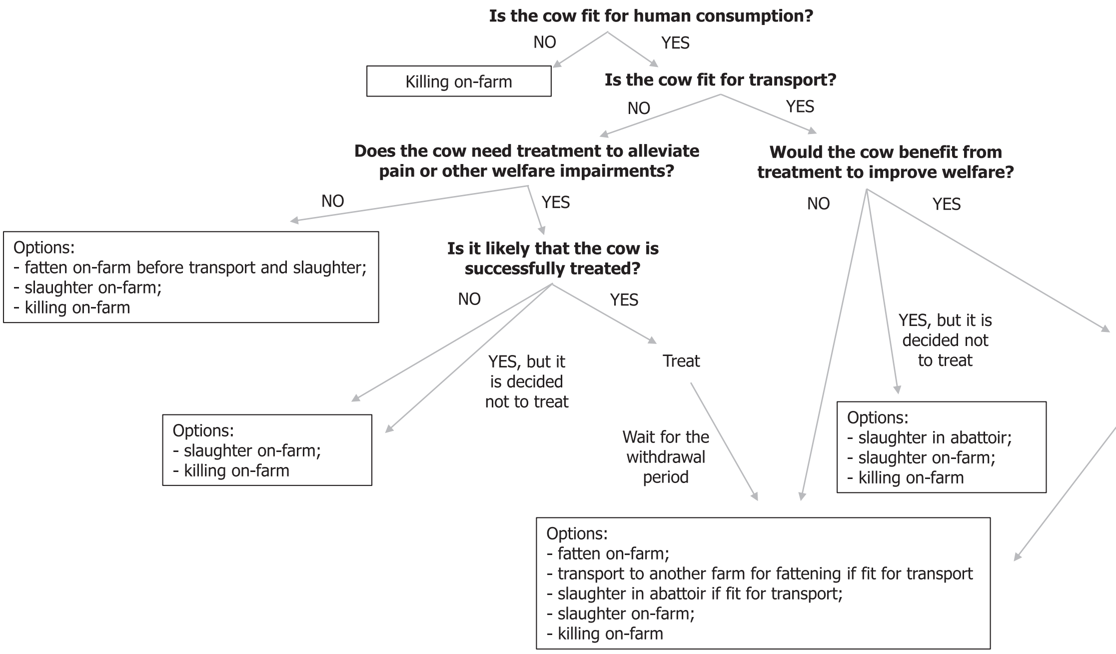

FIGURE 9 Decision tree on cull cows to be kept for fattening.

Firstly, whether or not the cow is fit for human consumption guides the options available. One of the most common reasons for cows not being fit for human consumption is drug withdrawal periods. If this is the case, it may only be necessary to wait for this period to conclude before the animal is considered fit for human consumption. For those cows that are not fit for human consumption for other reasons (e.g. generalised infections with poor recovery prospect), often the only option available is killing on farm. For cows fit for human consumption, the second question of fitness for transport should be evaluated. For the evaluation of fitness for transport, resources include a compilation of conditions that can make cattle unfit for transport (Table 16 of EFSA, 2022b) and a document listing possible injuries, physiological and pathological signs and related ABMs making an animal not fit for transport from the EU designated Reference Centre for Animal Welfare – Ruminants & Equines guidelines (EURCAW, 2024b). However, an agreed definition of fitness for transport and clearly defined ABM thresholds are currently lacking.

3.8.2.1 | *Cows not fit for transport*

Cows that cannot be transported must stay on the farm. If these cows do not need treatment to alleviate pain or other welfare impairments, for example having given birth in the previous week, they can be slaughtered or killed on the farm or fattened on the farm for subsequent slaughter (with or without transport).

For the evaluation of pain in cattle, resources include the Care4Dairy classification of levels of pain, a 'cow pain scale' by Gleerup et al. (2015) or a 'scale of facial expression of pain in Nellore and crossbred beef cattle' (Müller et al., 2019). If treatment of a cow not fit for transport is needed, then an estimation of the likelihood of success should be made. If successful treatment is likely (including consideration of feasibility), it should be undertaken and, once any withdrawal period is observed, five options become available: to (1) fatten on farm, (2) transport to another farm for fattening, (3) slaughter in abattoir (if the cow becomes fit for transport following treatment), (4) slaughter on farm or (5) kill on farm. If treatment is unlikely to be successful, the cow should be either slaughtered on farm or killed. In these cases, the cow should be killed as soon as possible to minimise the risk of welfare impairments. In the EU it is possible to transport the carcass to the slaughterhouse following emergency slaughter due to accidents that prevented the transport to the slaughterhouse in otherwise healthy animals (CR 853/2004) (Skúladóttir et al., 2022).

3.8.2.2 | *Cows fit for transport*

Cows fit for transport are unlikely to need treatment, though in some cases a cow would still benefit from treatment to improve her wellbeing before transport (e.g. minor form of diarrhoea). If the animal would not benefit from treatment (e.g. the animal has no indication of impaired welfare), she can be transported or stay on farm to be fattened, slaughtered or killed on the farm. If the animal would benefit from treatment, the farmer may still decide not to treat and to send her for slaughter in an abattoir, and in this case, this should be done with no delay. Alternatively, the farmer may decide to immediately end the animal's life on the farm (slaughter on farm or killing). However, if treatment is undertaken and any appropriate drug withdrawal period is observed, then the farmer has the option to either fatten the cow on farm or move her to another farm for fattening before sending her for slaughter after the withdrawal interval has ended.

Existing guidance on fitness for transport include the text part of the 'Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97' and the lists of criteria published in the EFSA Scientific Opinion on welfare of cattle during transport (EFSA AHAW Panel, 2022b) and EURCAW (2024a, 2024b). However, a broader consensus on relevant conditions with clearly defined ABM thresholds is needed.

Some case examples to illustrate the use of the decision tree are here discussed. These examples were selected to represent situations of cows leaving the productive herd for different reasons.

3.8.2.2.1 | *Cow with a broken leg*

A broken leg qualifies for emergency killing. Here, the cow is fit for human consumption but not fit for transport. She is in severe pain, not able to move and there is a low likelihood that treatment will be successful or considered feasible, therefore the options available to alleviate her condition are to immediately slaughter (and subsequently transport the carcass to an abattoir) or otherwise kill her on farm as soon as possible (Figure 10).

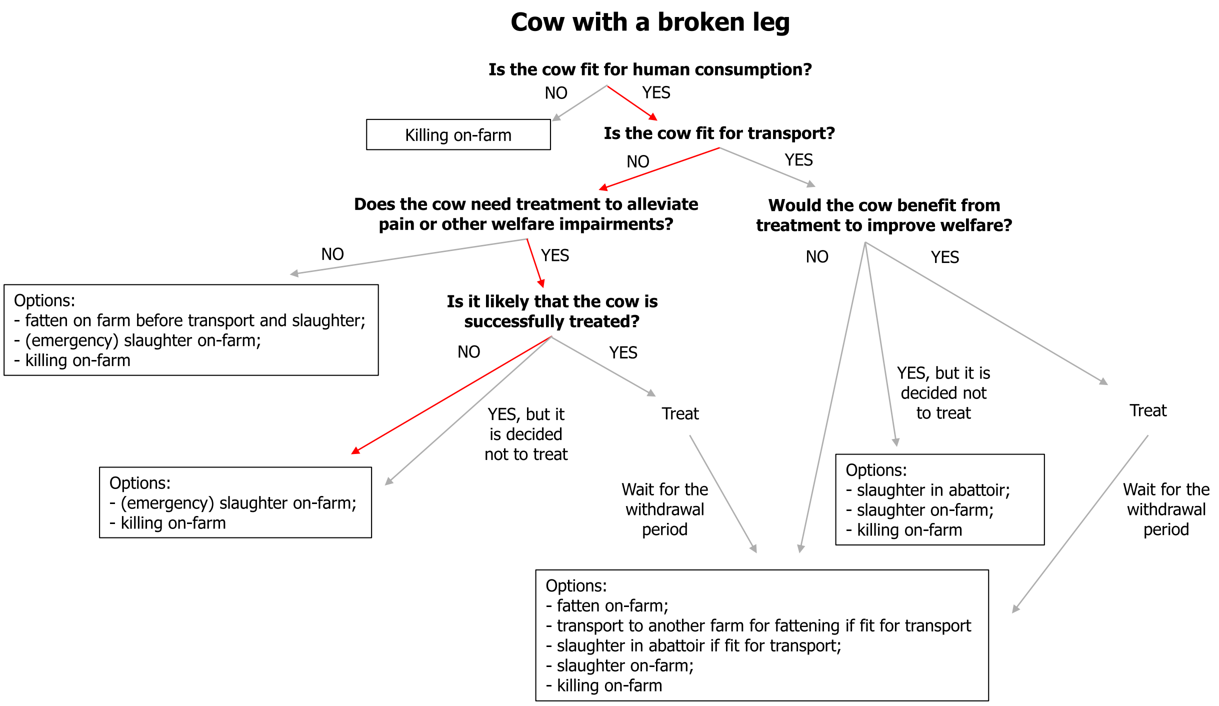

FIGURE 10 Decision tree on cull cows. Example of a cow with a broken leg.

3.8.2.2.2 | *Old, mildly lame (score 2 out of 5) suckler cull cow*

Figure 11 describes the path through the decision tree in the case of an old suckler cow who is mildly lame (score 2/5 Thomsen et al., 2008) that the farmer decided to cull. The cow is fit for human consumption and fit for transport (see EURCAW guide on fitness for transport of ruminants which states cows with lameness 3+/5 are not fit for transport, 2024b). However, the cow would likely benefit from treatment, and if that has been successful, the farmer will have all options mentioned above. If the farmer chooses not to treat the cow, then there are the options to transport to slaughter, slaughter on farm or kill on farm.

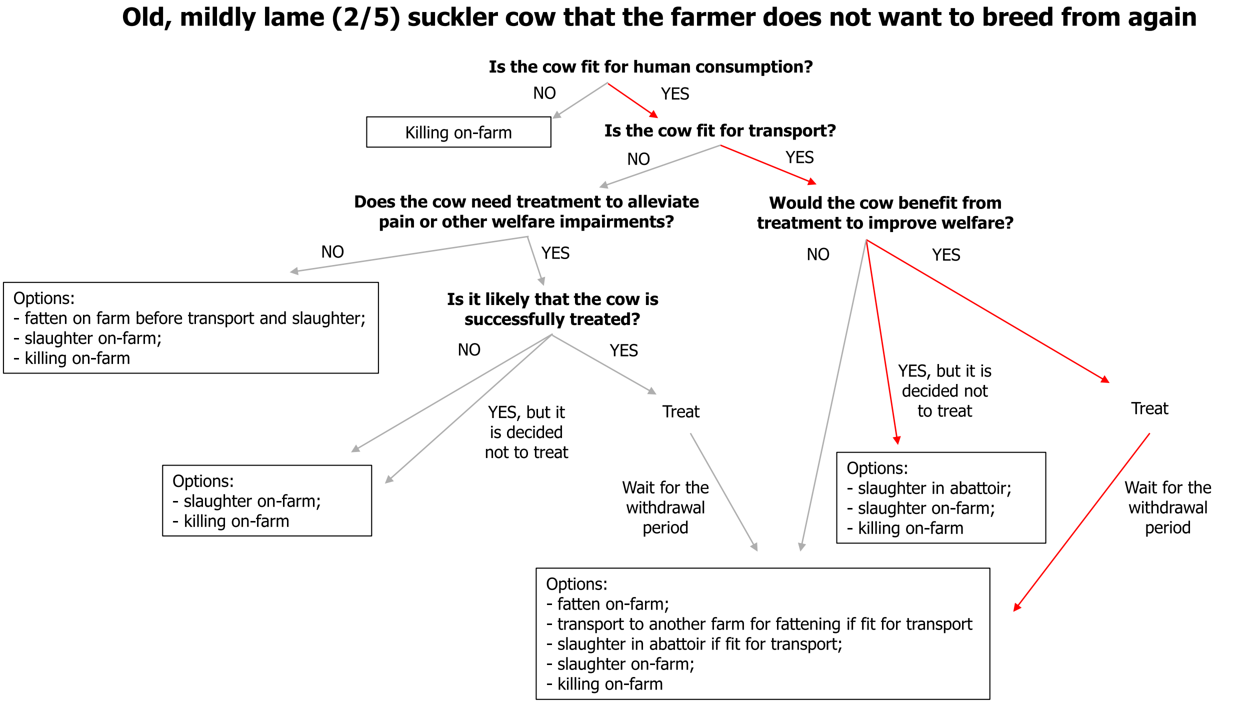

FIGURE 11 Decision tree on cull cows. Example of old, mildly lame (score 2 out of 5) suckler cow that the farmer does not want to breed again.

3.8.2.2.3 | *Dairy cow with recurrent somatic cell count (SCC) ~200,000 despite treatments*

Figure 12 describes the path through the decision tree in the case of a dairy cow with recurrent SCC of around 200,000 despite treatments. The cow is fit for human consumption and transport (no indication of painful condition), the likelihood of treatment is considered to be low, so the farmer has the option to (1) fatten on farm, (2) transport to another farm for fattening, (3) slaughter in abattoir, (4) slaughter on farm or (5) kill on farm (EURCAW, 2024b).

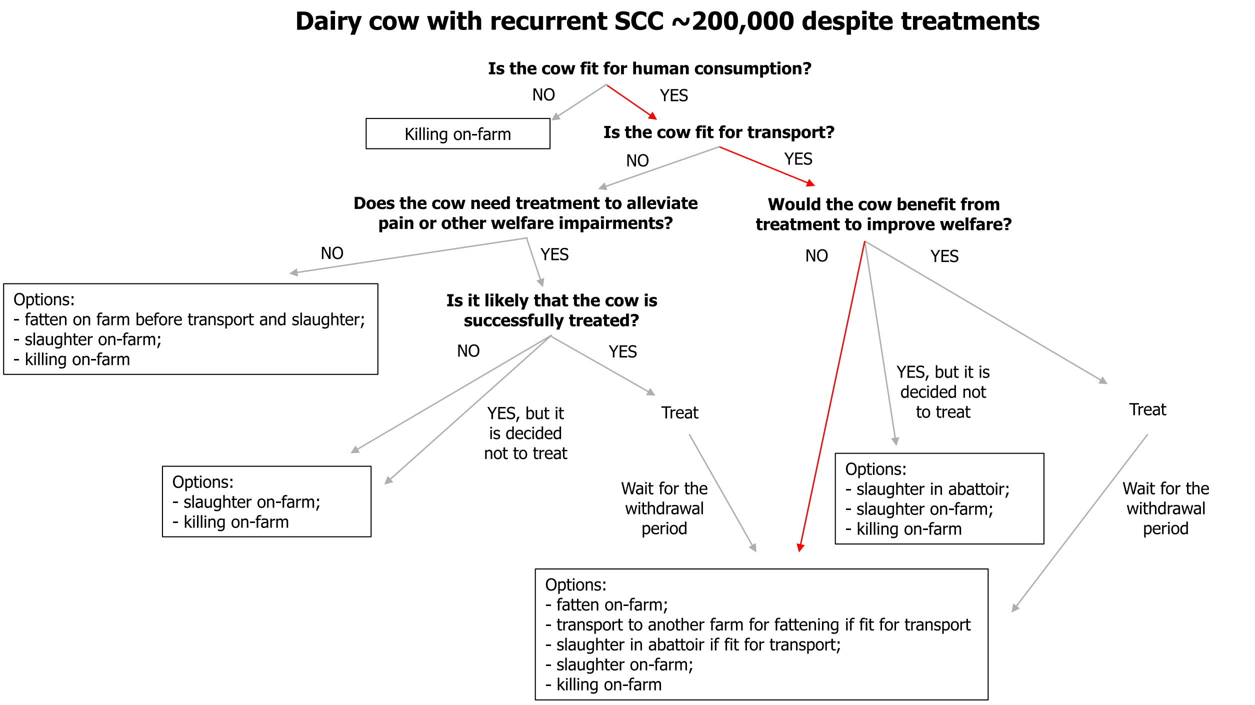

FIGURE 12 Decision tree on cull cows. Example of a dairy cow with recurrent SCC ~200,000 despite treatments.

3.8.2.2.4 | *Cow that is clinically well but has a positive faecal test for Johne's disease (Stage 2) and removal from the herd is advised by a veterinarian*

Figure 13 describes the path through the decision tree of a cow that has tested positive for Johne's disease through a faecal test but has no detectable clinical signs, and removal from the herd is advised by a veterinarian. In this case, the cow is fit for human consumption and transport, would not benefit from treatment and should not go to another farm. Therefore the cow can be transported to an abattoir for slaughter, slaughtered on-farm or killed.

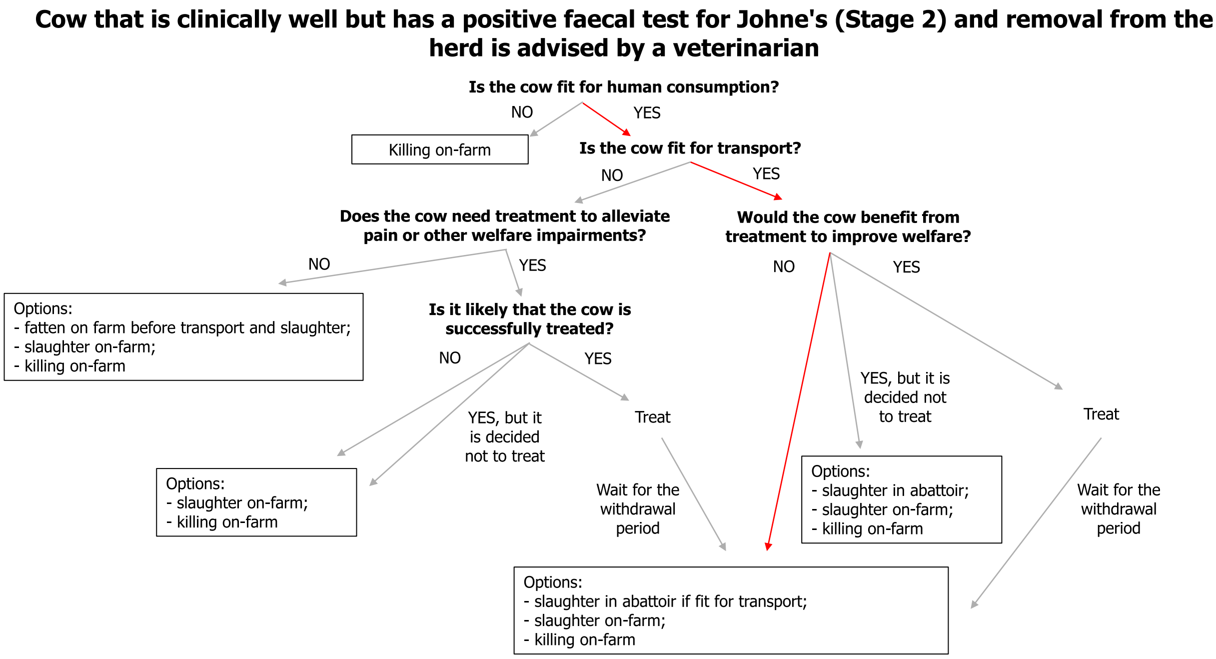

FIGURE 13 Decision tree on cull cows. Example of a cow that is clinically well but has a positive faecal test for Johne's (Stage 2) and removal from the herd is advised by a veterinarian.

3.8.2.2.5 | *Lame cow (score 4/5) that has not responded to treatment*

Figure 14 describes the path through the decision tree for a cow that is lame (score 4/5 Thomsen et al., 2008) and that has not responded to treatment. Her level of lameness is described as 'The cow is obviously lame on 1 or more legs. An observer will in most cases be able to identify the affected leg. In most cases, the back is typically arched both when standing and walking, and head bobbing is generally evident during locomotion' (Thomsen et al., 2008). Although fit for consumption, she is not fit for transport. However, her welfare is severely impaired and she cannot be treated successfully, therefore the only options are on-farm slaughter or killing. However, rules in place in each MS on the conditions for emergency slaughter (i.e. acceptance of emergency slaughtered carcasses in the abattoirs) influence the decision making and the extent to which emergency slaughtered is implemented (Skúladóttir et al., 2022).

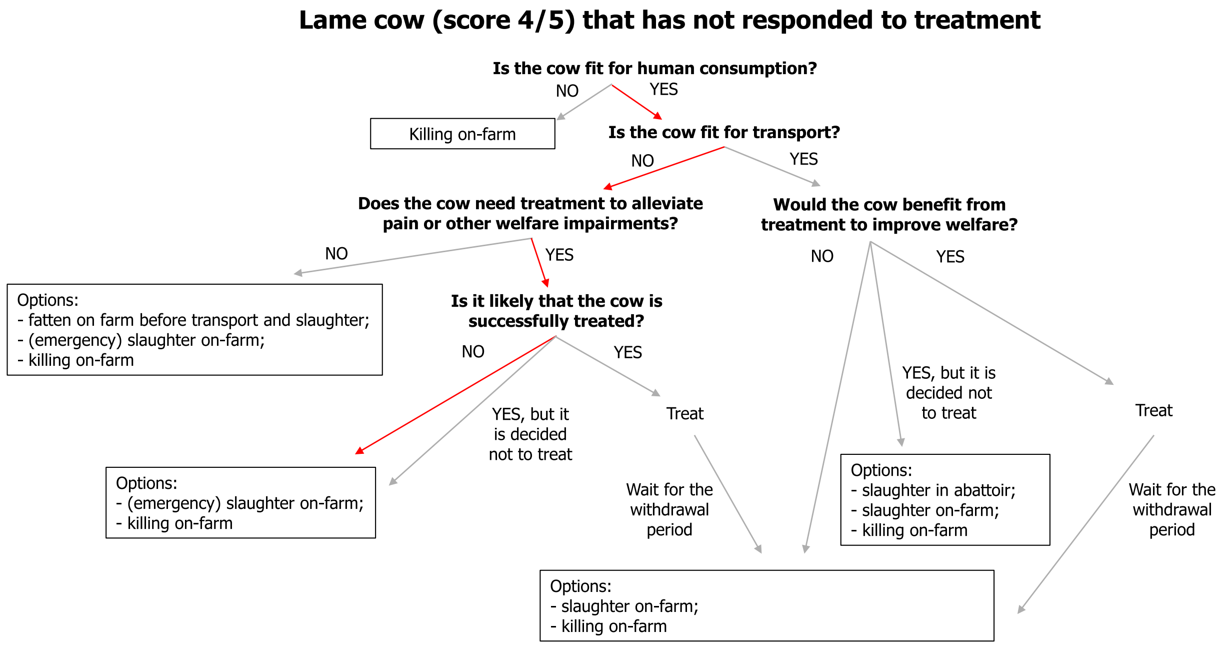

FIGURE 14 Decision tree on cull cows. Example of a lame cow (score 4 out of 5) that has not responded to treatment.

3.8.3 | Conclusions on decision-making criteria for euthanasia of cull cows kept for beef

1. The most common reasons for culling are involuntary, such as fertility issues, udder health problems and lameness.
2. The decision for the course of action to take for a cull cow depends on whether she is fit for human consumption, whether she is fit for transport, the likelihood of successful treatment, the level of welfare impairment of the cow and conditions for emergency slaughter.
3. Lists of criteria for decisions for fitness for transport are available, however, cases of doubt can occur and would benefit from a broader consensus on relevant conditions with clearly defined ABM thresholds.
4. There are knowledge gaps regarding how cows with different health issues respond to transport, their welfare state during the withdrawal period if the cow did not fully recover from the health issue she was treated for, their welfare state during the fattening period or welfare implications of delays between decisions and actions.

3.8.4 | Recommendations on decision-making criteria for euthanasia of cull cows kept for beef

1. The level of welfare impairment of all cows leaving the productive herd should be assessed to inform decisions about whether they should be kept for fattening or not. It is recommended to use the decision tree presented in this document to aid decisions.
2. Research is needed to establish criteria for the different steps of the decision tree including the development of broadly agreed ABM thresholds for fitness for transport, likelihood of successful treatment, welfare state during withdrawal period or further development of broadly agreed pain scales.
3. Where necessary, professional advice (e.g. from a veterinarian) should be sought on the level of welfare impairment, likelihood of successful treatment, fitness for human consumption and fitness for transport.
4. It is recommended to carry out studies to clarify for which conditions there will be no worsening of the welfare state during transport, on their welfare state during the withdrawal period if the cow did not fully recover from the health issue she was treated for, on their welfare state during the fattening period, and on welfare implications of delays between decisions and actions.

3.9 | The assessment of animal-based measures collected in slaughterhouses to monitor the level of welfare on farm for fattening cattle

3.9.1 | Results of the semi-quantitative consensus exercise

Out of the 25 identified ABMs for fattening cattle, 16 passed the first screening procedure and were considered in the selection step (see Figure 15). Three ABMs ('hernia', 'rectal prolapse' and 'carcass aspect') were directly excluded by the EFSA experts from the initial list because they were either considered rare in fattening beef cattle (i.e. rectal prolapse) or more relevant for calves (i.e. umbilical hernia).

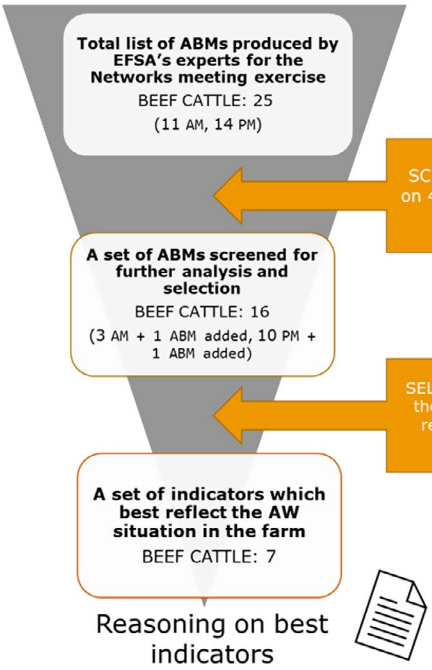

FIGURE 15 Flowchart of the process leading to the selection of the ABMs that were considered to best reflect the AW in the farm. AM, ABMs measured *ante-mortem*; LS, literature search; PM, ABMs measured *post-mortem*.

The outcome of the selection of ABMs is presented in Table 13, where the specific scores for the four criteria are reported for 16 ABMs.

The EFSA experts agreed to select 'body condition' (assessed *ante-mortem*, AM) and 'carcass fatness' (assessed *post-mortem*, PM), 'skin lesions – wounds and bursitis' (AM), 'skin lesions – bruises' (PM), 'lung lesions – pneumonia and pleuritis' (PM), 'carcass condemnations' (PM) and 'body cleanliness' (AM), as the most useful ABMs collected at slaughter to measure welfare of fattening beef cattle on farm (green rows). Body condition and carcass fatness are described in the same section (Section 3.9.2.2) because they are linked to similar WCs, and likely correlated (Minchin et al., 2009).

Table 13 presents the outcome of the assessment described in Section 2.2.5 regarding the selection of ABMs.

TABLE 13 Ranking of ABMs of beef cattle on the basis of four criteria (C1, C2, C3, C4) (see Section 2.2.5). The score goes from 0 to 4, with 0 indicating the lowest score and 4 the highest. The ABMs that were selected are highlighted in grey.

ABM	Assessment[a]	C1. Welfare consequences	C2. Technology readiness	C3. Already measured at slaughter	C4. Importance rated by the network	Weighted score[b]
Body condition	AM	2	3	2	2	2.28
Carcass fatness[c]	PM	2	3	2	2	2.28
Skin lesions – wounds/injuries	AM	2	1	2	3	1.89
Skin lesions - bruises	PM	2	1	2	3	1.89
Lung lesions - pneumonia/pleuritis[d]	PM	1	2	2	3	1.87
Skin lesions – bursitis	AM	1	1	3	3	1.84
Carcass condemnations	PM	2	0	2	4	1.78
Body cleanliness	AM	1	1	2	4	1.76
Liver disorders	PM	1	2	2	2	1.7
Pericarditis	PM	1	2	2	2	1.7
Skin lesions – abscesses	PM	1	1	2	3	1.59
Bursitis (swollen joints)	PM	1	1	1	3	1.34
Abomasal lesions	PM	1	0	1	1	0.72
Rumen lesions	PM	1	0	1	1	0.72
Mastitis	PM	1	0	0	2	0.64
Tail injuries[c]	PM	1	0	0	Na	0.3

[a]AM, ABMs measured *ante-mortem*; PM, ABMs measured *post-mortem*.

[b]The final weight was calculated considering the following criterion weights: C1 = 3, C2 = 2.8, C3 = 2.5, C4 = 1.7.

[c]These ABMs have been added to the initial list during group discussion in step (i), the screening.

[d]This ABM (lung lesions- pneumonia and pleuritis) is a combination of two ABMs listed in EFSA (2023).

In the following sections each selected ABM is described with its definition (as reported in EFSA, 2023), interpretation, current use, considerations for use as standard method and possibilities for automation.

3.9.2 | Selected ABMs

Official controls according to Regulation (EU) 2017/625 and Commission Implementing Regulation (EU) 2019/627 address the compliance with the rules in the areas of food and food safety as well as, where appropriate, animal health and animal welfare. In the case of slaughterhouses, this requires *ante-mortem* and *post-mortem* inspections, the latter including incision and palpation, when there are indications of a possible risk to human health, animal health or animal welfare.

While some ABMs, like carcass condemnation rates or obvious lung lesions, are already used for food safety purposes in EU slaughterhouses, routine implementation for welfare monitoring remains low. Even if data on certain ABMs are routinely collected (e.g. condemnation rates and reasons), their accessibility is largely unclear.

The ABMs selected reflect mostly health-related welfare consequences and inform less about the inability to perform species-specific behaviour. No ABMs indicative of inability to perform exploratory or foraging behaviour, or restriction of movement were identified. The selected ABMs are only assessed in the animals actually arriving at the slaughterhouses and thus do not include animals that were unfit from transport that presented major welfare impairments nor animals that died on farm.

3.9.2.1 | *Body cleanliness*

3.9.2.1.1 | *Description of the* ABM

Definition: Presence of organic matter (manure/faeces etc) on the body. Two types of dirt can be distinguished in splashing (i.e. the skin being covered with liquid and fresh dirtiness) and plaques (three-dimensional layers of dirtiness).

Interpretation: Cleanliness is an ABM often used in cattle, especially to assess criteria linked to the housing such as comfort around resting.

Animals primarily become soiled by faeces, mud, dust and vegetable matter, due to the animal's own defecation or animal-to-animal and environment-to-animal contamination. Animal cleanliness on farm is therefore affected by a range of factors in the following areas: (i) physical and environmental conditions like type of housing, air humidity, type and quantity of bedding, or season; (ii) management, e.g. frequency of supplying new bedding, frequency of floor cleaning; (iii) Feeding; and (iv) health conditions, especially related to the presence of diarrhoea. Poor body cleanliness may be associated with several welfare consequences, including health, comfort and behavioural issues. The presence of mud or faeces on the skin may be irritant and may lead to dermatitis. Cleanliness of the housing has been associated with the incidence of lameness and hock injuries (Chen et al., 2017; Roche et al., 2024; Schütz et al., 2019). A poor hygiene of the environment may also decrease the lying time of cattle. Cleanliness may therefore give information on cattle welfare. In the Welfare Quality protocol for fattening cattle (Welfare Quality, 2023a), body cleanliness is used to assess the comfort around resting.

This can occur on the farm but also during transport or at lairage. Plaques often indicate long-term soiling of the animals and are likely to originate from the on-farm conditions when assessed at the slaughterhouse.

3.9.2.1.2 | *Assessment*

Timing of assessment: *Ante-mortem*. The assessment of cleanliness may be performed at lairage or during the unloading of the truck if animals are slaughtered directly.

Current use of this ABM: Animal cleanliness must be recorded in all slaughterhouses following the Commission Implementing Regulation (EU) 853/2004. This regulation states that animals presented for slaughter must be clean to reduce carcass contamination and ensuring food safety. Therefore, in the European Member States (EU MSs), policy includes categorising cattle according to visual cleanliness and extensively dirty animals are rejected before entering the slaughter line.

Considerations for use as standard method: Existing scoring systems have been reported to be used at slaughter in form of yes/no. However, other on farm scoring systems exist that can be applied also at slaughter. For example, to assess comfort around resting of fattening cattle in farms, Welfare Quality includes a two-point scoring system of animal cleanliness (Welfare Quality, 2023a). Cleanliness can also be easily assessed at slaughter (Eastwood et al., 2017; Grandin, 2017) and this assessment might be associated with farm characteristics such as housing type (Burgstaller et al., 2022).

Few studies have explored the association between cleanliness at slaughter and cleanliness on beef farms. Hauge et al. (2012) found a correlation between dirty dairy cattle presented for slaughter and animal dirtiness on farm. In fact, herds classified as 'dirty' in the study, (i.e. those that had slaughtered many dirty animals in the 2 years preceding the experiment) had actually dirtier cattle (dairy cows, heifers and bulls/steers) during the on-farm assessment as compared with 'clean' herds (i.e. those had slaughtered only clean animals) (Hauge et al., 2012). Many factors on farm were associated with dirty animals, for example high air humidity, housing and manure texture. Other factors such as outdoor access or weather conditions may also play a role on cleanliness. Burgstaller et al. (2022) found that cattle housed in deep litter pens had higher odds of being contaminated at slaughter compared to cattle in a tethered housing system (although in this case the presence or type of bedding was unknown). Karhan et al. (2020) found that fattening cattle housed without straw or bedding material are more likely to be dirty.

Limitation on the use of cleanliness at slaughter in monitoring the welfare on farm is that preslaughter management practices towards cleaning animals may include clipping and trimming of the tail, brushing, washing and scraping, but these are generally not routinely done. Other practices such as isolating the animals in larger pens a few weeks before slaughter seem more frequent. These practices cannot really affect long-term animal welfare on farm but can change the cleanliness of animals at slaughter, making this indicator difficult to use to assess cattle welfare on farm.

Another limitation in using cleanliness at slaughter as an indicator of animal welfare on farm is the fact that cleanliness of animals and presence or amount of manure observed at slaughter can be the result of changes after the departure from the farm depending on factors such as transport duration and conditions and lairage conditions. This limitation could be overcome by assessing the presence of plaques, which are more likely related to on-farm conditions.

Possibilities for automation: Due to the difficulty in distinguishing between splashes and plaques, and assessing all the body surface of animals (despite existing video or camera tools), this ABM seems difficult to automate under commercial setting.

3.9.2.2 | *Body condition and carcass fatness*

3.9.2.2.1 | *Description of the ABM*

Definition of body condition: Murray (1919) defined body condition as the ratio between fat and non-fat body components of a live animal. From the 1970s and 1980s, multiple scoring systems have been extensively utilised worldwide to appraise the energy reserves of dairy cattle for the prevention of productive losses, health and welfare problems (Roche et al., 2009). As in dairy cows (Edmonson et al., 1989), BCS in beef cattle estimates the mobilisation of energy reserves generally using a 5-point scale (0 = thinnest, 5 = fattest) with quarter-point (0.25) increments. Alternative scoring ranges are the 1–9 scale in the USA (Corah, 1989) and the 0–2 method (0 = satisfactory condition and 2 = very lean) proposed by the Welfare Quality Project (Welfare Quality, 2023a).

Definition of carcass fatness: Carcass fatness is visually assessed based on the amount of subcutaneous fat of the carcass and in the thoracic cavity. In the EU, carcass fat coverage is scored according to the official EUROP carcass classification system using a five classes grid (from 1 = low to 5 = very high) (Council Regulations No. 1208/81 and No. 2930/81).

Interpretation: Body condition scoring and carcass fatness offer a subjective assessment of body reserves (subcutaneous fat and muscular reserves), thus providing valuable information regarding energy intake relative to the animals' requirements (overall energy status) (Roche et al., 2004).

3.9.2.2.2 | *Assessment*

Timing of assessment: Measuring BCS at the slaughterhouse should be performed *ante-mortem* in the pre-slaughter lairage area to visually identify lean or very lean animals. The carcass fatness score is assessed *post-mortem* at the end of the slaughter line or in the chilling rooms.

Current use of these ABMs: In beef cattle, BCS is mainly used on farm as a common indicator of the energy status of animals (Losada-Espinosa et al., 2018). It estimates the degree of fatness or thinness helping farmers and feed advisers to finetune the composition of fattening diets to the requirements of the different batches of animals. BCS is not routinely assessed at the slaughterhouse for welfare assessment purposes. Carcass fatness is routinely scored in the EU slaughterhouses according to the above-mentioned Council Regulations No. 1208/81 and No. 2930/81.

Consideration for use as standard method: Measuring BCS at the slaughterhouse could be a proxy for undernutrition since it provides information on long-term nutritional status of the livestock (Phythian et al., 2012). Batches of beef cattle with low BCS at the slaughterhouse may result from the provision diets inadequate to cattle requirements and/or to the exposure of the animals to management conditions they cannot cope with (Taylor et al., 2023). A Finnish study by Herva et al. (2011) found a positive relationship between an index that was based on 43 items evaluating opportunities for movement, lying area, social environment, management, feeding and health of animals and EUROP classification of carcass fatness. As for calves (EFSA AHAW Panel, 2023), the presence of emaciated beef cattle at the slaughterhouse may also be an indirect indicator of long-term health problems such as respiratory or claw disorders (Knock & Carroll, 2019). EUROP carcass classification is a standard method that can be used to identify very lean carcasses (i.e. with fat class levels of 1).

Possibilities for automation: Measuring BCS at the slaughterhouse can be considered highly feasible since body condition scoring is easily learned by assessors and requires no equipment (Morris et al., 2002). The adoption and the specific training of existing devices for automatic monitoring of BCS in beef cattle, such as image analysis and ultrasound scanning, could further promote its use at the slaughterhouse, avoiding variability due to different observers (Halachmi et al., 2013; Miller et al., 2019). To efficiently use *ante-mortem* BCS for welfare purposes the system for collecting and recording data should be harmonised. Similar technologies are available for the automation of carcass fatness evaluation (Delgado-Pando et al., 2021; Nisbet et al., 2024).

3.9.2.3 | *Carcass condemnation*

3.9.2.3.1 | *Description of the ABM*

Definition: Carcass or parts of the carcass that are unfit for human consumption (and not caused by the slaughter process itself), reported as a percentage of partially or fully condemned carcasses. Ideally, lesions that occurred during transport (e.g. bruising, Losada-Espinosa et al. (2021)) would not be included in the condemnation rate for on-farm welfare monitoring purposes.

Interpretation: Condemnations are mainly due to diseases or injuries and bruises (Collineau et al., 2022; Ellerbroek, 2022; Losada-Espinosa et al., 2021; Vecerek et al., 2003). In addition to condemnation rates, condemnation reasons are also relevant from the perspective of animal health and welfare surveillance (Vial et al., 2015). In a survey of about 16 million adult cattle slaughtered in France (total/partial condemnation rate 0.7%/3.8%) the main condemnation reasons were serous infiltration of connective tissue, peritonitis and abscess (total condemnation) and unique abscess, haemorrhagic infiltration and muscular sclerosis (partial condemnations) (Collineau et al., 2022). In Switzerland, severe lesions were the leading cause of whole carcass condemnation, with condemnation rates positively correlated to on-farm mortality (Vial et al., 2015; Vial & Reist, 2014). Condemnations thus reflect mainly health-related animal welfare problems on farm, but transport and lairage conditions can also lead to increased condemnation rates (Losada-Espinosa et al., 2021). It should, however, be taken into account that disease or lesions of low severity do not lead to condemnation and early or subclinical stages of disease are not likely to be detected by meat inspection. Furthermore, (Vial & Reist, 2014) found a non-reporting bias in a large number of slaughterhouses.

3.9.2.3.2 | *Assessment*

Timing of assessment: *post-mortem*

For food safety reasons, Commission Implementing Regulation (EU) 2019/627 requires the recording of whole carcass or partial condemnations (i.e. condemnations of part of the carcass or offal). Condemnations due to carcass contamination during the slaughter process should not be considered.

For welfare monitoring purposes, condemnation records should also include animals that are unfit for slaughter due to clinical signs of disease, which can be already determined during the *ante-mortem* inspection in case of visibly ill or disabled animals (Collineau et al., 2022).

Current use of this ABM: Condemnations must be recorded in all slaughterhouses following the Commission Implementing Regulation (EU) 2019/627. According to the replies gathered from the AHAW Network (AW topic), (EFSA, 2023), all countries that replied to the questionnaire (11/11) considered that collecting data on this ABM was 'easy' (the possible answers were easy/medium/difficult). This potentially reflects the fact that this indicator is part of a Commission Implementing Regulation mentioned earlier but no evidence on the accessibility of such information was found by the EFSA experts. No peer-reviewed studies mentioning the use of condemnation rates to assess on-farm welfare of fattening beef were found.

Consideration for use as standard method: Clear criteria/specifications/terminology as well as continuing training and auditing of inspectors are needed, if condemnation rates are to be used to compare welfare levels across farms (Collineau et al., 2022; Vial et al., 2015). For example, even after controlling for age, sex and breed, cattle condemnation rates varied between regions and slaughterhouses in France, due to variability in the animal-related factors (e.g. sex, age and type of breed) and slaughterhouse-related factors (status, type, slaughter volume) (Collineau et al., 2022). While a list of conditions leading to condemnation exists in Europe, harmonised description and specification of lesions and consequent decisions are still lacking (Collineau et al., 2022). Especially in the case of carcass condemnations due to reasons other than health and welfare (such as improper carcass handling or carcass contamination during slaughter and inspection), criteria for identification and subsequent exclusion need to be developed.

For animal welfare monitoring purposes, carcass condemnations should be expressed as the proportion of partially or fully condemned carcasses relative to the overall number of cattle slaughtered per farm. The underlying causes of condemnations would provide useful additional information for monitoring the welfare state on farm. The type and level of detail of carcass condemnations data recorded determines the usefulness of this ABM for animal welfare assessment purposes. Less informative for animal welfare surveillance are the weights of the entirely condemned carcass or of partial condemnations.

Possibilities for automation: The decision for condemnations cannot be automated due to the diversity of the underlying pathomorphological findings. However, the use of electronic recording systems during the assessment or databases might support the use of these data for health and welfare monitoring.

3.9.2.4 | *Lung lesions – Pneumonia and pleuritis*

3.9.2.4.1 | *Description of the ABM*

Definition: Inflammation of the lung tissue with or without an overlying pleurisy or inflammation of the pleurae with fibrinous pleural adhesions.

Interpretation: Lung lesions are ABMs mainly related to the WC of 'respiratory disorders'. It is estimated that 18% of cattle have lung lesions at slaughter (Fernández et al., 2020). Lung lesions in beef cattle are mainly associated to the presence of BRD. BRD has been reported to be the most common disease in beef cattle, whose prevalence is often underestimated as only 25% of cattle showing signs of severe BRD lesions showed clinical signs of disease (Griffin, 2014; Taylor et al., 2010).

The assessment of pneumonic lesions at the slaughterhouse could be a good indicator of the welfare on farm, helping to identify subclinical and clinical infections. Animals with pneumonic lesions at the slaughterhouse have lighter carcass weights than animals with no lesions of the same age group (Fernández et al., 2020; Rezac et al., 2014). Chronic catarrhal pneumonia of grade 1 (< 10% of lung affected) is associated with recovery of events experienced in the past (Lundborg et al., 2005; Rezac et al., 2014).

3.9.2.4.2 | *Assessment*

Timing of assessment: *post-mortem*

Current use of this ABM: *Post-mortem* scoring of pneumonia and pleuritis at the slaughterhouse is currently routinely carried out by visual inspection mainly for food safety purposes by veterinary inspectors (Regulation (EU) 2019/627). Carcasses with acute and severe pneumonia or pleuritis are provisionally condemned and proceed to a bacteriological test and testing for pharmaceutical residues. When tests are favourable (i.e. no issue is detected), carcasses are returned to the processing chain after removing the affected areas.

Consideration for use as standard method: According to EFSA (2023), 20 out of 26 EU MSs representatives reported that a 'yes/no' scoring would be enough to use pneumonia and pleuritis as ABMs for assessing animal welfare at the farm, and it would be easy to implement. However, more detailed information could provide more insights about the welfare of the cattle at the farm. Macroscopic evaluation of the lungs can include the distribution, location and changes consistent with pneumonia (Fernández et al., 2020), such as variation in colour (from red to grey), presence of consolidation areas or exudate (Leruste et al., 2012; Schneider et al., 2009). However, standard methods are not well stablished in the literature. A study involving the inspection of 2161 carcasses from 80 Italian commercial beef farms reported a wide variability in the prevalence of specific lesions among batches. The authors suggested that a system based on the allocation of batches to certain health classes could be used as a feedback tool for farmers and veterinarians (Magrin et al., 2021). Similarly, a study involving the inspection of 1101 beef-breed carcasses in Spain for chronic catarrhal pneumonia or acute fibrinous pneumonia highlighted the importance of scoring lungs *post-mortem* to improve farm health and welfare programmes (Fernández et al., 2020). When developing standardised methods there is a need for agreement on specifications/terminology to allow the use of lung lesions as a retrospective indicator of welfare conditions on farm. In addition, the difficulty of inspecting and scoring lungs under commercial conditions while the carcasses are moving along the slaughter line also needs to be taken into account.

Possibilities for automation: There is no published information on the use of automated tools for pneumonia or pleuritis scoring at the slaughterhouse in beef cattle. In pigs, an automated system using deep learning to score lung photographs had an average accuracy of 85% (Trachtman et al., 2020), with an application being further developed for commercial purposes (Dutch Food and Consumer Product Safety Authority, 2022). A similar approach could be developed for beef carcasses in the future. The attempts to automatically (Maes et al., 2023) diagnose lung diseases in field necropsies showed moderately high sensitivity in cattle (based on a comparison between the laboratory results with the automatic necropsy analysis results) (Bortoluzzi et al., 2023). However, this technology would have to be further developed before it can be reliably used in slaughterhouses.

3.9.2.5 | *Skin lesions – wounds and bursitis*

3.9.2.5.1 | *Description of the ABM*

Definition: Wounds on the skin of the body (excluding the tail) can range from scratches (surface penetration of the epidermis) to deeper wounds (penetration of the muscle tissue). Fresh wounds are bloody, older wounds carry scabs and healed wounds may be visible as scars, indicated by loss of hair and altered skin in terms of colour and thickness. Bursitis is the inflammation of the fluid-filled sac surrounding joints (bursa), commonly of superficial bursae located in the legs, namely at tarsal or carpal joints.

Interpretation: Wounds can be due to cuts, scratches, sores or skin infections. Fresh wounds have most likely not been caused on farm, but during transport or at the slaughterhouse. Bursitis can develop in animals kept in hard floors as the result of a pressure injury, although infectious causes are also possible.

Wounds and swellings may be painful. When these alterations of the integument and swellings of joints are due to trauma occur, they reflect repeated physical interactions of the animals with their environment, either because of collisions with housing equipment or pressure against hard surfaces in the lying or feeding area (for dairy cows: e.g. Brenninkmeyer et al., 2016), or because of agonistic interactions with horned herd mates (for dairy cows: Menke et al., 1999). In the first case, the most common locations of wounds are the tarsus, the carpus and the neck region, but also the hip bone, pin bones, sacrum or other regions can be affected (Brenninkmeyer et al., 2016 for dairy cows). Wounds caused by horns are characterised by a more vertical orientation and the most typical location is the lower part of the abdomen and the shoulder (Menke et al., 1999 for dairy cows). In an *ante-mortem* scoring of skin lesions, Knock and Carroll (2019) found most wounds at the legs (34.1% in beef cattle, 30.8% in end-of-career dairy cows), followed by the flank (30.1% and 22.2%). Skin lesions were not related to any other ABM (e.g. bruises) except lower carcass weight, possibly reflecting an increased risk of wounds in thinner dairy cattle. In the last month of fattening, the prevalence of leg wounds in ranged between 0.0% and 1.2% in Limousine bulls and 2.9% and 7.8% in Charolais bulls kept on CSFs and rubber coated slatted, respectively. The prevalence of bursitis ranged between 34.5% and 19% in Limousine bulls, and between 22.5% and 13.5% in Charolais Charolais, respectively (Magrin, Gottardo, Brscic, et al. (2019). Valkova et al. (2021) reported on *post-mortem* examinations of traumatic injury in cattle processed in Czech slaughterhouses. Wounds visible after skinning are included as traumatic injury (which further include bruises, fractures, dislocations etc.) while injuries that occurred *post-mortem* (i.e. technology-related damage after stunning) are excluded based on their appearance (e.g. tissue regeneration, presence of clotting, swelling, inflammation, scarring). These authors found frequencies of mostly below 1% (cows: 1.21% (limbs) and 0.51% (body), heifers: 0.56% and 0.16%, bulls: 0.22% and 0.06% respectively).

3.9.2.5.2 | *Assessment*

Timing of assessment: *ante-mortem*

Current use of this ABM: *Ante-mortem* scoring of wounds and bursitis at the slaughterhouse is currently not common, and is mainly performed in case severe wounds are observed (EFSA, 2023). Only severe wounds indicating accidents or that animals have not been fit for transport or need to be killed immediately, or swellings that indicate systemic disease, rendering the animal unfit for human consumption, are considered in the official *ante-mortem* inspections. Under experimental conditions, scoring of 'hair loss and lesions' has been carried out *ante-mortem* in beef cattle (Knock & Carroll, 2019) using a scoring scheme for dairy cows on farm.

Consideration for use as standard method: It can be difficult to thoroughly inspect the body and limbs of each animal before slaughter, especially when they are in a group. Knock and Carroll (2019) scored cattle from an elevated vantage point, after being moved from the lairage pen to the race. However, they note that due to the distance, some signs of injury could have gone unnoticed. Furthermore, the design of driveways, body position, animal cleanliness and light conditions will affect the reliability of the *ante-mortem* assessment. A *post-mortem* assessment before skinning could therefore be more reliable. In addition, however, to date definitions of these ABMs for use as a standard method in slaughterhouses are not standardised. To the EFSA experts' knowledge, there is only one published study on the use of wounds (Nielsen et al., 2017) as standard ABMs at slaughter *ante-mortem*, so these statements are largely based on expert opinion. Scoring schemes for beef cattle on farm are also available (e.g. Welfare Quality, 2023a) and might be adapted for use in slaughterhouses. Fresh wounds should not be considered for the assessment of welfare on farm as they most likely happened during transport or at the slaughterhouse.

Possibilities for automation: There is no published information on the use of automated tools for the detection of wounds and bursitis in cattle. It is conceivable to carry out a camera-based *post-mortem* assessment of wounds before skinning, as similar technology is available for skin lesions in other species (e.g. detection of tail lesions in pigs: Brünger et al., 2019; Blömke et al., 2020; detection of pododermatitis in turkeys: Stracke et al., 2022). However, currently no specific adaptation of such technologies for wound and bursitis detection is available.

3.9.2.6 | *Skin lesions – Bruises*

3.9.2.6.1 | *Description of the ABM*

Definition: An injury (contusion) involving rupture of small blood vessels and discoloration without a break in the overlying skin.

Interpretation: The accumulation of blood and serum due to the rupture of the vascular supply can develop after the application of sufficient force. Bruising causes pain (Gregory & Grandin, 2007) and occurs *ante-mortem* but is commonly not visible in the live animal because cattle have a thick skin. The lesions in the form of bruising are visible after removal of the skin (skinning) at the slaughterhouse though. Bruises can result from contact with other animals, inappropriate handling or physical interactions with the facilities at the farm, market, during loading and unloading, transport to the slaughterhouse, during handling and in lairage, and even during stunning (Jarvis et al., 1995). Bruises have been proposed to monitor the welfare of cattle at the slaughterhouse (Grandin, 2000). For the assessment of the welfare situation on farm, a distinction between old and fresh bruises needs to be made based on colour. Although no specific data have been conducted for beef, evidence from poultry suggests that bruises exhibiting light green, yellow-green or pale yellow coloration are typically older than 24 h and are therefore more likely to have originated on the farm. In contrast, bruises characterised by intense dark red to purple are considered more recent and are likely to have occurred during events such as loading, transport or lairage. Bright red bruises are generally considered more recent than 24 h and are attributed to injuries occurring at the slaughterhouse (EFSA AHAW Panel, 2023). In addition, considerations should be made about pseudo-bruises or *post-mortem* artefacts. These pseudo-bruises can result from the mechanical handling of the carcasses at the slaughter line and can lead to misinterpretation (Vanezis, 2001).

3.9.2.6.2 | *Assessment*

Timing of assessment: *post-mortem*

Current use of this ABM: Carcasses with bruises have to be trimmed as the affected parts are not fit for consumption; and severe bruising may lead to (partial) carcass condemnation by veterinary inspectors. However, *post-mortem* scoring of bruises at the slaughterhouse is currently not routinely carried out for welfare evaluation. Under experimental conditions, bruising has been scored at the slaughter line after skinning (Teiga-Teixeira et al., 2021; Zanardi et al., 2022). Several articles described the relationship of different bruising scores with pre-slaughter practices as well as on-farm, saleyard or transport practices (Blackshaw et al., 1987; Eldridge & Winfield, 1988; Teiga-Teixeira et al., 2021; Zanardi et al., 2022). Zanardi et al. (2022) found that the front and ribs anatomical sites presented high percentage of purple and yellow lesions attributed to traumatic events which occurred prior to transport; flank and hindquarters fresh bruises were observed and they were related to rough handling and use of driving instruments (Zanardi et al., 2022). Similar results were described by Teiga-Teixeira et al. (2021), who found that most bruises were circular and were indicative of the rapid handling of cattle to the stunning room. Fresh lesions in the loin are associated with mounting and agonistic behaviours in lairage. These agonistic behaviours also can affect the neck, flank and hindquarters (Blackshaw et al., 1987). One important relationship observed in Teiga-Teixeira et al. (2021) study was that cattle with worse body condition scores had higher numbers of carcass bruises.

Consideration for use as standard method: Scoring bruises can be considered a standard method not only for economical purposes but also for welfare evaluations. Different scoring methods have been described for bruises, therefore clear criteria/specifications/terminology are needed. Reliability among four observers that were asked to score the same 46 carcasses was moderate (intra-class correlation (ICC) = 0.70) for the total number of bruises, but ranged from fair (ICC = 0.43) to moderate (ICC = 0.80) for pairs of observers. Only slight overall agreement (ICC = 0.35) was found for the number of bruises scored per predefined anatomical sites (Strappini et al., 2012). As regards bruise characteristics, colour of the bruises achieved the lowest Kappa values for all observer pairs, ranging between 0.16 and 0.39 (i.e. 'slight' to 'fair' agreement). The authors considered experience of the observers, speed of the slaughter line and the difficulty to score while the carcass is moving to be factors for the unsatisfactory agreement between observers. Similar results were observed by another study in Uruguay (Huertas et al., 2010).

Some authors classified bruises based on anatomical site, size, shape and colour (Zanardi et al., 2022), while others (Teiga-Teixeira et al., 2021) scored bruise severity. Especially regarding colour, bruises can be differentiated between old and fresh based on an assessment of their colour, with bruises in tones of red being more recent and bruises in tones of blue/purple being older.

Possibilities for automation: There is no published information on the use of automated tools for bruise scoring in cattle carcasses. Recent publications on the successful detection of bruised apples with AI (Ünal et al., 2024) indicate the possibility of automated carcass bruise assessment, but similar technologies for bruise detection in cattle carcasses remain largely unexplored. Technological solutions capable of inspecting meat products in trays (e.g. to detect foreign bodies) may also detect bruises (Inspectra, online).

It is expected that automation will reduce the current reliability issues when scoring bruises.

3.9.3 | Conclusions on ABMs collected on slaughterhouses to evaluate on-farm welfare of fattening cattle

1. Currently, the ABMs body condition and carcass fatness, carcass condemnation, *post-mortem* lung lesions and *post-mortem* skin lesions (old bruises and bursitis) are not routinely recorded in EU slaughterhouses for animal welfare monitoring of fattening cattle, but some are already collected for food safety or classification purposes.
2. The ABMs listed in (1) are the most suitable and promising ABMs for collection at slaughterhouses to monitor the level of welfare on farm for fattening cattle (i.e. fattening bulls, heifers and steers) (certainty > 90%) although they have only to a very limited extent been evaluated under field conditions.
3. Although old wounds and body cleanliness were initially selected as promising ABMs, the literature review revealed limitations regarding the feasibility and reliability of measuring wounds and the validity of body cleanliness as an indicator of the welfare situation on farm.
4. Bursitis was selected to reflect lying comfort on farm, however limited information was found on the actual use of this ABM *ante-mortem*, which raises questions on its feasibility for monitoring purposes.
5. The ABMs selected refer mostly to health-related welfare consequences and only to a little extent to detect inability to perform species-specific behaviour on farm leading to welfare consequences (such as resting problems). No ABMs were identified to detect e.g. inability to perform exploratory or foraging behaviour, or restriction of movement. There are no ABMs for positive welfare that can be collected at slaughterhouses.
6. There is a large variation in the assessment methodologies used for all the ABMs (except for body condition and carcass fatness), which makes it difficult to compare the currently available data.
7. Unified and standardised scoring systems and protocols across different regions/countries are necessary to monitor and benchmark the welfare of fattening cattle transnationally.

8. The TRL of automated monitoring of ABMs at slaughterhouses is currently low. Automated methods for carcass fatness classification are the most advanced (certainty > 90%).

3.9.4 | Recommendations for ABMs collected in slaughterhouses

1. If a monitoring system is to be implemented, data on carcass fatness, carcass condemnations, lung lesions and skin lesions (old bruises and bursitis) in fattening cattle at slaughter could be collected to identify herds with some of the most common health-related welfare issues in fattening cattle. Such data would be useful to benchmark holdings and to inform about the need for implementation of preventive measures on farm.
2. More granular data on the underlying causes of condemnations are recommended.
3. Data already collected for commercial purposes, such as carcass fatness, should be made available to allow the incorporation of these ABMs in welfare monitoring systems.
4. Harmonised systems for data collection and recording should be developed, including training and reliability testing.
5. Systems for automatic and continuous assessment of ABMs and data recording should be developed ante and *post-mortem*.
6. For a comprehensive welfare assessment, ABMs collected at slaughter should be complemented with data on behavioural ABMs collected on farm and during transport, and with information on farm mortality.

3.10 | ABMs useful for detecting and monitoring each welfare consequence

Each highly relevant welfare consequence is linked to one or more animal-based measures (ABMs) that can be used for its assessment. An ABM is a response or effect observed in an animal that can be used as a 'diagnostic tool' for evaluating its welfare (EFSA, 2015). These ABMs can be physiological, behavioural or histopathological, for example. They can be directly observed in the animal, measured in a biological sample or indirectly derived with the use of animal records.

The following section provides a definition of each ABM, an interpretation of how the ABM is related to each selected welfare consequence, and a qualitative assessment of the feasibility, sensitivity and specificity of each ABM in relation to each welfare consequence.

In the context of this Scientific Opinion, feasibility refers to the practicality of carrying out an assessment of the ABM on farm during an animal welfare inspection conducted by an inspector of a Competent Authority, or a farmer or stockperson. The criteria for feasibility include factors such as access to the animals, visibility of the animals, costs and the time and training required to monitor and assess the ABM. For some ABMs, feasibility implies the handling and restraint of the animal.

The sensitivity of an ABM refers to the proportion of animals experiencing a WC that manifest that ABM. It therefore indicates the ABM's ability to identify animals experiencing the WC, i.e. how good it is at detecting the WC in an animal or group of animals. An ABM that exhibits high sensitivity will produce a low number of false negatives. In contrast, the specificity of an ABM with respect to a WC is the proportion of animals that do not exhibit the ABM in question among those that are not experiencing a WC. Therefore, specificity refers to the extent to which an ABM is specific for one WC or relates to several WCs. An ABM that exhibits high specificity will produce a low number of false positives, and this implies that the ABM is specific to a single WC. A poor specificity implies that the ABM could also indicate something other than the WC of interest. This could be a different WC or WCs, or it could imply something else completely, like exercise, for example. Feasibility does not relate to the sensitivity and specificity of an ABM.

The assessment of feasibility, sensitivity and specificity involves categorising them as either high, moderate or low. The categorisation of an ABM as having either a high sensitivity or high specificity is based on expert knowledge. Instances of low sensitivity and low specificity are justified by providing examples where false negatives or false positives could be expected, respectively. The method used to assess the ABM plays an important role regarding sensitivity, specificity and feasibility of the ABM. However, these are not described in detail in this opinion.

In this section, ABMs identified for the WCs considered highly relevant under the housing section (Section 3.2) for beef cattle are presented (Tables 14–33).

TABLE 14 ABMs selected for the assessment of inability to perform exploratory or foraging behaviour.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Non-nutritive oral manipulation	Definition: Licking, chewing or sucking directed towards items such as bars, hutch, bedding and excluding the animal's own body or that of a neighbouring animal (adapted from Downey et al., 2022). Interpretation: Inability to perform foraging behaviour is indicated by increased frequency or duration of non-nutritive oral manipulation of objects (Ridge et al., 2020). Inability to perform diverse exploratory behaviour is indicated by increased non-nutritive oral manipulation, in particular of newly presented items (Schulze Westerath et al., 2009). Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extremely increased quantities and corresponding alterations in pen equipment can be easily recognised. Sensitivity: High. Specificity: Low. Non-nutritive oral manipulation is partly exploratory behaviour and can also be increased in situations of isolation stress. It can also indicate the inability to perform sucking behaviour.

TABLE 14 (Continued)

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Tongue rolling	Definition: Tongue is repeatedly moved in a full or partial circular pattern either inside or outside the mouth (Redbo, 1990). Interpretation: Inability to perform foraging behaviour is indicated by the occurrence and extent of tongue rolling (Ridge et al., 2020). There is no clear relationship between the inability to perform exploratory behaviour and the extent of tongue rolling. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extremely increased quantities can be easily recognised. Sensitivity: Low. Not all animals experiencing inability to perform foraging behaviour will show tongue rolling. Specificity: Low. Tongue rolling can also be due to prolonged hunger and inability to chew and/or ruminate, and is affected by the ability to perform other behaviours (e.g. comfort behaviour, Park, Foster, & Daigle, 2020).

TABLE 15 ABMs selected for the assessment of inability to chew and/or ruminate.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Non-nutritive oral manipulation	Definition: Licking, chewing or sucking directed towards a non-nutritive item, e.g. bars, hutch, bedding and excluding the animal's own body or that of a neighbouring animal (adapted from Downey et al., 2022). Interpretation: Inability to chew and/or ruminate is indicated by increased frequency or duration of non-nutritive oral manipulation. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extreme quantities and corresponding alterations in pen equipment can be easily recognised. Sensitivity: High. Specificity: Low. Non-nutritive oral manipulation is partly an exploration behaviour and can also be increased in situations of isolation stress. It can also indicate the inability to perform sucking behaviour.
Tongue rolling	Definition: An open mouth with extended tongue repetitively moving in and out and/or side-to-side (adapted from Park, Foster, & Daigle, 2020). Tongue is held in a full or partial circular position or moves in a full or partial circular motion (adapted from Downey et al., 2022). Interpretation: Inability to chew and/or ruminate is indicated by the increased occurrence and duration of tongue rolling. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extremely increased quantities can be easily recognised. Sensitivity: Low. Not all animals experiencing inability to chew and/or ruminate will show this behaviour. Specificity: High. Although it can also be due to prolonged hunger and inability to perform exploratory behaviour, and is affected by the ability to perform other behaviours (e.g. comfort behaviour, Park, Foster, & Daigle, 2020), a main cause of tongue rolling is insufficient ability to chew and ruminate.

TABLE 16 ABMs selected for the assessment of inability to perform comfort behaviour.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Self-grooming	Definition: Licking any part of the animal's own body, scratching with foot or horn or rubbing against an object (adapted from Horvath & Miller-Cushon, 2019). Interpretation: Absence or low levels of self-grooming indicate the inability to perform comfort behaviour. Feasibility: Low. Prolonged continuous observation is necessary to obtain reliable quantitative information. Sensitivity: High. Specificity: Low. Low levels of self-grooming may also be due to low levels or absence of skin irritation, or to low activity due to an impaired state of health.
Brush use[a]	Definition: The animal touches a brush with any part of the body (Newby et al., 2013, slightly modified). Interpretation: The inability to perform comfort behaviour is indicated by low levels of or no brush use, including lack of brush. However, increased brush use after introducing a new brush can indicate prior inability to perform comfort behaviour. Feasibility: Moderate. In case of a lacking brush, absence of brush use can be deduced. Determining reliably the level of brush use at individual or group level requires prolonged observation. Brush use can also be detected through sensors, but reliability is questionable (Toaff-Rosenstein et al., 2017). Sensitivity: High (but depends on the stocking density at the brush). Specificity: Low. Low levels of brush use may also result from low levels or absence of skin irritation, or from low activity due to an impaired state of health. Animals can also use other objects for self-grooming.

[a]Only applicable if a brush is present.

TABLE 17 ABMs selected for the assessment of inability to perform play behaviour.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Locomotor play	Definition: Galloping, leaping, jumping, bucking and turning (up- and sidewards movement) (modified after Jensen et al., 1998). Interpretation: Absence or low levels of locomotor play indicate the inability to perform play behaviour. The likelihood of locomotor play decreases with age. Feasibility: Low. Prolonged continuous observation is necessary to obtain reliable quantitative information. Sensitivity: High. Specificity: Low. Lower levels of locomotor play may also be due to an impaired health state.

(Continues)

TABLE 17 (Continued)

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Object play	Definition: Butting equipment such as water bowls, hayracks or fence-posts or butting straw or rubbing head, throat or neck in straw while kneeling on the two forelegs in a playful manner (modified after Jensen et al., 1998). Interpretation: Absence or low levels of object play indicate the inability to perform play behaviour. Feasibility: Low. Due to the overall infrequent and brief occurrence of play behaviours, prolonged continuous observations are required to obtain reliable data. Sensitivity: High. Specificity: Low. Lower levels of object play may also be due to an impaired health state.
Social play	Definition: Pushing, butting, horn rubbing on body or horn contacts in a non-agonistic manner (modified after Bagnato et al., 2023). Interpretation: Absence or low levels of social play indicate the inability to perform play behaviour. Feasibility: Low. Due to the overall infrequent and brief occurrence of play behaviours, prolonged continuous observations are required to obtain reliable data. Sensitivity: High. Specificity: Low. Lower levels of social play may also be due to an impaired health state.

TABLE 18 ABMs selected for the assessment of inability to perform sexual behaviour.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Mounting attempts	Definition: Sexually mature animal lifts their front legs from the ground but fails to support themself on a (sexual) partner. Interpretation: Low levels of mounting attempts in animals in heat indicate inability to perform sexual behaviour. Feasibility: Low. Prolonged continuous observations are required to obtain reliable data. Sensitivity: High (if no anti-mounting devices are present). Specificity: High.
Slipping while mounting	Definition: Loss of balance in which cattle lose their foothold, or one or more hooves slide unintendedly over a small distance on the floor surface. No other body parts except hooves and/or legs are in contact with the floor surface (Welfare Quality, 2023a). Interpretation: High levels of slipping while mounting of slipping indicate the inability to perform sexual behaviour. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extremely increased frequencies can be easily recognised. Sensitivity: High. Specificity: High.

TABLE 19 ABMs selected for the assessment of inability to avoid unwanted sexual behaviour.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Disorientated mounting	Definition: Disoriented mounts are head-to-head, head-to-side and intention mounts. These occur when an animal is being mounted by another animal (same sex or different sex) and shows attempts to avoid such contact, e.g. moving away or changing position. Interpretation: Inability to avoid unwanted sexual behaviour is indicated by increased frequencies of disoriented mounting. Cattle kept at high stocking densities may be less interactive because of the presence of dominant animals, but these animals may exhibit their authority by mounting subordinate cattle. Homosexual mounting may persist in groups of intensively housed adult bulls, and some subordinate bulls may be excessively ridden as a form of aggression by the dominant bulls. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extremely increased frequencies can be easily recognised. Sensitivity: High. Specificity: High (in groups of bulls).
Skin lesions/wounds	Definition: 'Fresh or healed injuries on the skin of the body, which can be scratches, scabs (surface penetration of the epidermis) or wounds (penetration of the muscle tissue)' (EFSA, 2023). Interpretation: Skin lesions can be caused by trauma, e.g. falling down, slipping or collisions with harmful objects in the enclosures. Repeated mounting may lead to skin lesions per se. The greater the number of skin lesions per animal and the greater the number of animals with skin lesions, the higher the level of inability to avoid unwanted sexual behaviour. Feasibility: Moderate. Smaller lesions cannot be detected when animals can only be observed from outside the pen, or light conditions or soiling of animals impair inspection. However, large skin lesions are easy to detect. Sensitivity: Low. Repeated mounting may not always lead to skin lesions/wounds. Specificity: High when observed on the tail head in bulls. Low for other skin lesions that may be caused by different reasons (fights, chasing, slipping events, etc.). In heifers and cows, skin lesions on the tail head are observed and associated with normal mounting behaviour during heat.

TABLE 20 ABMs selected for the assessment of restriction of movement.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Slipping[a]	Definition: Loss of balance in which cattle lose their foothold, or one or more hooves slide unintendedly over a small distance on the floor surface. No other body parts except hooves and/or legs are in contact with the floor surface (Welfare Quality, 2023a). Interpretation: Slipping is mainly due to an inadequate grip of the floor. Insufficient space allowance can increase the contacts between animals, which makes difficult for them to balance, potentially leading to an increased number of slips. Feasibility: High (as it can be easily assessed by making the observed animals move). Sensitivity: Low. An animal restricted in movement may not show slipping events. Specificity: High.
Falling[a]	Definition: Loss of balance in which part(s) of the body, other than the feet and legs, get in contact with the floor surface (Consortium of the Animal Transport Guides Project, 2018). A fall is 'an unintentional loss of balance that leads to failure of postural stability'. Interpretation: Insufficient space allowance could make it difficult for animals to balance, leading to falls. Falling events are more frequently observed on slippery floors. Feasibility: Moderate. As the falling event must be observed, prolonged continuous observation is necessary to obtain reliable quantitative information. Sensitivity: Low. An animal restricted in movement may not show falling events. Specificity: Low. Animals may also fall due to handling stress.
Latency to stand up after a falling event[b]	Definition: A quantification of the time required by the animals to regain the standing up posture after falling down. Interpretation: An increased latency to stand up after falling could occur due to inadequate space to adjust posture. Feasibility: Low. Prolonged continuous observation is necessary to obtain reliable quantitative information. Sensitivity: High. Specificity: Low. Increased latency could arise from other reasons such as leg problems (e.g. lameness) or old age (leading to reduced mobility).
Step activity or walking distance[b,c]	Definition: Number of steps per day (step activity) or walking distance (distance walked per day). Alternatively, the assessment of space allowance may be considered a proxy. Interpretation: Low number of steps or low walking distance is indicative of restriction of movement. Feasibility: Low. These measures can be assessed using pedometers, GPS (Shepley, Lensink, Leruste, & Vasseur, 2020; Shepley, Lensink, & Vasseur, 2020). Currently, sensors are not consistently available on beef farms - potential future measure. Sensitivity: High. Specificity: Low. Low step activity could also be caused by other factors such as lameness or heat stress.
Locomotor play	Definition: Galloping, leaping, jumping, bucking and turning (up- and sidewards movement) (modified after Jensen et al., 1998). Interpretation: Restriction of movement due to both insufficient space allowance and slippery flooring system prevents cattle from showing locomotor play behaviour. The likelihood of locomotor play decreases with age. Feasibility: Low. Due to the overall infrequent and brief occurrence of play behaviours, prolonged continuous observations are required to obtain reliable data. Sensitivity: High. Specificity: Low. Lower levels of locomotor play may also be due to an impaired health state.

[a]These ABMs focus mostly on aspects related to impaired movement due to floor quality and less due to spatial constraints.

[b]For the assessment of the effect of a housing system, these ABMs do not apply if cattle spend part of the day on pasture, and during specific times of the production cycle (e.g. parturition).

[c]Sensitivity and specificity of the ABM was assessed in a qualitative manner, considering a situation of a farm inspection by veterinary authorities to assess the welfare at the herd level.Further considerations: ABM for restriction of movement could be locomotory activity, but this requires long observation times or access to automatic data recording, e.g. use of accelerometers. Alternatively, the assessment of space allowance may be considered a proxy.

TABLE 21 ABMs selected for the assessment of resting problems.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Lying time	Definition: Time spent with flank in contact with ground (Winckler et al., 2015). Interpretation: Short lying time (< 9 h/day; Tucker et al., 2021) for cattle housed indoors is indicative of resting problems. Feasibility: Moderate. Prolonged observation is necessary to obtain reliable quantitative information, but it can also be recorded using sensor technology (e.g. Ledgerwood et al., 2010). Sensitivity: High. Specificity: Low. A short lying time can also be related to group stress or separation stress.
Thwarted lying intentions	Definition: Repeated ground sniffing with sweeping movements without lying down (Österman & Redbo, 2001) or repeated bending of the carpal joint without reaching the carpal stance phase. Interpretation: Inadequate resting area (low space allowance or unsuitable resting surface) can hamper cattle attempts to lie down. Several attempts might be observed. Feasibility: Low. Prolonged continuous observation is necessary to obtain reliable quantitative information. Sensitivity: High. Specificity: High.

(Continues)

TABLE 21 (Continued)

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Duration of lying down movement	Definition: Duration of behaviour sequence starting with bending of the first carpal joint and ending with pulling out the front leg after the hindquarter has touched ground (Welfare Quality, 2023a). Interpretation: Longer duration is indicative of a higher degree of resting problems. Feasibility: High. Sensitivity: Low. Thwarted lying intentions have a higher sensitivity than the lying down movement itself. Specificity: Low. Animals with leg problems will take longer to lie down.
Deviation from normal, uninterrupted getting up movement	Definition: Deviation from normal getting up movements, such as non-fluent movement, long pause on knees, some difficulty in rising, e.g. awkward twisting of head and neck, or deviation from the normal sequence of events (Chaplin & Munksgaard, 2001). Interpretation: Resting problems are indicated by a higher proportion of observed animals showing a deviation from normal getting up movements. Feasibility: High (via direct observation at individual level; rising movements can be assessed in a standardised test situation, i.e. encouraging animals to stand up). Sensitivity: High. Specificity: High (resting problems can be a linked WC of restriction of movement).
Lying behaviour synchronisation	Definition: Percentage of animals simultaneously exhibiting a lying posture. Different thresholds of synchronous posture are possible (e.g. 70%, 80% or 100% (Stoye et al., 2012). Interpretation: A lower degree of lying synchrony is indicative of resting problems. Feasibility: Low. Prolonged observation is necessary to obtain reliable quantitative information. Expected to be higher in the future when validated sensors for monitoring cattle activity become available for use in beef farms. Sensitivity: High (more sensitive than lying time). Specificity: Low. Group stress or heat stress may lead to low synchrony.
Time spent in lateral recumbency	Definition: Lying with legs extended (relaxed posture) (Færevik et al., 2008; Ketelaar de Lauwere & Smits, 1991). Interpretation: Lack of adoption of this type of posture suggests resting problems. Feasibility: Low. Prolonged observation is necessary to obtain reliable quantitative information and validated automated monitoring systems (e.g. video) are not yet available on beef cattle farms. Sensitivity: High. Specificity: Low. Cattle may not lie down in a relaxed posture due to cold stress or group stress.
Overlying	Definition: Animals lying down (or attempting to) on conspecifics. Interpretation: When space is restricted, overlying can occur as some animals are observed to lie down on another animal when both attempt to lie down at the same time. Feasibility: Low. Prolonged observation is necessary to obtain reliable quantitative information. Sensitivity: High. Specificity: High.
Hock (tarsus) alterations	Definition: Integument alteration on the hock that includes multiple clinical presentations ranging from mild hair loss to cellulitis, swelling and ulceration, and even severe alterations in subcutaneous tissue, bones or joints (e.g. Welfare Quality, 2023a). Interpretation: Higher prevalence of hock alterations is indicative of resting problems. Feasibility: High. Sensitivity: High. Specificity: High.
Knee (carpus) alterations	Definition: Integument alteration on the knee that include multiple clinical presentations ranging from mild hair loss to cellulitis, swelling and ulceration, and even severe alterations in subcutaneous tissue, bones or joints (e.g. Welfare Quality, 2023a). Interpretation: Higher prevalence of knee alterations is indicative of resting problems. Feasibility: High. Sensitivity: High. Specificity: High.

TABLE 22 ABMs selected for the assessment of group stress.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Skin lesions	Definition: Tissue damage such as bruises, scratches and wounds (EFSA AHAW Panel, 2012a) caused by physical agonistic interactions or in the course of retreat from conspecifics, at the head, neck, shoulder, back, abdomen, flank, hindquarters, udder and anogenital region. This excludes technopathies, defined as areas of hair loss, ulcers or swellings likely resulting from improper housing equipment and typically occurring in multiple animals at similar, mostly protruding body sites, such as the hocks, carpal joints, hip bones, shoulders or neck. Interpretation: The greater the number of skin lesions per animal and the greater the proportion of animals with skin lesions, the higher the level of group stress. Feasibility: Moderate. Smaller lesions cannot be detected when animals can only be observed from outside the pen, or light conditions or soiling of animals impair inspection. However, large skin lesions are easy to detect. Sensitivity: High (although much lower in hornless than in horned cattle). Specificity: High (as long as they are distinguished from technopathies).

TABLE 22 (Continued)

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Physical agonistic interactions	Definition: Agonistic behaviour is defined as social behaviour related to social hierarchy and includes aggressive as well as submissive behaviours (Welfare Quality, 2023a). Physical agonistic interactions include head-butting, displacement involving physical contact, chasing, fighting and chasing up (Welfare Quality, 2023a). Interpretation: Increased group stress due to mixing of groups or individuals, competition for resources or lack of withdrawal space is indicated by increased frequencies of physical agonistic interactions. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but extremely increased frequencies can be easily recognised. Sensitivity: High (although slight increases in group stress may not be reflected by increased agonistic interactions, and restriction of space and slippery floors may decrease the frequency of agonistic interactions despite high group stress levels). Specificity: High.
Body condition score	Definition: Body condition scoring (BCS) is used to visually assess the level of body fat by evaluating the loin, tail head, hip bones, spine and ribs. The overall body shape and fat cover are assessed, differentiating between a satisfactory (at most two body regions classified as very lean) and a very lean (classified as very lean in at least three body regions) body condition (Welfare Quality, 2023a). The following criteria are taken into account: Cavity around tail head; Visible depression between backbone and hip bones (*tuber coxae*); Ends of transverse processes distinguishable; Tail head, hip bones (*tuber coxae*), spine and ribs visible. Interpretation: Group stress is indicated by the presence and an increased proportion of very lean animals, as e.g. repeated displacements from the feed bunk result in impaired feed intake. Feasibility: High (but visibility of all individuals may be impaired under certain housing conditions). Sensitivity: Low. Cattle will only show low body condition if group stress and prevention from accessing feed sources occur over a long period of time. Specificity: Low. Situations of prolonged hunger not caused by group stress or chronic disease may also result in poor body condition.

TABLE 23 ABMs selected for the assessment of handling stress.

ABM[a]	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Avoidance distance	Definition: Percentage of animals that can be touched by an approaching observer, or cannot be touched but can be approached up to a certain distance (< 50 cm, 50–100 cm, > 100 cm), in a standardised test on group level (Welfare Quality, 2023a). The avoidance distance classes can also be applied at individual level. Interpretation: Increased avoidance distance indicates negative past experiences during human-animal interactions, including handling. Feasibility: Moderate. Performing the standardised test is time-consuming, but extreme avoidance distances are easy to recognise. Sensitivity: High. Specificity: High.
Slipping	Definition: Loss of balance in which the animal loses its foothold, or one or more hooves slide unintentionally over a short distance on the floor surface (Consortium of the Animal Transport Guides Project, 2018). No other body parts except hooves and/or legs are in contact with the floor surface. Slipping is noticed as a lowering of an animals´ body due to the gliding or folding of leg/legs, possibly in combination with an interruption of movement (Welfare Quality, 2023a). Interpretation: Cattle may slip as a result of hasty or violent handling, behaviour of other animals, slippery ground, slope or obstacles. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased occurrences can be easily recognised. Sensitivity: Low. Cattle may not slip due to handling stress. Specificity: Low. Cattle may slip for other reasons, i.e. the quality of the flooring or antagonistic encounters.
Falling	Definition: Loss of balance in which part(s) of the body, other than the feet and legs, get in contact with the floor surface (Consortium of the Animal Transport Guides Project, 2018). A fall is 'an unintentional loss of balance that leads to failure of postural stability'. Interpretation: Cattle may fall as a result of hasty or aggressive handling. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased occurrences can be easily recognised. Sensitivity: Low. Cattle may not fall due to handling stress. Specificity: Low. Cattle may fall due to other reasons such as behaviour of other animals, slippery ground, slope or obstacles.
Freezing	Definition: Freezing is defined as when the route is free in front or behind the animal but the animal refuses to move forward or backwards within 4 s from being touched/coerced by the handler. If the animal takes more than one step and stops again, or moves backwards, a 'freeze' is recorded again when a new driving attempt is made. An animal that stops but continues to walk when the handler drives it forward is not frozen (Welfare Quality, 2023a). Interpretation: Cattle may freeze as a fear response to handling. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased occurrences can be easily recognised. Sensitivity: Low. Cattle may not freeze due to handling stress. Specificity: High.

(Continues)

TABLE 23 (Continued)

ABM[a]	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Moving backwards	Definition: Moving backwards is defined as when the animal moves backwards, by itself or as a reaction to handling. When an animal takes a few steps backwards to achieve balance or changes position in relation to other animals when crowding, it is not considered as moving backwards (Welfare Quality, 2023a). Interpretation: Cattle may move backwards as a fear response to handling. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased occurrences can be easily recognised. Sensitivity: Low. Cattle may not move backwards due to handling stress. Specificity: High.
Vocalisations	Definition: Frequency of open-mouth vocalisations with inhalation between two occurrences, i.e. of mooing and bellowing (Johnsen et al., 2015; Loberg et al., 2008). Interpretation: Increased handling stress is indicated by increased frequency of vocalisations (Green et al., 2021; Johnsen et al., 2015). Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased occurrences can be easily recognised. Sensitivity: Low. Cattle may not vocalise due to handling stress. Specificity: Low. Vocalisations may also occur in cases of prolonged hunger or separation stress.
Respiratory rate or occurrence of panting	Definition: Frequency of breathing, usually measured by counting the movements of the flank through direct observation and converting it into number of breaths per minute. Panting is accompanied by a decrease in tidal volume and can be measured through a 5-point score: 0 – normal respiration; 1 – elevated respiration; 2 – moderate panting and/or presence of drool or small amount of saliva; 3 – heavy open-mouth panting; saliva usually present; 4 – severe open-mouth panting accompanied by protruding tongue and excessive salivation; usually with neck extended forward (Mader et al., 2006). Interpretation: Increased handling stress is indicated by an increased respiratory rate or the occurrence of panting as result of high physical activity (Lees, Sullivan, et al., 2019). Feasibility: High. Sensitivity: Low. Cattle may not pant or increase their respiratory rate due to handling stress. Specificity: Low. Animals may pant or increase their respiratory rate due to other reasons such as respiratory disorders (e.g. pneumonia) or heat stress.

[a]Except avoidance distance, all ABMs used to assess handling stress can only be assessed while the animals are handled.

TABLE 24 ABMs selected for the assessment of separation stress.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Vocalisations	Definition: Frequency of open-mouth vocalisations with inhalation between two occurrences, i.e. of mooing and bellowing (Johnsen et al., 2015; Loberg et al., 2008). Interpretation: Increased separation stress is indicated by increased frequencies of vocalisations, as agitated animals tend to increase the frequency of vocalisations (Green et al., 2021; Johnsen et al., 2015). Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased frequencies can be easily recognised. Sensitivity: Low. Cattle may not vocalise due to separation stress. Specificity: Low. Vocalisations may also occur in cases of prolonged hunger or handling stress.
Lying time	Definition: Time spent with flank in contact with the ground (Flower & Weary, 2001; Stěhulová et al., 2008; Winckler et al., 2015). Interpretation: Increased separation stress is indicated by a decreased lying duration. Feasibility: Moderate. Prolonged observation is necessary to obtain reliable quantitative information, but it can also be recorded using sensor technology (e.g. Ledgerwood et al., 2010). Sensitivity: High. Specificity: Low. A low lying duration can also be related to prolonged hunger, group stress or resting problems.
Frequency of lying bouts	Definition: Number of times when the animal switches from standing to lying. Interpretation: Increased separation stress is indicated by an increased number of lying bouts. Feasibility: Moderate. Prolonged observation is necessary to obtain reliable quantitative information, but it can also be recorded using sensor technology (e.g. Ledgerwood et al., 2010). Sensitivity: Low. Separation stress can also be present without increased frequencies of lying bouts. Specificity: Low. Increased frequencies of lying bouts can also be related to group stress or inappropriate environmental conditions, particularly in the lying area.
Feeding duration	Definition: Amount of time the animal spends taking feed into the mouth, followed by chewing and swallowing (Loberg et al., 2008). Interpretation: Increased separation stress is indicated by a decreased feeding duration. Feasibility: Low. Prolonged observation is necessary to obtain reliable quantitative information. Sensitivity: High. Specificity: Low. A low feeding duration can also be related to sickness, group stress or inappropriate environmental conditions, particularly in the feeding area.
Duration of locomotion or pacing	Definition: Pacing is moving forth and back parallel to walls, pen partitions, fences (Johnsen et al., 2015, slightly modified). Interpretation: Increased separation stress is indicated by increased pacing. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased frequencies can be easily recognised. In addition, it can be recorded using sensor technology (e.g. Ledgerwood et al., 2010). Sensitivity: High. Specificity: Low. Increased pacing can also be related to group stress or handling stress.

TABLE 25 ABMs selected for the assessment of sensory under-and/or overstimulation.[a]

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Non-nutritive oral manipulation	Definition: Licking, chewing or sucking directed towards items such as bars, hutch, bedding and excluding the animal's own body or that of a neighbouring animal (Downey et al., 2022, slightly modified). Interpretation: Sensory understimulation is indicated by increased frequency or duration of non-nutritive oral manipulation of objects (Schulze Westerath et al., 2009). Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extremely increased quantities and corresponding alterations in pen equipment can be easily recognised. Sensitivity: High. Specificity: Low. Non-nutritive oral manipulation can also occur and be increased in situations of isolation stress or when the animals are not able to perform sucking behaviour.
Tongue rolling	Definition: Tongue is repeatedly moved in a full or partial circular pattern either inside or outside the mouth (Redbo, 1990). Interpretation: Sensory understimulation is indicated by the occurrence and extent of tongue rolling. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information. However, extremely increased quantities can be easily recognised. Sensitivity: High. Specificity: Low. Tongue rolling can also occur in situations where the animals experience inability to chew and/or ruminate.
Restlessness	Definition: Number of transitions between behaviours or between classes of behaviours (Wildemann, 2023). Interpretation: Higher restlessness is indicative of sensory understimulation in fattening cattle. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased frequencies can be easily recognised. Sensitivity: High. Specificity: Low. Restlessness can be due to subclinical ruminal acidosis.

[a]Here only the aspect of 'understimulation' is addressed, because the issue of 'overstimulation' was not identified for any of the factors assessed.

TABLE 26 ABMs selected for the assessment of soft tissue lesions and integument damage.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Hairless spots	Definition: Areas with hair loss (skin not damaged) (EFSA AHAW Panel, 2012a). Interpretation: The greater the number of hairless spots per animal and the greater the proportion of animals with hairless spots, the higher the level of soft tissue lesions and integument damage. Feasibility: Moderate. Smaller areas with hair loss cannot be detected when animals can only be observed from outside the pen, or light conditions or soiling of animals impair the inspection. However, large hairless spots are easier to detect. Sensitivity[a]: High (although lower in hornless than in horned cattle). Specificity: High.
Wounds, scratches	Definition: Injury to the body involving broken skin or scab (Welfare Quality, 2023a). Interpretation: The greater the number of wounds/scratches per animal and the greater the proportion of animals with wounds/scratches, the higher the level of soft tissue lesions and integument damage. Feasibility: Moderate. Smaller wounds/scratches cannot be detected when animals can only be observed from outside the pen, or light conditions or soiling of animals impair the inspection. However, large wounds are easier to detect. Sensitivity[a]: High. Specificity: High.
Swellings	Definition: Obvious increase in circumference compared to healthy state in any part of the body (Welfare Quality, 2023a). Interpretation: The greater the number of swellings per animal and the greater the proportion of animals with swellings, the higher the level of soft tissue lesions and integument damage. Feasibility: Moderate. Smaller lesions cannot be detected when animals can only be observed from outside the pen, or light conditions or soiling of animals impair the inspection. However, severe swellings are easier to detect. Sensitivity[a]: High. Specificity: High.
Bruises	Definition: Accumulation of blood and serum at the site of a contusion, visible *post-mortem* as superficial discoloration of tissue due to haemorrhages caused by rupture of the vascular supply (Sánchez et al., 2022). Interpretation: The greater the number of bruises per animal and the greater the proportion of animals with bruises, the higher the level of soft tissue lesions and integument damage. Feasibility: Low. Bruises are subcutaneous alterations and require *post-mortem* inspection at the slaughterhouse for reliable assessment (EFSA AHAW Panel, 2023a). Sensitivity: High. Specificity: High.

[a]These ABMs should always be assessed together to obtain a full picture of soft tissue lesions and integument damage.

TABLE 27 ABMs selected for the assessment of locomotory disorders (including lameness).

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Lameness	Definition: Lameness is the inability to express a normal and functional gait pattern in one or more limbs. It can be assessed using a 2-point scale (0 = not lame, 2 = lame) (Welfare Quality, 2023a). Interpretation: The higher the score and the greater the proportion of animals with lameness, the higher the level of locomotory disorders. Feasibility: High (but visibility of all individuals while walking may be impaired under certain housing conditions). Sensitivity: High. Specificity: High.
Digital dermatitis	Definition: Bacterial infection of the heel bulbs causing ulcerative lesions. The type and severity of lesions can be assessed using the M-stages scoring system (Egger-Danner et al., 2020). Interpretation: The higher the score per animal and the higher the proportion of animals with digital dermatitis, the higher the level of locomotory disorders. Feasibility: Low. Scoring requires animal restraint as for hoof trimming, which is not a routine practice in beef cattle. Moreover, it should be performed by professional claw trimmers or veterinarians. Sensitivity: High. Specificity: High (relates solely to identification of digital dermatitis).
Claw lesions	Definition: Claw horn disruption lesions are a set of non-infectious foot lesions that include double soles, horn fissures, sole haemorrhages, sole ulcers and white line disease (reviewed in Alvergnas et al., 2019). Different scoring systems exist for different types of claw lesions (Egger-Danner et al., 2020). Interpretation: The higher the proportion of animals with claw lesions, the higher the level of locomotory disorders. Feasibility: Low. Scoring requires animal restraint as for hoof trimming, which is not a routine practice in beef cattle. Moreover, it should be performed by professional claw trimmers or veterinarians. Sensitivity: High. Specificity: High.
Hock (tarsus) alterations	Definition: Integument alteration on the hock that includes multiple clinical presentations such as ulceration and swelling (Welfare Quality, 2023a). Interpretation: The greater the number of hock alterations per animal and the higher the proportion of animals with hock alterations, the higher the level of locomotory disorders. Feasibility: High (but visibility of all individuals may be impaired under certain housing conditions). Sensitivity: Low. Animals with hock alterations do not necessarily show impaired locomotion. Specificity: Low. Hock alterations may also be due to resting problems.
Knee (carpus) alterations	Definition: Integument alteration on the carpal joint that includes multiple clinical presentations such as ulceration and swelling (Welfare Quality, 2023a). Interpretation: The greater the number of knee alterations per animal and the higher the proportion of animals with knee alterations, the higher the level of locomotory disorders. Feasibility: High (but visibility of all individuals may be impaired under certain housing conditions). Sensitivity: Low. Animals with knee alterations do not necessarily show impaired locomotion. Specificity: Low. Knee alterations may also be due to resting problems.

TABLE 28 ABMs selected for the assessment of metabolic disorders: Subacute rumen acidosis (SARA).

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Rumen pH (measured by rumen bolus)	Definition: Logarithmic measure of the concentration of hydrogen ions in the rumen liquid. A rumen pH lower than or equal to 6 is considered as a sign of subacute rumen acidosis (Neubauer et al., 2018). Interpretation: The higher the proportion of animals with rumen pH < 6, the higher the level of metabolic disorders, here: SARA. Feasibility: Low. Rumen pH can be measured continuously by a rumen bolus equipped with a pH electrode, administered orally with a dedicated balling gun (Villot et al., 2018). Such expensive technology is not widely applied in beef cattle. It is already used in some dairy farms and may become realistic with advances in technology. Sensitivity: High. Specificity: High.
Diarrhoea	Definition: Loose watery faeces below the tail head on both sides of the tail, area affected at least the size of a hand (Welfare Quality, 2023a). Interpretation: The higher the proportion of animals with diarrhoea, the higher the level of metabolic disorders, here: SARA. Feasibility: High. Sensitivity: Low. Not all animals affected by SARA will show signs of diarrhoea. Specificity: Low. Also gastro-enteric disorders may lead to diarrhoea.

TABLE 29 ABMs selected for the assessment of gastro-enteric disorders.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Diarrhoea	Definition: Loose watery faeces below the tail head on both sides of the tail, area affected at least the size of a hand (Welfare Quality, 2023a). Interpretation: The higher the proportion of animals with diarrhoea, the higher the level of gastro-enteric disorders. Feasibility: High. Sensitivity: Low. Not all animals affected by gastro-enteric disorders will show signs of diarrhoea. Specificity: Low. Also metabolic disorders such as SARA may lead to diarrhoea.
Bloated rumen	Definition: A characteristic 'bulge' between the hip bone and the ribs on the left side of the animal (Welfare Quality, 2023a). Interpretation: The higher the proportion of animals with bloated rumen, the higher the level of gastro-enteric disorders. Feasibility: High. Sensitivity: Low. Not all gastro-enteric disorders are associated with a bloated rumen. Specificity: High (in standing animals; transitory bloated rumen can be observed on lying cattle)

TABLE 30 ABMs selected for the assessment of respiratory disorders.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Respiratory rate	Definition: Frequency of breathing, usually measured by counting the movements of the flank through direct observation and converting it into number of breaths per minute. Interpretation: Increased respiratory rate indicates affected breathing capacity due to respiratory disorders. Feasibility: High. Sensitivity: High. Specificity: Low. Cattle may show increased respiratory rate due to other reasons for the activation of the sympathetic system (such as handling) or thermal regulation (heat stress).
Hampered respiration	Definition: Deep and laboured or overtly difficult breathing. Expiration is supported by the muscles of the trunk, mostly accompanied by a pronounced sound. Respiratory rate may be only slightly increased (Welfare Quality, 2023a). Interpretation: Hampered respiration indicates impaired lung function due to respiratory disorders. Feasibility: High. Sensitivity: High. Specificity: High.
Respiratory sounds at lung auscultation[a]	Definition: Increased respiratory sounds at lung auscultation. Interpretation: Pathological alterations in lung parenchyma or fluid accumulation due to infection/inflammation lead to altered lung sounds at auscultation during respiration. Feasibility: Low. It requires animal restraint and skilled personnel/veterinarians. Sensitivity: Low. Upper respiratory disease may not always cause increased respiratory sounds. Specificity: High.
Coughing[a]	Definition: Brisk expel of air from the lungs by sudden contraction of the diaphragm and intercostal muscles in response to irritation of the lower respiratory tract (EFSA AHAW Panel, 2023a). Interpretation: Cough indicates that the respiratory tract is irritated. Different types of coughs might be linked to different respiratory diseases, which can involve the upper or the lower respiratory tract, with or without fluid accumulation. Feasibility: High. Sensitivity: High (in acute cases of bovine respiratory disease). Specificity: High.
Nasal discharge[a]	Definition: Nasal discharges can be serous (thin, clear and colourless), catarrhal (grey, flocculent), purulent (thick, yellow) or haemorrhagic (red). Assigned scores range from 0 to 3 as the clinical sign progresses from normal to very abnormal. 0 = normal, serous discharge; 1 = small amount of unilateral, cloudy discharge; 2 = bilateral, cloudy or excessive mucus; 3 = copious, bilateral mucopurulent nasal discharge (Love et al., 2014). Interpretation: Upper and lower respiratory tract infection will cause an increase in mucous or purulent discharge. Unilateral discharge indicates localised conditions involving the nose or sinuses, whereas bilateral discharge may indicate thoracic or systemic conditions (Love et al., 2014; McGuirk, 2008). Feasibility: High (clearly visible from the nostril). Sensitivity: Low. Animals with respiratory disease do not always show nasal discharge. Specificity: High.

[a]ABMs included in scoring systems for detection of bovine respiratory disease.

TABLE 31 ABMs selected for the assessment of prolonged hunger.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Body condition score (BCS)	Definition: Body condition scoring (BCS) is used to visually assess the level of body fat by evaluating the loin, tail head, hip bones, spine and ribs. The overall body shape and fat cover are assessed, differentiating between a satisfactory (at most two body regions classified as very lean) and a very lean (classified as very lean in at least three body regions) body condition (Welfare Quality, 2023a). The following criteria are taken into account: Cavity around tail head; Visible depression between backbone and hip bones (*tuber coxae*); Ends of transverse processes distinguishable; Tail head, hip bones (*tuber coxae*), spine and ribs visible. Interpretation: Prolonged hunger is indicated by the presence and an increased proportion of very lean animals. Feasibility: High (but visibility of all individuals may be impaired under certain housing conditions). Sensitivity: Low. Fattening cattle will only show lean body condition after a long period of hunger. Specificity: Low. Situations of group stress or chronic disease may also result in poor body condition.
Vocalisations	Definition: Frequency of open-mouth vocalisations with inhalation between two occurrences, i.e. of mooing and bellowing (Johnsen et al., 2015; Loberg et al., 2008). Interpretation: When cattle are hungry, they tend to increase the frequency of vocalisations. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased frequencies can be easily recognised. Sensitivity: Low. Cattle may not vocalise when experiencing hunger. Specificity: Low. Vocalisations may also occur e.g. during separation stress and handling stress.

TABLE 32 ABMs selected for the assessment of prolonged thirst.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Drinking behaviour	Definition: Drinking bout frequency and water intake per bout (Nizzi et al., 2025). Interpretation: Increased frequency of drinking bouts and/or increased water intake at each bout can indicate thirst (as shown for dairy cattle after 2–4 h water restriction after milking compared to cows with no restriction; Nizzi et al., 2025). Feasibility: Low (unless automated). Prolonged continuous observation is necessary to obtain reliable quantitative information. Sensitivity: High. Specificity: High.

TABLE 33 ABMs selected for the assessment of heat stress.

ABM	Definition, interpretation, feasibility, sensitivity and specificity of the ABM
Panting	Definition: Increase in respiratory frequency accompanied by a decrease in tidal volume to increase ventilation of the upper respiratory tract. Panting can be measured through a 5-point score: 0 – normal respiration; 1 – elevated respiration; 2 – moderate panting and/or presence of drool or small amount of saliva; 3 – heavy open-mouth panting; saliva usually present; 4 – severe open-mouth panting accompanied by protruding tongue and excessive salivation; usually with neck extended forward (Mader et al., 2006). Interpretation: Increase in respiratory rate is the first visible response of cattle to heat stress and changes with thermal environment. Initially, the rate of panting increases proportionally to the increase in environmental temperature. Subsequently, after reaching a certain environmental temperature, the rate of panting slows down and the animal's physiological mechanisms change. Feasibility: Moderate. Prolonged continuous observation is necessary to obtain reliable quantitative information, but highly increased frequencies and occurrences can be easily recognised. Sensitivity: High. Specificity: Low. Animals may pant due to other reasons, such as respiratory disorders (e.g. pneumonia) or acute physical exercise (Lees, Sullivan, et al., 2019).
Sweating	Definition: Visual signs of sweating in cattle are wet patches along the animals' backs and shoulders. Interpretation: When the effective temperature increases above the comfort zone, the animals will start to sweat. Further increases in the effective temperature will see increased rates of sweating. Evaporative cooling is the only form of heat loss once the ambient temperature exceeds the skin temperature (Cunningham, 2002). Feasibility: High. Sensitivity: Low. Cattle sweat at a low rate so that it may be imperceptible (Gebremedhin et al., 2008; Wang et al., 2020). Specificity: Low. Cattle may sweat due to other reasons such as intense physical exercise or stress.

4 | CONCLUSIONS

The certainty of each conclusion statement was assessed following the method described in Section 2.4. When a certainty category is added at the end of a paragraph, it is considered that it applies to all sentences within that paragraph.

For conclusions on:

- Housing conditions – Water access, see Section 3.2.1.4.
- Flooring, see Section 3.2.2.4.

- Nutrition and feeding, see Section 3.2.3.4.
- Lack of outdoor access, Section 3.2.4.4.
- Lack of environmental enrichment, see Section 3.2.5.4.
- Mixing of cattle, see Section 3.2.6.4.
- High environmental temperatures, see Section 3.2.7.4.
- Minimum space allowance, see Section 3.3.5.
- Welfare of cattle kept on pasture, Section 3.4.1.6.
- Welfare of fattening cattle in outdoor feedlots, Section 3.4.2.3.
- Risks associated with weaning of suckler calves, Section 3.5.4.
- Mutilations – disbudding and dehorning, see Section 3.6.1.4.
- Mutilations – castration, see Section 3.6.2.4.
- Mutilations – tail docking, see Section 3.6.3.4.
- Breeding and genetics – polledness, see Section 3.7.2.6.
- Breeding and genetics – temperament, see Section 3.7.3.6.
- Breeding and genetics – hypermuscularity, see Section 3.7.4.6.
- Breeding and genetics – dystocia and C-section, see Section 3.7.5.6.
- Breeding and genetics – maternal ability, see Section 3.7.6.6.
- Decision making criteria for euthanasia of cull cows kept for beef, see Section 3.8.4.
- ABMs in slaughterhouses to monitor the level of welfare on farm for fattening cattle, see Section 3.9.3.

5 | RECOMMENDATIONS

For recommendations on:

- Water access, see Section 3.2.1.5.
- Flooring, see Section 3.2.2.5.
- Nutrition and feeding, see Section 3.2.3.5.
- Lack of outdoor access, Section 3.2.4.5.
- Lack of environmental enrichment, see Section 3.2.5.5.
- Mixing of cattle, see Section 3.2.6.5.
- High environmental temperatures, see Section 3.2.7.5.
- Minimum space allowance, see Section 3.3.6.
- Welfare of cattle kept on pasture, Section 3.4.1.5.
- Welfare of fattening cattle in outdoor feedlots, Section 3.4.2.4.
- Risks associated with weaning of suckler calves, Section 3.5.5.
- Mutilations – disbudding and dehorning, see Section 3.6.1.5.
- Mutilations – castration, see Section 3.6.2.5.
- Mutilations – tail docking, see Section 3.6.3.5.
- Breeding and genetics – polledness, see Section 3.7.2.7.
- Breeding and genetics – temperament, see Section 3.7.3.7.
- Breeding and genetics – hypermuscularity, see Section 3.7.4.7.
- Breeding and genetics – dystocia and C-section, see Section 3.7.5.7.
- Breeding and genetics – maternal ability, see Section 3.7.6.7.
- Decision making criteria for euthanasia of cull cows kept for beef, see Section 3.8.4.
- ABMs in slaughterhouses to monitor the level of welfare on farm for fattening cattle, see Section 3.9.4.

ABBREVIATIONS

ABM(s)	animal-based measure(s)
ACTH	adrenocorticotropic hormone
AHAW	Animal Health and Animal Welfare
AM	ante-mortem
BCS	body condition score
BRD	bovine respiratory disease
BW	body weight
CNB	cornual nerve block
C-sections	caesarean sections
CSF(s)	concrete slatted floor(s)
DM	double muscled
DMI	dry matter intake
dmin	minimum inter-individual distance
EKE	expert knowledge elicitation

GIN	gastro-intestinal nematodes
GnRH	gonadotrophin releasing hormone
GWAS(s)	genome-wide association study/studies. GWAS is a research approach used in genetics to identify associations between specific genetic variations and particular traits, diseases or conditions in populations. It aims to identify associations of genotypes with phenotypes by testing for differences in the allele frequency of genetic variants between individuals who are similar but differ phenotypically.
LCT	lower critical temperature
MS(s)	Member State(s)
NDF	neutral detergent fibre
NGO(s)	Non-Governmental Organization(s)
NSAID(s)	non-steroidal anti-inflammatory drug(s)
OR	odds ratio
OWP	outwintering pads
peNDF	physically effective neutral detergent fibre
PM	post-mortem
QTL(s)	quantitative trait locus/loci
RH	relative humidity
RM(s)	rubber mat(s)
SARA	subacute rumen acidosis
SCC	somatic cell count
TCZ	thermal comfort zone
THI	temperature-humidity index
TMR	total mixed ration
TNZ	thermoneutral zone
ToR(s)	Term(s) of Reference
UCT	upper critical temperature
WC(s)	welfare consequence(s)
WG	Working Group
WOAH	World Organisation for Animal Heath

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REFERENCES

Absmanner, E., Rouha-Mülleder, C., Scharl, T., Leisch, F., & Troxler, J. (2009). Effects of different housing systems on the behaviour of beef bulls—An on-farm assessment on Austrian farms. *Applied Animal Behaviour Science*, *118*(1–2), 12–19. https://doi.org/10.1016/j.applanim.2009.02.009

Adam, M., Jokela, A., Salla, K., Aho, R., Raekallio, M., Hänninen, L., & Hokkanen, A.-H. (2025). Efficacy of procaine, with and without epinephrine, compared to lidocaine in local Anesthesia for calves before thermocautery disbudding. *Journal of Veterinary Pharmacology and Therapeutics*, *48*(3), 170–179. https://doi.org/10.1111/jvp.13493

Adamczyk, K., Jagusiak, W., & Makulska, J. (2018). Analysis of lifetime performance and culling reasons in black-and-White Holstein-Friesian cows compared with crossbreds. *Annals of Animal Science*, *18*(4), 1061–1079. https://doi.org/10.2478/aoas-2018-0036

Adamczyk, K., Pokorska, J., Makulska, J., Earley, B., & Mazurek, M. (2013). Genetic analysis and evaluation of behavioural traits in cattle. *Livestock Science*, *154*(1–3), 1–12. https://doi.org/10.1016/j.livsci.2013.01.016

Adcock, S. J., Cruz, D. M., & Tucker, C. B. (2020). Behavioral changes in calves 11 days after cautery disbudding: Effect of local anesthesia. *Journal of Dairy Science*, *103*(9), 8518–8525. https://doi.org/10.3168/jds.2020-18337

Adcock, S. J., Downey, B. C., Owens, C., & Tucker, C. B. (2023). Behavioral changes in the first 3 weeks after disbudding in dairy calves. *Journal of Dairy Science*, *106*(9), 6365–6374. https://doi.org/10.3168/jds.2023-23237

Adcock, S. J. J., & Tucker, C. B. (2018). The effect of disbudding age on healing and pain sensitivity in dairy calves. *Journal of Dairy Science*, *101*(11), 10361–10373. https://doi.org/10.3168/jds.2018-14987

Adcock, S. J. J., Vieira, S. K., Alvarez, L., & Tucker, C. B. (2019). Iron and laterality effects on healing of cautery disbudding wounds in dairy calves. *Journal of Dairy Science*, *102*(11), 10163–10172. https://doi.org/10.3168/jds.2018-16121

Agethen, K., von Davier, Z., & Efken, J. (2023). *Steckbriefe zur Tierhaltung in Deutschland: Mastrinder*. Thünen-Institut für Betriebswirtschaft. 15 pp. https://www.thuenen.de/media/ti-themenfelder/Nutztierhaltung_und_Aquakultur/Haltungsverfahren_in_Deutschland/Rindermast/Steckbrief_Mastrinder_2023.pdf.

Ahlberg, C. M., Allwardt, K., Broocks, A., Bruno, K., McPhillips, L., Taylor, A., Krehbiel, C. R., Calvo-Lorenzo, M. S., Richards, C. J., Place, S. E., DeSilva, U., VanOverbeke, D. L., Mateescu, R. G., Kuehn, L. A., Weaber, R. L., Bormann, J. M., & Rolf, M. M. (2018). Environmental effects on water intake and water intake prediction in growing beef cattle. *Journal of Animal Science*, *96*(10), 4368–4384. https://doi.org/10.1093/jas/sky267

Aiello, D., Patel, K., & Lasagna, E. (2018). The myostatin gene: An overview of mechanisms of action and its relevance to livestock animals. *Animal Genetics*, *49*(6), 505–519. https://doi.org/10.1111/age.12696

Albertsen, D., & Held, S. (2017). The natural weaning window of suckler beef cattle. *Proceedings of the 51st Congress of the International Society for Applied Ethology*, 234. https://doi.org/10.3920/9789086868582_191

Aldersey, J. E., Sonstegard, T. S., Williams, J. L., & Bottema, C. D. K. (2020). Understanding the effects of the bovine POLLED variants. *Animal Genetics*, *51*(2), 166–176. https://doi.org/10.1111/age.12915

Algra, M., de Keijzer, L., Arndt, S. S., van Eerdenburg, F. J. C. M., & Goerlich, V. C. (2023). Evaluation of the thermal response of the horns in dairy cattle. *Animals*, *13*(3), 500. https://doi.org/10.3390/ani13030500

Ali, S., Goonewardene, L. A., & Basarab, J. A. (1994). Estimating water consumption and factors affecting intake in grazing cattle. *Canadian Journal of Animal Science*, *74*(3), 551–554. https://doi.org/10.4141/cjas94-077

Allais-Bonnet, A., Grohs, C., Medugorac, I., Krebs, S., Djari, A., Graf, A., Fritz, S., Seichter, D., Baur, A., Russ, I., Bouet, S., Rothammer, S., Wahlberg, P., Esquerré, D., Hoze, C., Boussaha, M., Weiss, B., Thépot, D., Fouilloux, M. N., … Capitan, A. (2013). Novel insights into the bovine polled phenotype and horn ontogenesis in *Bovidae*. *PLoS One*, *8*(5), e63512. https://doi.org/10.1371/journal.pone.0063512

Allen, W. M. (1977). New developments in muscle pathology: Nutritional myopathies including “muscular dystrophy” or “white muscle disease”. *Veterinary Science Communications*, *1*(1), 243–250. https://doi.org/10.1007/bf02267655

Alvergnas, M., Strabel, T., Rzewuska, K., & Sell-Kubiak, E. (2019). Claw disorders in dairy cattle: Effects on production, welfare and farm economics with possible prevention methods. *Livestock Science*, *222*, 54–64. https://doi.org/10.1016/j.livsci.2019.02.011

Amatayakul-Chantler, S., Hoe, F., Jackson, J. A., Roca, R. O., Stegner, J. E., King, V., Howard, R., Lopez, E., & Walker, J. (2013). Effects on performance and carcass and meat quality attributes following immunocastration with the gonadotropin releasing factor vaccine Bopriva or surgical castration of Bos indicus bulls raised on pasture in Brazil. *Meat Science*, *95*(1), 78–84. https://doi.org/10.1016/j.meatsci.2013.04.008

ANABIC (Associazione Nazionale Allevatori Bovini Italiani da Carne). (2024). Razza Marchigiana - Ipertrofia Muscolare. https://www.anabic.it/inner-page.html?pagina=%27//www.anabic.it/anomalie_genetiche/marchigiana_miostatina.htm%27&altezza=1000&titolo=Centri%20Genetici%20-%20Marchigiana%20-%20Ipertrofia%20Muscolare [Accessed on 20 June 2024].

ANABORAPI (Associazione Nazionale Allevatori Bovini di Razza Piemontese). (online a). Valutazioni genetiche. https://anaborapi.it/selezione/ [Accessed on 20 June 2024].

ANABORAPI (Associazione Nazionale Allevatori Bovini di Razza Piemontese). (online b). BUTA BIN: Note Illustrative. https://lg.anaborapi.it/pdf/bb_intro_it.pdf [Accessed on 4 April 2024].

ANABORAPI I-BEEF. (online). Docilità -Temperamento in Centro Genetico. https://ibeef.anaborapi.it/pbl/ibeef?cOrd=0&cFilt=0&cOth=l&cOth2=0&nRec=2 [Accessed on 4 April 2024].

Anadón, A., Martínez-Larrañaga, M. R., Ares, I., & Martínez, M. A. (2018). *Poisonous plants of the Europe* (pp. 891–909). Veterinary Toxicology. Elsevier. https://doi.org/10.1016/B978-0-12-811410-0.00062-3

Andersen, H. R., Jensen, L. R., Munksgaard, L., & Ingvartsen, K. L. (1997). Influence of floor space allowance and access sites to feed trough on the production of calves and young bulls and on the carcass and meat quality of young bulls. Acta Agriculturae Scandinavica, Section A —. *Animal Science*, *47*(1), 48–56. https://doi.org/10.1080/09064709709362369

Andersen, I. L., Andenæs, H., Bøe, K. E., Jensen, P., & Bakken, M. (2000). The effects of weight asymmetry and resource distribution on aggression in groups of unacquainted pigs. *Applied Animal Behaviour Science*, *68*(2), 107–120. https://doi.org/10.1016/S0168-1591(00)00092-7

Anderson, D. E., Desrochers, A., & Jean, G. S. (2008). Management of Tendon Disorders in cattle. *Veterinary Clinics of North America: Food Animal Practice*, *24*(3), 551–566. https://doi.org/10.1016/j.cvfa.2008.07.008

Andersson, M., Schaar, J., & Wiktorsson, H. (1984). Effects of drinking water flow rates and social rank on performance and drinking behaviour of tied-up dairy cows. *Livestock Production Science*, *11*(6), 599–610. https://doi.org/10.1016/0301-6226(84)90074-5

Andreae, U. (1979). Zur Aktivitätenfrequenz von Mastbullen bei Spaltenbodenhaltung. *Landbauforschung Völkenrode Sonderheft*, *48*, 89–94.

Andreae, U., & Smidt, D. (1982). Behavioural alterations in young cattle on slatted floors. In *Disturbed behaviour in farm animals: Seminar in the EEC program of coordination of research on animal welfare* (pp. 51–60). University of Hohenheim.

Ansay, M., & Hanset, R. (1979). Anatomical, physiological and biochemical differences between conventional and double-muscled cattle in the Belgian blue and White breed. *Livestock Production Science*, *6*(1), 5–13. https://doi.org/10.1016/0301-6226(79)90027-7

Appuhamy, J. A. D. R. N., Judy, J. V., Kebreab, E., & Kononoff, P. J. (2016). Prediction of drinking water intake by dairy cows. *Journal of Dairy Science*, *99*(9), 7191–7205. https://doi.org/10.3168/jds.2016-10950

Aquilani, C., Confessore, A., Bozzi, R., Sirtori, F., & Pugliese, C. (2022). Review: Precision livestock farming technologies in pasture-based livestock systems. *Animal*, *16*(1), 100429. https://doi.org/10.1016/j.animal.2021.100429

Arias, R. A., & Mader, T. L. (2011). Environmental factors affecting daily water intake on cattle finished in feedlots. *Journal of Animal Science*, *89*(1), 245–251. https://doi.org/10.2527/jas.2010-3014

Armengol, R., & Fraile, L. (2018). Descriptive study for culling and mortality in five high-producing Spanish dairy cattle farms (2006–2016). *Acta Veterinaria Scandinavica*, *60*(45), 1–11. https://doi.org/10.1186/s13028-018-0399-z

Arthington, J. D., & Ranches, J. (2021). Trace mineral nutrition of grazing beef cattle. *Animals*, *11*(10), 2767. https://doi.org/10.3390/ani11102767

Arthur, P. (1995). Double muscling in cattle: A review. *Australian Journal of Agricultural Research*, *46*(8), 1493–1515. https://doi.org/10.1071/AR9951493

Arthur, P. F., Makarechian, M., & Price, M. A. (1988). Incidence of dystocia and perinatal calf mortality resulting from reciprocal crossing of double-muscled and normal cattle. *The Canadian Veterinary Journal*, *29*(2), 163–167.

Asai, M., Berryere, T. G., & Schmutz, S. M. (2004). The locus in cattle maps to bovine chromosome 19. *Animal Genetics*, *35*(1), 34–39. https://doi.org/10.1111/j.1365-2052.2003.01079.x

ASEAVA (Asociación Española de criadores de ganado vacuno selecto de la raza Asturiana de los Valles). (2024a). *Interpretaciòn del Catàlogo de la raza Asturiana de los Valles. Asociación Española de criadores de ganado vacuno selecto de la raza Asturiana de los Valles on-line site* .

ASEAVA (Asociación Española de criadores de ganado vacuno selecto de la raza Asturiana de los Valles). (2024b). Sementales. https://www.aseava.com/sementales_lista.aspx?tipo=LG [Accessed on 4 June 2024].
Assié, S., Seegers, H., Makoschey, B., Désiré-Bousquié, L., & Bareille, N. (2009). Exposure to pathogens and incidence of respiratory disease in young bulls on their arrival at fattening operations in France. *Veterinary Record*, *165*(7), 195–199. https://doi.org/10.1136/vr.165.7.195
Australian Agricultural Council. Ruminants Subcommittee. (1990). *Feeding standards for Australian livestock: Ruminants. Standing Committee on Agriculture Ruminants Subcommittee* .
Auvermann, B., Koziel, J., Parker, D., Parnell, C., Amosson, S., Greene, L., Weinheimer, B., Cole, N., & Sweeten, J. (2001). *Cattle feedlot odor and dust control: Approaches and recent results*. American Agricultural Economics Association Meeting. https://www.ars.usda.gov/research/publications/publication/?seqNo115=118264.
AVMA (American Veterinary Medical Association). (2020). AVMA guidelines for the euthanasia of animals: 2020 edition. 121 pp. https://cec.ufro.cl/images/documentos/marco_normativo/2020_Euthanasia_Final_1-15-20.pdf [Accessed March 2013].
Baars, T., Jahreis, G., Lorkowski, S., Rohrer, C., Vervoort, J., & Hettinga, K. (2019). Changes under low ambient temperatures in the milk lipodome and metabolome of mid-lactation cows after dehorning as a calf. *Journal of Dairy Science*, *102*(3), 2698–2702. https://doi.org/10.3168/jds.2018-15425
Bagnato, S., Pedruzzi, L., Goracci, J., & Palagi, E. (2023). The interconnection of hierarchy, affiliative behaviours, and social play shapes social dynamics in Maremmana beef cattle. *Applied Animal Behaviour Science*, *260*, 105868. https://doi.org/10.1016/j.applanim.2023.105868
Barreto, A. N., Barioni Junior, W., Pezzopane, J. R. M., Bernardi, A. C. C., Pedroso, A. F., Marcondes, C. R., Jacintho, M. A. C., Romanello, N., Sousa, M. A. P., Nanni Costa, L., & Garcia, A. R. (2022). Thermal comfort and behavior of beef cattle in pasture-based systems monitored by visual observation and electronic device. *Applied Animal Behaviour Science*, *253*, 105687. https://doi.org/10.1016/j.applanim.2022.105687
Barrier, A. C., Coombs, T. M., Dwyer, C. M., Haskell, M. J., & Goby, L. (2014). Administration of a NSAID (meloxicam) affects lying behaviour after caesarean section in beef cows. *Applied Animal Behaviour Science*, *155*, 28–33. https://doi.org/10.1016/j.applanim.2014.02.015
Barrier, A. C., Ruelle, E., Haskell, M. J., & Dwyer, C. M. (2012). Effect of a difficult calving on the vigour of the calf, the onset of maternal behaviour, and some behavioural indicators of pain in the dam. *Preventive Veterinary Medicine*, *103*(4), 248–256. https://doi.org/10.1016/j.prevetmed.2011.09.001
Barrozo, D., Buzanskas, M. E., Oliveira, J. A., Munari, D. P., Neves, H. H. R., & Queiroz, S. A. (2012). Genetic parameters and environmental effects on temperament score and reproductive traits of Nellore cattle. *Animal*, *6*(1), 36–40. https://doi.org/10.1017/S1751731111001169
Basiel, B. L., Barragan, A. A., Felix, T. L., & Dechow, C. D. (2024). The impact of beef sire breed on dystocia, stillbirth, gestation length, health, and lactation performance of cows that carry beef× dairy calves. *Journal of Dairy Science*, *107*(4), 2241–2252. https://doi.org/10.3168/jds.2023-24112
Becker, J., Doherr, M. G., Bruckmaier, R. M., Bodmer, M., Zanolari, P., & Steiner, A. (2012). Acute and chronic pain in calves after different methods of rubber-ring castration. *The Veterinary Journal*, *194*(3), 380–385. https://doi.org/10.1016/j.tvjl.2012.04.022
Beede, D. K., & Myers, Z. H. (2000). Water nourishment of dairy cattle. Proceedings of the 24th Quebec Symposium on Dairy Nutrition, Saint-Hyacinthe, Quebec, Canada. 19 October 2000. pp. 1–28.
Beilharz, R., & Zeeb, K. (1982). Social dominance in dairy cattle. *Applied Animal Ethology*, *8*(1–2), 79–97. https://doi.org/10.1016/0304-3762(82)90134-1
Bellinge, R. H. S., Liberles, D. A., Iaschi, S. P. A., O'brien, P. A., & Tay, G. K. (2005). Myostatin and its implications on animal breeding: A review. *Animal Genetics*, *36*(1), 1–6. https://doi.org/10.1111/j.1365-2052.2004.01229.x
Bennett, G. L., Thallman, R. M., Snelling, W. M., Keele, J. W., Freetly, H. C., & Kuehn, L. A. (2021). Genetic changes in beef cow traits following selection for calving ease. Translational. *Animal Science*, *5*(1), txab009. https://doi.org/10.1093/tas/txab009
Berdusco, N., Kelton, D., Haley, D., Wood, K. M., & Duffield, T. F. (2024). Can 60 days of feeding lead to increased fitness for transport in cull dairy cows? *Journal of Dairy Science*, *107*(9), 7267–7275. https://doi.org/10.3168/jds.2023-24525
Bergamasco, L., Edwards-Callaway, L. N., Bello, N. M., Mijares, S. H., Cull, C. A., Rugan, S., Mosher, R. A., Gehring, R., & Coetzee, J. F. (2021). Unmitigated surgical castration in calves of different ages: Cortisol concentrations, heart rate variability, and infrared thermography findings. *Animals*, *11*(9), 2719. https://doi.org/10.3390/ani11092719
Berger, P. J. (1994). Genetic prediction for calving ease in the United States: Data, models, and use by the dairy industry. *Journal of Dairy Science*, *77*(4), 1146–1153. https://doi.org/10.3168/jds.S0022-0302(94)77051-X
Bergeron, R., Badnell-Waters, A. J., Lambton, S., & Mason, G. (2006). Stereotypic oral behaviour in captive ungulates: Foraging, diet and gastrointestinal function. In G. Mason & J. Rushen (Eds.), *Stereotypic animal behaviour: Fundamentals and applications to welfare* (pp. 19–57). CABI. Oxfordshire. https://doi.org/10.1079/9780851990040.0019
Berges, K., & Stracke, J. (2023). Einsatz von Beschäftigungsmaterial in einem konventionellen Bullenmaststall. In *Aktuelle Arbeiten zur artgemäßen Tierhaltung 2023* (pp. 188–198). KTBL. https://www.ktbl.de/fileadmin/user_upload/Allgemeines/Download/DVG-Tagung/P_11537.pdf
Bernier, A. F., Erickson, N., Campbell, J., & Moya, D. (2025). Effects of administering local anesthesia immediately before surgical castration on indicators of pain and discomfort of beef calves. *Translational Animal Science*, *9*. https://doi.org/10.1093/tas/txaf010
Berry, D., Friggens, N., Lucy, M., & Roche, J. (2016). Milk production and fertility in cattle. *Annual Review of Animal Biosciences*, *4*, 269–290. https://doi.org/10.1146/annurev-animal-021815-111406
Bertelsen, M., & Jensen, M. B. (2019). Does dairy calves' motivation for social play behaviour build up over time? *Applied Animal Behaviour Science*, *214*, 18–24. https://doi.org/10.1016/j.applanim.2019.02.017
Bevans, D. W., Beauchemin, K. A., Schwartzkopf-Genswein, K. S., McKinnon, J. J., & McAllister, T. A. (2005). Effect of rapid or gradual grain adaptation on subacute acidosis and feed intake by feedlot cattle. *Journal of Animal Science*, *83*(5), 1116–1132. https://doi.org/10.2527/2005.8351116x
Biagini, D., & Lazzaroni, C. (2019). Cow-calf morphometric relationships and birth dystocia in Piemontese breed. Proceedings of the 23nd ASPA Congress, Sorrento (Italy).
Bica, G. S., Pinheiro Machado Filho, L. C., & Teixeira, D. L. (2021). Beef cattle on pasture have better performance when supplied with water trough than pond. Frontiers in veterinary. *Science*, *8*, 616904. https://doi.org/10.3389/fvets.2021.616904
Bica, G. S., Pinheiro Machado Filho, L. C., Teixeira, D. L., De Sousa, K. T., & Hötzel, M. J. (2020). Time of grain supplementation and social dominance modify feeding behavior of heifers in rotational grazing systems. Frontiers in veterinary. *Science*, *7*, 61. https://doi.org/10.3389/fvets.2020.00061
Birkelo, C., & Lounsbery, J. (1992). *Limiting intake of finishing diets by restricting access time to feed and the interaction with monensin* (p. 4). South Dakota State University. https://openprairie.sdstate.edu/sd_beefreport_1992/11
Blackshaw, J., & Blackshaw, A. (1994). Heat stress in cattle and the effect of shade on production and behaviour: A review. *Australian Journal of Experimental Agriculture*, *34*(2), 285–295. https://doi.org/10.1071/EA9940285
Blackshaw, J., Blackshaw, A., & Kusano, T. (1987). Cattle behaviour in a saleyard and its potential to cause bruising. *Australian Journal of Experimental Agriculture*, *27*(6), 753–757. https://doi.org/10.1071/EA9870753
Blackshaw, J. K., Blackshaw, A. W., & McGlone, J. J. (1997). Buller steer syndrome review. *Applied Animal Behaviour Science*, *54*(2–3), 97–108. https://doi.org/10.1016/S0168-1591(96)01170-7
Blanco, M., Villalba, D., Ripoll, G., Sauerwein, H., & Casasús, I. (2008). Effects of pre-weaning concentrate feeding on calf performance, carcass and meat quality of autumn-born bull calves weaned at 90 or 150 days of age. *Animal*, *2*(5), 779–789. https://doi.org/10.1017/S1751731108001808
Blazquez, N. B., Long, S. E., Mayhew, T. M., Perry, G. C., Prescott, N. J., & Wathes, C. (1994). Rate of discharge and morphology of sweat glands in the perineal, lumbodorsal and scrotal skin of cattle. *Research in Veterinary Science*, *57*(3), 277–284. https://doi.org/10.1016/0034-5288(94)90118-X

Blömke, L., Volkmann, N., & Kemper, N. (2020). Evaluation of an automated assessment system for ear and tail lesions as animal welfare indicators in pigs at slaughter. *Meat Science*, *159*, 107934. https://doi.org/10.1016/j.meatsci.2019.107934

Boakari, Y. L., & Ali, H. E. S. (2021). Management to prevent dystocia. *Bovine Reproduction*, 590–596. https://doi.org/10.1002/9781119602484.ch49

Bøe, K. E., & Færevik, G. (2003). Grouping and social preferences in calves, heifers and cows. *Applied Animal Behaviour Science*, *80*(3), 175–190. https://doi.org/10.1016/S0168-1591(02)00217-4

Boesch, D., Steiner, A., Gygax, L., & Stauffacher, M. (2008). Burdizzo castration of calves less than 1-week old with and without local anaesthesia: Short-term behavioural responses and plasma cortisol levels. *Applied Animal Behaviour Science*, *114*(3), 330–345. https://doi.org/10.1016/j.applanim.2008.02.010

Boissy, A., & Le Neindre, P. (1997). Behavioral, cardiac and cortisol responses to brief peer separation and Reunion in cattle. *Physiology & Behavior*, *61*(5), 693–699. https://doi.org/10.1016/S0031-9384(96)00521-5

Boissy, A., Manteuffel, G., Jensen, M. B., Moe, R. O., Spruijt, B., Keeling, L. J., Winckler, C., Forkman, B., Dimitrov, I., Langbein, J., Bakken, M., Veissier, I., & Aubert, A. (2007). Assessment of positive emotions in animals to improve their welfare. *Physiology & Behavior*, *92*(3), 375–397. https://doi.org/10.1016/j.physbeh.2007.02.003

Boland, H., Scaglia, G., Swecker, W., Jr., & Burke, N. (2008). Effects of alternate weaning methods on behavior, blood metabolites, and performance of beef calves. The professional animal. *Scientist*, *24*(6), 539–551. https://doi.org/10.15232/S1080-7446(15)30903-7

Bolt, S. L., Boyland, N. K., Mlynski, D. T., James, R., & Croft, D. P. (2017). Pair housing of dairy calves and age at pairing: Effects on weaning stress, health, production and social networks. *PLoS One*, *12*(1), e0166926. https://doi.org/10.1371/journal.pone.0166926

Borderas, T. F., Pawluczuk, B., de Passillé, A. M., & Rushen, J. (2004). Claw hardness of dairy cows: Relationship to water content and claw lesions. *Journal of Dairy Science*, *87*(7), 2085–2093. https://doi.org/10.3168/jds.S0022-0302(04)70026-0

Bortolussi, G., McIvor, J., Hodgkinson, J., Coffey, S., & Holmes, C. (2005). The northern Australian beef industry, a snapshot. 2. Breeding herd performance and management. *Australian Journal of Experimental Agriculture*, *45*(9), 1075–1091. https://doi.org/10.1071/EA03097

Bortoluzzi, E. M., Schmidt, P. H., Brown, R. E., Jensen, M., Mancke, M. R., Larson, R. L., Lancaster, P. A., & White, B. J. (2023). Image classification and automated machine learning to classify lung pathologies in deceased feedlot cattle. *Veterinary Sciences*, *10*(2), 113. https://doi.org/10.3390/vetsci10020113

Bouissou, M. (1972). Influence of body weight and presence of horns on social rank in domestic cattle. *Animal Behaviour*, *20*(3), 474–477. https://doi.org/10.1016/S0003-3472(72)80011-3

Bouissou, M.-F. (1980). Social relationships in domestic cattle under modern management techniques. *Italian Journal of Zoology, Bollettino di Zoologia*, *47*(3–4), 343–353. https://doi.org/10.1080/11250008009438691

Bouissou, M. F., Boissy, A., Pl, N., & Veissier, I. (2001). The social behaviour of cattle. In *Social behaviour in farm animals* (pp. 113–145). CABI Publishing. https://doi.org/10.1079/9780851993973.0113

Bouissou, M. F., & Hovels, J. (1976). Effect of early social contact on some aspects of social behaviour in domestic cattle. *Biology of Behaviour*, *1*, 17–36.

Boyle, L. A., Boyle, R. M., & French, P. (2008). Welfare and performance of yearling dairy heifers out-wintered on a wood-chip pad or housed indoors on two levels of nutrition. *Animal*, *2*(5), 769–778. https://doi.org/10.1017/S1751731108001870

Bradford, H., Moser, D., Minick Bormann, J., & Weaber, R. (2015). Estimation of genetic parameters for udder traits in Hereford cattle. *Journal of Animal Science*, *93*(6), 2663–2668. https://doi.org/10.2527/jas.2014-8858

Braghieri, A., Pacelli, C., De Rosa, G., Girolami, A., De Palo, P., & Napolitano, F. (2011). Podolian beef production on pasture and in confinement. *Animal*, *5*(6), 927–937. https://doi.org/10.1017/S1751731110002685

Braun, U., Storni, E., Hässig, M., & Nuss, K. (2014). Eating and rumination behaviour of Scottish Highland cattle on pasture and in loose housing during the winter. *Schweizer Archiv für Tierheilkunde*, *156*(9), 425–431. https://doi.org/10.1024/0036-7281/a000624

Breck, S., Clark, P., Howery, L., Johnson, D., Kluever, B., Smallidge, S., & Cibils, A. (2012). A perspective on livestock–wolf interactions on Western rangelands. *Rangelands*, *34*(5), 6–11. https://doi.org/10.2111/RANGELANDS-D-11-00069.1

Brenninkmeyer, C., Dippel, S., Brinkmann, J., March, S., Winckler, C., & Knierim, U. (2016). Investigating integument alterations in cubicle housed dairy cows: Which types and locations can be combined? *Animal*, *10*(2), 342–348. https://doi.org/10.1017/S1751731115001032

Bretschneider, G. (2005). Effects of age and method of castration on performance and stress response of beef male cattle: A review. *Livestock Production Science*, *97*(2), 89–100. https://doi.org/10.1016/j.livprodsci.2005.04.006

Brown, A., Towne, S., & Jephcott, S. (2003). An observational study on calf losses on the Barkly Tableland Technical bulletin (Northern Territory. Department of Business Industry and Resource Development) no. 309. p. 14.

Brown, A. C., Powell, J. G., Kegley, E. B., Gadberry, M. S., Reynolds, J. L., Hughes, H. D., Carroll, J. A., Burdick Sanchez, N. C., Thaxton, Y. V., Backes, E. A., & Richeson, J. T. (2015). Effect of castration timing and oral meloxicam administration on growth performance, inflammation, behavior, and carcass quality of beef calves12. *Journal of Animal Science*, *93*(5), 2460–2470. https://doi.org/10.2527/jas.2014-8695

Brown, W. G., Jr. (1974). Some aspects of beef cattle behaviour as related to productivity. *Dissertation Abstracts International*, *34*, 1805.

Brown, M. S., Ponce, C. H., & Pulikanti, R. (2006). Adaptation of beef cattle to high-concentrate diets: Performance and ruminal metabolism. *Journal of Animal Science*, *84*(Suppl. E 13), E25–E33. https://doi.org/10.2527/2006.8413_supplE25x

Brown-Brandl, T. M. (2018). Understanding heat stress in beef cattle. *Revista Brasileira de Zootecnia*, *47*(e20160414). https://doi.org/10.1590/rbz4720160414

Brown-Brandl, T. M., Eigenberg, R. A., & Nienaber, J. A. (2010). Water spray cooling during handling of feedlot cattle. *International Journal of Biometeorology*, *54*, 609–616. https://doi.org/10.1007/s00484-009-0282-8

Brown-Brandl, T. M., Nienaber, J. A., Eigenberg, R. A., Mader, T. L., Morrow, J., & Dailey, J. (2006). Comparison of heat tolerance of feedlot heifers of different breeds. *Livestock Science*, *105*(1–3), 19–26. https://doi.org/10.1016/j.livsci.2006.04.012

Brscic, M., Ricci, R., Prevedello, P., Lonardi, C., De Nardi, R., Contiero, B., Gottardo, F., & Cozzi, G. (2015). Synthetic rubber surface as an alternative to concrete to improve welfare and performance of finishing beef cattle reared on fully slatted flooring. *Animal*, *9*(8), 1386–1392. https://doi.org/10.1017/S1751731115000592

Brünger, J., Dippel, S., Koch, R., & Veit, C. (2019). 'Tailception': Using neural networks for assessing tail lesions on pictures of pig carcasses. *Animal*, *13*(5), 1030–1036. https://doi.org/10.1017/S1751731118003038

Budras, K. D., Habel, R. E., Mülling, C. K., Greenough, P. R., Jahrmärker, G., Richter, R., & Starke, D. (2011). *Bovine anatomy: An illustrated text* (2nd ed.). Schlütersche. https://doi.org/10.1201/9783842683594

Buhman, M. J., Perino, L. J., Galyean, M. L., & Swingle, R. S. (2000). Eating and drinking Behaviors of newly received feedlot calves. *The Professional Animal Scientist*, *16*(4), 241–246. https://doi.org/10.15232/S1080-7446(15)31706-X

Bunter, K. L., & Johnston, D. J. (2013). Genetic parameters for calf mortality and correlated cow and calf traits in tropically adapted beef breeds managed in extensive Australian production systems. *Animal Production Science*, *54*(1), 50–59. https://doi.org/10.1071/AN12422

Bunter, K. L., Johnston, D. J., Wolcott, M. L., & Fordyce, G. (2014). Factors associated with calf mortality in tropically adapted beef breeds managed in extensive Australian production systems. *Animal Production Science*, *54*(1), 25–36. https://doi.org/10.1071/An12421

Burdick, N. C., Randel, R. D., Carroll, J. A., & Welsh, T. H., Jr. (2011). Interactions between temperament, stress, and immune function in cattle. *International Journal of Zoology*, *2011*(1), 373197. https://doi.org/10.1155/2011/373197

Burgstaller, J., Wittek, T., Sudhaus-Jörn, N., & Conrady, B. (2022). Associations between animal welfare indicators and animal-related factors of slaughter cattle in Austria. *Animals*, *12*(5), 659. https://doi.org/10.3390/ani12050659

Burrow, H. M. (1997). Measurements of temperament and their relationships with performance traits of beef cattle. *Animal Breeding Abstracts*, *65*, 477–495.

Burrow, H. M. (2001). Variances and covariances between productive and adaptive traits and temperament in a composite breed of tropical beef cattle. *Livestock Production Science*, *70*(3), 213–233. https://doi.org/10.1016/S0301-6226(01)00178-6

Cabezas-Garcia, E. H., Lowe, D., & Lively, F. (2021). Energy requirements of beef cattle: Current energy systems and factors influencing energy requirements for maintenance. *Animals*, *11*, 1–22. https://doi.org/10.3390/ani11061642

Cakmakci, C., Magalhaes, D. R., Pacor, V. R., de Almeida, D. H. S., Çakmakçı, Y., Dalga, S., Szabo, C., María, G. A., & Titto, C. G. (2023). Discovering the hidden personality of lambs: Harnessing the power of deep convolutional neural networks (DCNNs) to predict temperament from facial images. *Applied Animal Behaviour Science*, *267*, 106060. https://doi.org/10.1016/j.applanim.2023.106060

Caldrow, G. (2016). Health planning for the beef cow herd. In *Proceedings of the 29th world Buiatrics congress*. Ireland. https://www.ivis.org/library/wab/wbc-congress-ireland-2016/health-planning-for-beef-cow-herd

Calsamiglia, S., Blanch, M., Ferret, A., & Moya, D. (2012). Is subacute ruminal acidosis a pH related problem? Causes and tools for its control. *Animal Feed Science and Technology*, *172*(1–2), 42–50. https://doi.org/10.1016/j.anifeedsci.2011.12.007

Cambra-López, M., Aarnink, A. J. A., Zhao, Y., Calvet, S., & Torres, A. G. (2010). Airborne particulate matter from livestock production systems: A review of an air pollution problem. *Environmental Pollution*, *158*(1), 1–17. https://doi.org/10.1016/j.envpol.2009.07.011

Campbell, C. P., Marshall, S. A., Mandell, I. B., & Wilton, J. W. (1992). Effects of source of dietary neutral detergent fiber on chewing behavior in beef cattle fed pelleted concentrates with or without supplemental roughage. *Journal of Animal Science*, *70*(3), 894–903. https://doi.org/10.2527/1992.703894x

Canozzi, M. E. A., Mederos, A., Manteca, X., Turner, S., McManus, C., Zago, D., & Barcellos, J. O. J. (2017). A meta-analysis of cortisol concentration, vocalization, and average daily gain associated with castration in beef cattle. *Research in Veterinary Science*, *114*, 430–443. https://doi.org/10.1016/j.rvsc.2017.07.014

Capitan, A., Grohs, C., Weiss, B., Rossignol, M. N., Reversé, P., & Eggen, A. (2011). A newly described bovine type 2 Scurs syndrome segregates with a frame-shift mutation in *TWIST1*. *PLoS One*, *6*(7), e22242. https://doi.org/10.1371/journal.pone.0022242

Capitan, B., Krehbiel, C., Kirskey, R., Lauriault, L., Duff, G., & Donart, G. (2004). Effects of winter and summer forage type on pasture and feedlot performance and carcass characteristics by beef steers. *The Professional Animal Scientist*, *20*(3), 225–236. https://doi.org/10.15232/S1080-7446(15)31305-X

Caray, D., AB, d. R., Frouja, S., Andanson, S., & Veissier, I. (2015). Hot-iron disbudding: Stress responses and behavior of 1-and 4-week-old calves receiving anti-inflammatory analgesia without or with sedation using xylazine. *Livestock Science*, *179*, 22–28. https://doi.org/10.1016/j.livsci.2015.05.013

Care4Dairy. (2024). *End of career-cow* https://care4dairy.eu/wp-content/uploads/2024/03/End_of_Career-cow.pdf

Carroll, R. I., Forbes, A., Graham, D. A., & Messam, L. L. M. (2020). The impact of liver fluke infection on steers in Ireland: A meta-analytic approach. *Preventive Veterinary Medicine*, *174*, 104807. https://doi.org/10.1016/j.prevetmed.2019.104807

Carvalho, F. E., Espigolan, R., Berton, M. P., Neto, J. B. S., Silva, R. P., Grigoletto, L., Silva, R. M. O., Ferraz, J. B. S., Eler, J. P., Aguilar, I., Lôbo, R. B., & Baldi, F. (2020). Genome-wide association study and predictive ability for growth traits in Nellore cattle. *Livestock Science*, *231*, 103861. https://doi.org/10.1016/j.livsci.2019.103861

Casoni, D., Mirra, A., Suter, M. R., Gutzwiller, A., & Spadavecchia, C. (2019). Can disbudding of calves (one versus four weeks of age) induce chronic pain? *Physiology & Behavior*, *199*, 47–55. https://doi.org/10.1016/j.physbeh.2018.11.010

Castaneda, C., Sakaguchi, Y., & Gaughan, J. (2004). Relationships between climatic conditions and the behaviour of feedlot cattle. *Science Access*, *1*(1), 33–36. https://doi.org/10.1071/SA0401009

Caton, J. S., & Olson, B. E. (2016). Energetics of grazing cattle: Impacts of activity and climate1. *Journal of Animal Science*, *94*(suppl_6), 74–83. https://doi.org/10.2527/jas.2016-0566

Ceccobelli, S., Perini, F., Trombetta, M. F., Tavoletti, S., Lasagna, E., & Pasquini, M. (2022). Effect of Myostatin gene mutation on slaughtering performance and meat quality in Marchigiana bulls. *Animals*, *12*(4), 518. https://doi.org/10.3390/ani12040518

Cervantes, I., Gutiérrez, J. P., Fernández, I., & Goyache, F. (2010). Genetic relationships among calving ease, gestation length, and calf survival to weaning in the Asturiana de los Valles beef cattle breed. *Journal of Animal Science*, *88*(1), 96–101. https://doi.org/10.2527/jas.2009-2066

Červená, B., Anettová, L., Nosková, E., Pafčo, B., Pšenková, I., Javorská, K., Příhodová, P., Ježková, J., Václavek, P., & Malát, K. (2022). The winner takes it all: Dominance of Calicophoron daubneyi (Digenea: Paramphistomidae) among flukes in central European beef cattle. *Parasitology*, *149*(5), 612–621. https://doi.org/10.1017/S0031182021002158

Chaplin, S., & Munksgaard, L. (2001). Evaluation of a simple method for assessment of rising behaviour in tethered dairy cows. *Animal Science*, *72*(1), 191–197. https://doi.org/10.1017/S1357729800055685

Charlton, G. L., Rutter, S. M., East, M., & Sinclair, L. A. (2011). Preference of dairy cows: Indoor cubicle housing with access to a total mixed ration vs. access to pasture. *Applied Animal Behaviour Science*, *130*(1–2), 1–9. https://doi.org/10.1016/j.applanim.2010.11.018

Chen, J. M., Schütz, K. E., & Tucker, C. B. (2015). Cooling cows efficiently with sprinklers: Physiological responses to water spray. *Journal of Dairy Science*, *98*(10), 6925–6938. https://doi.org/10.3168/jds.2015-9434

Chen, J. M., Stull, C. L., Ledgerwood, D. N., & Tucker, C. B. (2017). Muddy conditions reduce hygiene and lying time in dairy cattle and increase time spent on concrete. *Journal of Dairy Science*, *100*(3), 2090–2103. https://doi.org/10.3168/jds.2016-11972

Chen, X., Ogdahl, W., Hulsman Hanna, L. L., Dahlen, C. R., Riley, D. G., Wagner, S. A., Berg, E. P., & Sun, X. (2021). Evaluation of beef cattle temperament by eye temperature using infrared thermography technology. *Computers and Electronics in Agriculture*, *188*, 106321. https://doi.org/10.1016/j.compag.2021.106321

Choinière, M., Melzack, R., Rondeau, J., Girard, N., & Paquin, M.-J. (1989). The pain of burns: Characteristics and correlates. *Journal of Trauma and Acute Care Surgery*, *29*(11), 1531–1539.

Choudhary, G. A., Patell, M. K., & Sulieman, H. A. (2015). The effects of repeated caesarean sections on maternal and fetal outcomes. *Saudi Journal of Medicine & Medical Sciences*, *3*(1), 44–49. https://doi.org/10.4103/1658-631X.149676

Ciborowska, P., Michalczuk, M., & Bień, D. (2021). The effect of music on livestock: Cattle, poultry and pigs. *Animals*, *11*(12), 3572. https://doi.org/10.3390/ani11123572

Clarke, M., & Kelly, A. (1996). *Some effects of shade on Hereford steers in a feedlot*.

Cockram, M. S. (2021). Invited review: The welfare of cull dairy cows. Applied. *Animal Science*, *37*(3), 334–352. https://doi.org/10.15232/aas.2021-02145

Coetzee, H. (2012). *Update on pain management in cattle*.

Coetzee, J., Gehring, R., Bettenhausen, A., Lubbers, B., Toerber, S., Thomson, D., Kukanich, B., & Apley, M. (2007). Attenuation of acute plasma cortisol response in calves following intravenous sodium salicylate administration prior to castration. *Journal of Veterinary Pharmacology and Therapeutics*, *30*(4), 305–313. https://doi.org/10.1111/j.1365-2885.2007.00869.x

Coetzee, J. F. (2011). A review of pain assessment techniques and pharmacological approaches to pain relief after bovine castration: Practical implications for cattle production within the United States. *Applied Animal Behaviour Science*, *135*(3), 192–213. https://doi.org/10.1016/j.applanim.2011.10.016

Coetzee, J. F., KuKanich, B., Mosher, R., & Allen, P. S. (2009). Pharmacokinetics of intravenous and oral meloxicam in ruminant calves. *Veterinary Therapeutics*, *10*(4), E1–E8.
Cohen, R. D. H., King, B. D., Thomas, L. R., & Janzen, E. D. (1990). Efficacy and stress of chemical versus surgical castration of cattle. *Canadian Journal of Animal Science*, *70*(4), 1063–1072. https://doi.org/10.4141/cjas90-129
Coimbra, P. A. D., Machado Filho, L. C. P., & Hötzel, M. J. (2012). Effects of social dominance, water trough location and shade availability on drinking behaviour of cows on pasture. *Applied Animal Behaviour Science*, *139*(3–4), 175–182. https://doi.org/10.1016/j.applanim.2012.04.009
Collineau, E., Corbière, F., Darnal, S., Holleville, N., & Salines, M. (2022). Analysis of bovine postmortem condemnation data in France: Contributions from a comprehensive and standardised information system at the slaughterhouse. *Veterinary Record*, *191*(2), e1733. https://doi.org/10.1002/vetr.1733
Collings, L., Weary, D., Chapinal, N., & Von Keyserlingk, M. (2011). Temporal feed restriction and overstocking increase competition for feed by dairy cattle. *Journal of Dairy Science*, *94*(11), 5480–5486. https://doi.org/10.3168/jds.2011-4370
Colston, K. P., Ede, T., Mendl, M. T., & Lecorps, B. (2024). Cold therapy and pain relief after hot-iron disbudding in dairy calves. *PLoS One*, *19*(7), e0306889. https://doi.org/10.1371/journal.pone.0306889
Compiani, R., Sgoifo Rossi, C. A., Baldi, G., & Desrochers, A. (2014). Dealing with lameness in Italian beef cattle rearing. *Large Animal Review*, *20*, 239–247.
Conneely, M., Berry, D. P., Sayers, R., Murphy, J. P., Lorenz, I., Doherty, M. L., & Kennedy, E. (2013). Factors associated with the concentration of immunoglobulin G in the colostrum of dairy cows. *Animal*, *7*(11), 1824–1832. https://doi.org/10.1017/S1751731113001444
Consortium of the Animal Transport Guides Project. (2018). Guide to good practices for the transport of cattle. https://data.europa.eu/doi/10.2875/352545
Cook, N. B., Mentink, R. L., Bennett, T. B., & Burgi, K. (2007a). The impact of mild heat stress and lameness on the time budgets of dairy cattle. *Proceedings of the 6th International Dairy Housing Conference, Minneapolis, Minnesota*. https://doi.org/10.13031/2013.22796
Cook, N. B., Mentink, R. L., Bennett, T. B., & Burgi, K. (2007b). The effect of heat stress and lameness on time budgets of lactating dairy cows. *Journal of Dairy Science*, *90*(4), 1674–1682. https://doi.org/10.3168/jds.2006-634
Cooke, R. F., Bohnert, D. W., Cappellozza, B. I., Mueller, C. J., & DelCurto, T. (2012). Effects of temperament and acclimation to handling on reproductive performance of beef females. *Journal of Animal Science*, *90*(10), 3547–3555. https://doi.org/10.2527/jas.2011-4768
Cooke, R. F., Moriel, P., Cappellozza, B. I., Miranda, V. F. B., Batista, L. F. D., Colombo, E. A., Ferreira, V. S. M., Miranda, M. F., Marques, R. S., & Vasconcelos, J. L. M. (2019). Effects of temperament on growth, plasma cortisol concentrations and puberty attainment in Nelore beef heifers. *Animal*, *13*(6), 1208–1213. https://doi.org/10.1017/S1751731118002628
Cooke, R. F., Schubach, K. M., Marques, R. S., Peres, R. F. G., Silva, L. G. T., Carvalho, R. S., Cipriano, R. S., Bohnert, D. W., Pires, A. V., & Vasconcelos, J. L. M. (2017). Effects of temperament on physiological, productive, and reproductive responses in *Bos indicus* beef cows. *Journal of Animal Science*, *95*(1), 1–8. https://doi.org/10.2527/jas.2016.1098
Corah, L. (1989). Body condition - an indicator of the nutritional status of beef cows. *Agri-Practice*, *10*(4), 25–28.
Cortese, M., Brščić, M., Ughelini, N., Andrighetto, I., Contiero, B., & Marchesini, G. (2020). Effectiveness of stocking density reduction on mitigating lameness in a Charolais finishing beef cattle farm. *Animals*, *10*(7), 1147. https://doi.org/10.3390/ani10071147
Cortés-Lacruz, X., Casasús, I., Revilla, R., Sanz, A., Blanco, M., & Villalba, D. (2017). The milk yield of dams and its relation to direct and maternal genetic components of weaning weight in beef cattle. *Livestock Science*, *202*, 143–149. https://doi.org/10.1016/j.livsci.2017.05.025
Costa, J. H. C., von Keyserlingk, M. A. G., & Weary, D. M. (2016). Invited review: Effects of group housing of dairy calves on behavior, cognition, performance, and health. *Journal of Dairy Science*, *99*(4), 2453–2467. https://doi.org/10.3168/jds.2015-10144
Council of Europe. (1988). Recommendation concerning cattle adopted by the standing Committee of the European Convention for the protection of animals kept for farming purposes (T-AP) on 21 October 1988. https://www.coe.int/en/web/cdcj/1988-rec-cattle [Accessed on 7 March 2024]
Cozzi, G., Brscic, M., & Gottardo, F. (2009). Main critical factors affecting the welfare of beef cattle and veal calves raised under intensive rearing systems in Italy: A review. *Italian Journal of Animal Science*, *8*(Suppl. 1), 67–80. https://doi.org/10.4081/ijas.2009.s1.67
Cozzi, G., & Gottardo, F. (2005). Feeding behaviour and diet selection of finishing Limousin bulls under intensive rearing system. *Applied Animal Behaviour Science*, *91*(3–4), 181–192. https://doi.org/10.1016/j.applanim.2004.10.004
Cozzi, G., Gottardo, F., & Andrighetto, I. (2005). The use of coarse maize silage as a dietary source of roughage for finishing Limousin bulls: Effects on growth performance, feeding behaviour and meat quality. *Animal Science*, *80*(1), 111–118. https://doi.org/10.1079/ASC40720111
Cozzi, G., Gottardo, F., Brscic, M., Contiero, B., Irrgang, N., Knierim, U., Pentelescu, O., Windig, J. J., Mirabito, L., Kling Eveillard, F., Dockes, A. C., Veissier, I., Velarde, A., Fuentes, C., Dalmau, A., & Winckler, C. (2015). Dehorning of cattle in the EU member states: A quantitative survey of the current practices. *Livestock Science*, *179*, 4–11. https://doi.org/10.1016/j.livsci.2015.05.011
Cozzi, G., Prevedello, P., Boukha, A., Winckler, C., Knierim, U., Pentelescu, O., Windig, J., Mirabito, L., Kling Eveillard, F., Dockes, A. C., Veissier, I., Velarde, A., Fuentes, C., & Dalmau, A. (2009). Report on dehorning practices across EU member states. *Alternatives to Castration and Dehorning* https://www.vuzv.sk/DB-Welfare/telata/calves_alcasde_D-2-1-1.pdf
Cozzi, G., Tessitore, E., Contiero, B., Ricci, R., Gottardo, F., & Brscic, M. (2013). Alternative solutions to the concrete fully-slatted floor for the housing of finishing beef cattle: Effects on growth performance, health of the locomotor system and behaviour. *The Veterinary Journal*, *197*(2), 211–215. https://doi.org/10.1016/j.tvjl.2013.03.001
CRV. (2022). Sire calving ease increases through selection and breeding. https://crv4all.com/en/news/sire-calving-ease-increases-through-selection-and-breeding [Accessed on 20 June 2024].
Cull, C. A., Rezac, D. J., DeDonder, K. D., Seagren, J. E., Cull, B. J., Singu, V. K., Theurer, M. E., Martin, M., Amachawadi, R. G., & Kleinhenz, M. D. (2022). Behavioral and performance response associated with administration of intravenous flunixin meglumine or oral meloxicam immediately prior to surgical castration in bull calves. *Journal of Animal Science*, *100*(5), skac049. https://doi.org/10.1093/jas/skac049
Cunningham, J. G. (2002). *Textbook of veterinary physiology* (3rd ed.). The Veterinary Journal.
Currin, J. F., Whittier, W. D., & Currin, N. (2005). *Foot rot in beef cattle*. Virginia Cooperative Extension.
Cuttance, E. L., Mason, W. A., McDermott, J., Laven, R. A., McDougall, S., & Phyn, C. V. C. (2017). Calf and replacement heifer mortality from birth until weaning in pasture-based dairy herds in New Zealand. *Journal of Dairy Science*, *100*(10), 8347–8357. https://doi.org/10.3168/jds.2017-12793
Dachrodt, L., Arndt, H., Bartel, A., Kellermann, L. M., Tautenhahn, A., Volkmann, M., Birnstiel, K., Duc, P. D., Hentzsch, A., Jensen, K. C., Klawitter, M., Paul, P., Stoll, A., Woudstra, S., Zuz, P., Knubben, G., Metzner, M., Müller, K. E., Merle, R., & Hoedemaker, M. (2021). Prevalence of disorders in preweaned dairy calves from 731 dairies in Germany: A cross-sectional study. *Journal of Dairy Science*, *104*(8), 9037–9051. https://doi.org/10.3168/jds.2021-20283
Dahl-Pedersen, K., Herskin, M. S., Houe, H., & Thomsen, P. T. (2018). Risk factors for deterioration of the clinical condition of Cull dairy cows during transport to slaughter. *Frontiers in Veterinary Science*, *5*, 297. https://doi.org/10.3389/fvets.2018.00297
Danchuk, O. V., Karposvkii, V. I., Tomchuk, V. A., Zhurenko, O. V., Bobryts'ka, O. M., & Trokoz, V. O. (2020). Temperament in cattle: A method of evaluation and main characteristics. *Neurophysiology*, *52*(1), 73–79. https://doi.org/10.1007/s11062-020-09853-6
Daros, R. R., Costa, J. H. C., von Keyserlingk, M. A. G., Hötzel, M. J., & Weary, D. M. (2014). Separation from the dam causes negative judgement bias in dairy calves. *PLoS One*, *9*(5), e98429. https://doi.org/10.1371/journal.pone.0098429
Darrington, J. (2016). *Managing dust in dry lots. SDSU extension service*. South Dakota State University.
Davis, M., Mader, T., Holt, S., & Parkhurst, A. (2003). Strategies to reduce feedlot cattle heat stress: Effects on tympanic temperature. *Journal of Animal Science*, *81*(3), 649–661. https://doi.org/10.2527/2003.813649x

Davis-Unger, J., Schwartzkopf-Genswein, K. S., Pajor, E. A., Hendrick, S., Marti, S., Dorin, C., & Orsel, K. (2019). Prevalence and lameness-associated risk factors in Alberta feedlot cattle. *Translational Animal Science*, *3*(2), 595–606. https://doi.org/10.1093/tas/txz008

Dawkins, M. S. (1985). Social space: The need for a new look at animal communication. In *Social space for domestic animals* (pp. 15–22). Springer.

De Campeneere, S., Fiems, L. O., De Bosschere, H., De Boever, J. L., & Ducatelle, R. (2002). The effect of physical structure in maize silage-based diets for beef bulls. *Journal of Animal Physiology Animal Nutrition (Berlin)*, *86*(5–6), 174–184. https://doi.org/10.1046/j.1439-0396.2002.00371.x

De Coensel, E., Sarrazin, S., Opsomer, G., & Dewulf, J. (2020). Antimicrobial use in the uncomplicated cesarean section in cattle in Flanders. *Vlaams Diergeneeskundig Tijdschrift*, *89*(1). https://doi.org/10.21825/vdt.v89i1.15983

De Paula, M. R., Rocha, N. B., Miqueo, E., Silva, F. L. M., Coelho, M. G., & Bittar, C. M. M. (2019). Passive immune transfer, health, pre-weaning performance, and metabolism of dairy calves fed a colostrum supplement associated with medium-quality maternal colostrum. *Revista Brasileira de Zootecnia*, *48*, e20190006. https://doi.org/10.1590/rbz4820190006

de Souza, T. O., Kuczynski da Rocha, M., Mendes Paizano Alforma, A., Silva Fernandes, V., de Oliveira, F. J., Nunes Corrêa, M., Andrighetto Canozzi, M. E., McManus, C., & Jardim Barcellos, J. O. (2021). Behavioural and physiological responses of male and female beef cattle to weaning at 30, 75 or 180 days of age. *Applied Animal Behaviour Science*, *240*, 105339. https://doi.org/10.1016/j.applanim.2021.105339

Delgado-Pando, G., Allen, P., Troy, D. J., & McDonnell, C. K. (2021). Objective carcass measurement technologies: Latest developments and future trends. *Trends in Food Science & Technology*, *111*, 771–782. https://doi.org/10.1016/j.tifs.2020.12.016

Destrez, A., Haslin, E., Elluin, G., Gaillard, C., Hostiou, N., Dasse, F., Zanella, C., & Boivin, X. (2018). Evaluation of beef herd responses to unfamiliar humans and potential influencing factors: An exploratory survey on French farms. *Livestock Science*, *212*, 7–13. https://doi.org/10.1016/j.livsci.2018.03.011

Devani, K., Valente, T. S., Crowley, J. J., & Orsel, K. (2019). Development of optimal genetic evaluations for teat and udder structure in Canadian Angus cattle. *Journal of Animal Science*, *97*(11), 4445–4452. https://doi.org/10.1093/jas/skz314

Devant, M., Quintana, B., Aris, A., & Bach, A. (2015). Fattening Holstein heifers by feeding high-moisture corn (whole or ground) *ad libitum* separately from concentrate and straw. *Journal of Animal Science*, *93*(10), 4903–4916. https://doi.org/10.2527/jas.2014-8382

DeVries, T. J., Schwaiger, T., Beauchemin, K. A., & Penner, G. B. (2014). The duration of time that beef cattle are fed a high-grain diet affects feed sorting behavior both before and after acute ruminal acidosis. *Journal of Animal Science*, *92*(4), 1728–1737. https://doi.org/10.2527/jas.2013-7252

Dickson, E. J., Campbell, D. L. M., Lee, C., Lea, J. M., McDonald, P. G., & Monk, J. E. (2022). Beef cattle preference and usage of environmental enrichments provided simultaneously in a pasture-based environment. *Animals*, *12*(24), 1–17. https://doi.org/10.3390/ani12243544

Dickson, E. J., Campbell, D. L. M., Monk, J. E., Lea, J. M., Colditz, I. G., & Lee, C. (2022). Increasing mud levels in a feedlot influences beef cattle behaviours but not preference for feedlot or pasture environments. *Applied Animal Behaviour Science*, *254*, 105718. https://doi.org/10.1016/j.applanim.2022.105718

Dickson, E. J., Monk, J. E., Lee, C., McDonald, P. G., Narayan, E., & Campbell, D. L. M. (2024). Loss of a grooming enrichment impacts physical, behavioural, and physiological measures of welfare in grazing beef cattle. *Animal*, *18*(3), 1–11. https://doi.org/10.1016/j.animal.2024.101091

Digesti, R., & Weeth, H. (1976). A defensible maximum for inorganic sulfate in drinking water of cattle. *Journal of Animal Science*, *42*(6), 1498–1502. https://doi.org/10.2527/jas1976.4261498x

Dijkman, J. T., & Lawrence, P. R. (1997). The energy expenditure of cattle and buffaloes walking and working in different soil conditions. *The Journal of Agricultural Science*, *128*(1), 95–103. https://doi.org/10.1017/S0021859696003929

Distel, R. A., Arroquy, J. I., Lagrange, S., & Villalba, J. J. (2020). Designing diverse agricultural pastures for improving ruminant production systems. *Frontiers in Sustainable Food Systems*, *4*, 1–18. https://doi.org/10.3389/fsufs.2020.596869

Dockweiler, J., Coetzee, J., Edwards-Callaway, L., Bello, N., Glynn, H., Allen, K., Theurer, M., Jones, M., Miller, K., & Bergamasco, L. (2013). Effect of castration method on neurohormonal and electroencephalographic stress indicators in Holstein calves of different ages. *Journal of Dairy Science*, *96*(7), 4340–4354. https://doi.org/10.3168/jds.2012-6274

Dodd, J. M., Crowther, C. A., Grivell, R. M., & Deussen, A. R. (2017). Elective repeat caesarean section versus induction of labour for women with a previous caesarean birth. *Cochrane Database of Systematic Reviews*, *7*. https://doi.org/10.1002/14651858.CD004906.pub5

Dominguez-Castaño, P., Maiorano, A., De Oliveira, M., dos Santos, C. L., & Silva, J. A. I. I. V. (2021). Genetic and environmental effects on weaning weight in crossbred beef cattle (*Bos taurus*× *Bos indicus*). *The Journal of Agricultural Science*, *159*(1–2), 139–146. https://doi.org/10.1017/S0021859621000344

Downey, B. C., Jensen, M. B., & Tucker, C. B. (2022). Hay provision affects 24-h performance of normal and abnormal oral behaviors in individually housed dairy calves. *Journal of Dairy Science*, *105*(5), 4434–4448. https://doi.org/10.3168/jds.2021-21439

Drennan, M. J., & Berry, D. P. (2006). Factors affecting body condition score, live weight and reproductive performance in spring-calving suckler cows. *Irish Journal of Agricultural and Food Research*, *45*(1), 25–38.

Drennan, M. J., & McGee, M. (2009). Performance of spring-calving beef suckler cows and their progeny to slaughter on intensive and extensive grassland management systems. *Livestock Science*, *120*, 1–12. https://doi.org/10.1016/j.livsci.2008.04.013

Drögemüller, C., Wöhlke, A., Mömke, S., & Distl, O. (2005). Fine mapping of the polled locus to a 1-Mb region on bovine chromosome 1q12. *Mammalian Genome*, *16*, 613–620. https://doi.org/10.1007/s00335-005-0016-0

Drolia, H., Luescher, U. A., Meek, A. H., & Wilcock, B. P. (1991). Tail tip necrosis in Ontario beef feedlot cattle. *Canadian Veterinary Journal*, *32*(1), 23–29.

Druet, T., Ahariz, N., Cambisano, N., Tamma, N., Michaux, C., Coppieters, W., Charlier, C., & Georges, M. (2014). Selection in action: Dissecting the molecular underpinnings of the increasing muscle mass of Belgian blue cattle. *BMC Genomics*, *15*, 796. https://doi.org/10.1186/1471-2164-15-796

Drwencke, A. M., Adcock, S. J. J., & Tucker, C. B. (2023). Wound healing and pain sensitivity following caustic paste disbudding in dairy calves. *Journal of Dairy Science*, *106*(9), 6375–6387. https://doi.org/10.3168/jds.2023-23238

Dudink, S., Simonse, H., Marks, I., de Jonge, F. H., & Spruijt, B. M. (2006). Announcing the arrival of enrichment increases play behaviour and reduces weaning-stress-induced behaviours of piglets directly after weaning. *Applied Animal Behaviour Science*, *101*(1–2), 86–101. https://doi.org/10.1016/j.applanim.2005.12.008

Dunston-Clarke, E. J., Stockman, C., Sinclair, J., & Collins, T. (2024). Brush use in lot-fed cattle shows continued use and positive behaviour. *Animals*, *15*(1), 44. https://doi.org/10.3390/ani15010044

Duranton, C., & Gaunet, F. (2016). Behavioural synchronization from an ethological perspective: Overview of its adaptive value. *Adaptive Behavior*, *24*(3), 181–191. https://doi.org/10.1177/1059712316644966

Dutch Food and Consumer Product Safety Authority. (2022). *Advice from the director of the Office for Risk Assessment and Research (BuRO)*. The Netherlands. https://english.nvwa.nl/documents/animal/welfare/buro/documents/advice-from-buro-on-the-use-of-sensor-technology-to-promote-animal-welfare-in-slaughterhouses.

Duve, L. R., & Jensen, M. B. (2011). The level of social contact affects social behaviour in pre-weaned dairy calves. *Applied Animal Behaviour Science*, *135*(1), 34–43. https://doi.org/10.1016/j.applanim.2011.08.014

Duve, L. R., Weary, D. M., Halekoh, U., & Jensen, M. B. (2012). The effects of social contact and milk allowance on responses to handling, play, and social behavior in young dairy calves. *Journal of Dairy Science*, *95*(11), 6571–6581. https://doi.org/10.3168/jds.2011-5170

Earley, B., & Crowe, M. A. (2002). Effects of ketoprofen alone or in combination with local anesthesia during the castration of bull calves on plasma cortisol, immunological, and inflammatory responses. *Journal of Animal Science*, *80*(4), 1044–1052. https://doi.org/10.2527/2002.8041044x

Eastwood, L., Boykin, C., Harris, M., Arnold, A., Hale, D., Kerth, C., Griffin, D., Savell, J., Belk, K., & Woerner, D. (2017). National Beef Quality Audit-2016: Transportation, mobility, and harvest-floor assessments of targeted characteristics that affect quality and value of cattle, carcasses, and by-products. *Translational Animal Science*, *1*(2), 229–238. https://doi.org/10.2527/tas2017.0029

Ebinghaus, A., Johns, J., & Knierim, U. (2023). Blood in milk in horned dairy cows–Exploration of incidences and prevention opportunities. *Veterinary and Animal Science*, *21*, 100307, pp. 1–9. https://doi.org/10.1016/j.vas.2023.100307

Ebinghaus, A., Thiessen, G., Ivemeyer, S., & Knierim, U. (2025). Are horned cows in loose housing more stressed than hornless cows? A cross-sectional study in organic dairy farms. *Animal*, *19*(2), 101405. https://doi.org/10.1016/j.animal.2024.101405

Edmonson, A., Lean, I. J., Weaver, L., Farver, T., & Webster, G. (1989). A body condition scoring chart for Holstein dairy cows. *Journal of Dairy Science*, *72*(1), 68–78. https://doi.org/10.3168/jds.S0022-0302(89)79081-0

Edwards-Callaway, L. N., Cramer, M. C., Cadaret, C. N., Bigler, E. J., Engle, T. E., Wagner, J. J., & Clark, D. L. (2021). Impacts of shade on cattle well-being in the beef supply chain. *Journal of Animal Science*, *99*(2), skaa375. https://doi.org/10.1093/jas/skaa375

EFFAB (European forum of farm animal breeders). (2024). Re: EFFAB submission to the public consultation. Message to EFSA service desk. 31 January 2024. Email.

EFSA (European Food Safety Authority). (2015). The use of animal-based measures to assess animal welfare in EU – State of the art of 10 years of activities and analysis of gaps. *EFSA Supporting Publications*, *12*(11), 884. https://doi.org/10.2903/sp.efsa.2015.EN-884

EFSA (European Food Safety Authority), Hart, A., Maxim, L., Siegrist, M., Von Goetz, N., da Cruz, C., Merten, C., Mosbach-Schulz, O., Lahaniatis, M., Smith, A., & Hardy, A. (2019). Guidance on communication of uncertainty in scientific assessments. *EFSA Journal*, *17*(1), 5520. https://doi.org/10.2903/j.efsa.2019.5520

EFSA (European Food Safety Authority), Vitali, M., Aboagye, G., Ashe, S., Fabris, C., Van de Stede, Y., & Candiani, D. (2023). The use of animal-based measures at slaughter for assessing the welfare of beef cattle on farm: EFSA AHAW network exercise. *EFSA Supporting Publications*, *20*(11), EN-8462. https://doi.org/10.2903/sp.efsa.2023.EN-8462

EFSA (European Food Safety Authority), Vitali, M., Zanna, M. B., Ashe, S., D'Alessio, R. M., Fabris, C., Van der Stede, Y., & Candiani, D. F. (2024). The practice of mutilations inbeef cattle – exercise of the EFSA Networks on Animal Welfare. *EFSA Supporting Publications*, EN-9139. https://doi.org/10.2903/sp.efsa.2024.EN-9139

EFSA (European Food Safety Authority), Cozzi, G., Knierim, U., Marti, S., Mullan, S., Ashe, S., Lima, E., Van der Stede, Y., Vitali, M., Cecchinato, G., Zanna, M. B., D'Alessio, R. M., & Winckler, C. (2025). Common husbandry systems and practices for keeping beef cattle. *EFSA Supporting Publications*, EN-9565. https://doi.org/10.2903/sp.efsa.2025.EN-9565

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare). (2012a). Guidance on risk assessment for animal welfare. *EFSA Journal*, *10*(1), 2513. https://doi.org/10.2903/j.efsa.2012.2513

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare). (2012b). Scientific Opinion on the welfare of cattle kept for beef production and the welfare in intensive calf farming systems. *EFSA Journal*, *10*(5), 2669. https://doi.org/10.2903/j.efsa.2012.2669

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Depner, K., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Gortázar Schmidt, C., Herskin, M., Michel, V., Miranda Chueca, M. Á., Roberts, H. C., Sihvonen, L. H., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., … Winckler, C. (2020). Welfare of cattle during killing for purposes other than slaughter. *EFSA Journal*, *18*(11), 6312. https://doi.org/10.2903/j.efsa.2020.6312

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Rojas, J. L. G., Schmidt, C. G., Herskin, M., Chueca, M. A. M., Michel, V., Padalino, B., Pasquali, P., Roberts, H. C., Spoolder, H., Stahl, K., Velarde, A., … Winckler, C. (2022a). Methodological guidance for the development of animal welfare mandates in the context of the farm to fork strategy. *EFSA Journal*, *20*(7), 7403. https://doi.org/10.2903/j.efsa.2022.7403

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Gortázar Schmidt, C., Michel, V., Miranda Chueca, M. Á., Padalino, B., Pasquali, P., Roberts, H. C., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., … Herskin, M. (2022b). Welfare of cattle during transport. *EFSA Journal*, *20*(9), 7442. https://doi.org/10.2903/j.efsa.2022.7442

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Schmidt, G., Herskin, M., Michel, V., Miranda Chueca, M. Á., Mosbach-Schulz, O., Padalino, B., Roberts, H. C., Stahl, K., Velarde, A., Viltrop, A., … Spoolder, H. (2022c). Scientific Opinion on the welfare of pigs on farm. *EFSA Journal*, *20*(8), 7421. https://doi.org/10.2903/j.efsa.2022.7421

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Gortazar Schmidt, C., Herskin, M., Michel, V., Miranda Chueca, M. A., Padalino, B., Pasquali, P., Roberts, H. C., Spoolder, H., Stahl, K., Velarde, A., … Winckler, C. (2023a). Scientific Opinion on the welfare of calves. *EFSA Journal*, *21*(3), 7896. https://doi.org/10.2903/j.efsa.2023.7896

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Gortázar Schmidt, C., Herskin, M., Michel, V., Miranda Chueca, M. Á., Padalino, B., Roberts, H. C., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., … Winckler, C. (2023b). Scientific Opinion on the welfare of dairy cows. *EFSA Journal*, *21*(5), 7993. https://doi.org/10.2903/j.efsa.2023.7993

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Schmidt, C. G., Herskin, M. S., Miranda Chueca, M. Á., Padalino, B., Pasquali, P., Roberts, H. C., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., … Michel, V. (2023c). Scientific Opinion on the welfare of broilers on farm. *EFSA Journal*, *21*(2), 7788. https://doi.org/10.2903/j.efsa.2023.7788

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Gortázar Schmidt, C., Herskin, M., Miranda Chueca, M. Á., Padalino, B., Pasquali, P., Roberts, H. C., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., … Michel, V. (2023d). Scientific Opinion on the welfare of laying hens on farm. *EFSA Journal*, *21*(2), 7789. https://doi.org/10.2903/j.efsa.2023.7789

EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), Nielsen, S. S., Alvarez, J., Boklund, A., Dippel, S., Dorea, F., Figuerola, J., Herskin, M., Miranda Chueca, M. A., Nannoni, E., Nonno, R., Riber, A., Stahl, K., Stegeman, J. A., Thulke, H.-H., Tuyttens, F., Winckler, C., Raj, M., Velarde, A., … Michel, V. (2025). Welfare of horses during killing for purposes other than slaughter. *EFSA Journal*, *23*(1), e9195. https://doi.org/10.2903/j.efsa.2025.9195

EFSA Scientific Committee, Benford, D., Halldorsson, T., Jeger, M. J., Knutsen, H. K., More, S., Naegeli, H., Noteborn, H., Ockleford, C., Ricci, A., Rychen, G., Schlatter, J. R., Silano, V., Solecki, R., Turck, D., Younes, M., Craig, P., Hart, A., Von Goetz, N., … Hardy, A. (2018a). Guidance on uncertainty analysis in scientific assessments. *EFSA Journal*, *16*(1), 5123. https://doi.org/10.2903/j.efsa.2018.5123

EFSA Scientific Committee, Benford, D., Halldorsson, T., Jeger, M. J., Knutsen, H. K., More, S., Naegeli, H., Noteborn, H., Ockleford, C., Ricci, A., Rychen, G., Schlatter, J. R., Silano, V., Solecki, R., Turck, D., Younes, M., Craig, P., Hart, A., Von Goetz, N., … Hardy, A. (2018b). Scientific Opinion on the principles and methods behind EFSA's guidance on uncertainty analysis in scientific assessment. *EFSA Journal*, *16*(1), 5122. https://doi.org/10.2903/j.efsa.2018.5122

Egger-Danner, C., Nielsen, P., Fiedler, A., Müller, K., Fjeldaas, T., Döpfer, D., Daniel, V., Bergsten, C., Cramer, G., & Christen, A. M. (2020). ICAR claw health atlas. *ICAR Technical Series* https://www.icar.org/ICAR_Claw_Health_Atlas.pdf

Eicher, S., Morrow-Tesch, J., Albright, J., Dailey, J., Young, C., & Stanker, L. (2000). Tail-docking influences on behavioral, immunological, and endocrine responses in dairy heifers. *Journal of Dairy Science*, *83*(7), 1456–1462. https://doi.org/10.3168/jds.S0022-0302(00)75017-X

Eicher, S., Morrow-Tesch, J., Albright, J., & Williams, R. (2001). Tail-docking alters fly numbers, fly-avoidance behaviors, and cleanliness, but not physiological measures. *Journal of Dairy Science*, *84*(8), 1822–1828. https://doi.org/10.3168/jds.S0022-0302(01)74621-8

Eicher, S. D., Cheng, H. W., Sorrells, A. D., & Schutz, M. M. (2006). Short communication: Behavioral and physiological indicators of sensitivity or chronic pain following tail docking. *Journal of Dairy Science*, *89*(8), 3047–3051. https://doi.org/10.3168/jds.S0022-0302(06)72578-4

Eicher, S. D., & Dailey, J. W. (2002). Indicators of acute pain and Fly avoidance Behaviors in Holstein calves following tail-docking. *Journal of Dairy Science*, *85*(11), 2850–2858. https://doi.org/10.3168/jds.S0022-0302(02)74372-5

Eisenberg, S. W., Nielen, M., Santema, W., Houwers, D. J., Heederik, D., & Koets, A. P. (2010). Detection of spatial and temporal spread of Mycobacterium avium subsp. paratuberculosis in the environment of a cattle farm through bio-aerosols. *Veterinary Microbiology*, *143*(2–4), 284–292. https://doi.org/10.1016/j.vetmic.2009.11.033

Eldridge, G., & Winfield, C. (1988). The behaviour and bruising of cattle during transport at different space allowances. *Australian Journal of Experimental Agriculture*, *28*(6), 695–698. https://doi.org/10.1071/EA9880695

Ellerbroek, L. I. (2022). Which conclusions can be drawn from rates and reasons for condemnation of cattle at meat inspection from 2007 to 2018 in German slaughterhouses? *Journal of Food Safety and Food Quality*, *73*(1), 4–12. https://doi.org/10.2376/0003-925x-73-4

Elmore, M. R. P., Elischer, M. F., Claeys, M. C., & Pajor, E. A. (2015). The effects of different flooring types on the behavior, health, and welfare of finishing beef steers. *Journal of Animal Science*, *93*(3), 1258–1266. https://doi.org/10.2527/jas.2014-8399

EMA (European Medicines Agency). (online). Veterinary Medicines. https://medicines.health.europa.eu/veterinary/en [Accessed on 26 May 2025].

Emmerson, M. (1933). *Nerve Blocking in the Dehorning of Cattle*, *34*(52), 5–18.

Enríquez, D., Hötzel, M. J., & Ungerfeld, R. (2011). Minimising the stress of weaning of beef calves: A review. *Acta Veterinaria Scandinavica*, *53*, 28. https://doi.org/10.1186/1751-0147-53-28

Enríquez, D. H., Ungerfeld, R., Quintans, G., Guidoni, A. L., & Hötzel, M. J. (2010). The effects of alternative weaning methods on behaviour in beef calves. *Livestock Science*, *128*(1–3), 20–27. https://doi.org/10.1016/j.livsci.2009.10.007

Eriksson, S., Näsholm, A., Johansson, K., & Philipsson, J. (2004). Genetic parameters for calving difficulty, stillbirth, and birth weight for Hereford and Charolais at first and later parities. *Journal of Animal Science*, *82*(2), 375–383. https://doi.org/10.2527/2004.822375x

Estévez-Moreno, L. X., Miranda-de la Lama, G. C., Villarroel, M., García, L., Abecia, J. A., Santolaria, P., & María, G. A. (2021). Revisiting cattle temperament in beef cow-calf systems: Insights from farmers' perceptions about an autochthonous breed. *Animals*, *11*(1), 82. https://doi.org/10.3390/ani11010082

EURCAW (European Union Reference Centre for Animal Welfare) Ruminants & Equines. (2024a). *Emergency killing of bovines and small ruminants* https://www.eurcaw-ruminants-equines.eu/wp-content/uploads/2024/07/Q2E-Ruminants-Equines-2024-003.pdf

EURCAW (European Union Reference Centre for Animal Welfare) Ruminants & Equines. (2024b). *Fitness for transport of bovine animals* https://www.eurcaw-ruminants-equines.eu/wp-content/uploads/2024/06/IFS-Ruminants-Equines-2023-01-EN_v2.pdf.

Eurogroup for Animals. (2020). The Welfare of Cattle Finished on Feedlots. https://www.eurogroupforanimals.org/files/eurogroupforanimals/2021-12/2020_12_eurogroup_for_animals_cattle_feedlots.pdf retrieved from EFSA Public call for evidence 2024 - PC-0742 4 submitted by Four Paws.

Evans, M. G., Ribeiro, G. O., Henry, D. H., Johnson, J. A., Campbell, J. R., Waldner, C., & Penner, G. B. (2024). Effect of sodium sulfate concentration in drinking water for beef heifers, and the in vitro effect of bismuth subsalicylate on H2S production and fiber disappearance. *Canadian Journal of Animal Science*, *104*(2), 142–155. https://doi.org/10.1139/cjas-2023-0054

Færevik, G., Andersen, I. L., Jensen, M. B., & Bøe, K. E. (2007). Increased group size reduces conflicts and strengthens the preference for familiar group mates after regrouping of weaned dairy calves (Bos taurus). *Applied Animal Behaviour Science*, *108*(3–4), 215–228. https://doi.org/10.1016/j.applanim.2007.01.010

Færevik, G., Jensen, M. B., & Bøe, K. E. (2006). Dairy calves social preferences and the significance of a companion animal during separation from the group. *Applied Animal Behaviour Science*, *99*(3–4), 205–221. https://doi.org/10.1016/j.applanim.2005.10.012

Færevik, G., Tjentland, K., Løvik, S., Andersen, I. L., & Bøe, K. E. (2008). Resting pattern and social behaviour of dairy calves housed in pens with different sized lying areas. *Applied Animal Behaviour Science*, *114*(1), 54–64. https://doi.org/10.1016/j.applanim.2008.01.002

Farm Advisory Service. (2022). Water Requirements at Grass. https://www.fas.scot/article/water-requirements-at-grass/ [Accessed: 8 May 2025].

Farney, J. K. (2023). Weaning method evaluation for beef cattle. *Kansas Agricultural Experiment Station Research Reports*, *9*(2), 5. https://doi.org/10.4148/2378-5977.8438

Faulkner, P., & Weary, D. (2000). Reducing pain after dehorning in dairy calves. *Journal of Dairy Science*, *83*(9), 2037–2041. https://doi.org/10.3168/jds.S0022-0302(00)75084-3

FAWC (Farm Animal Welfare Committee). (2019). Opinion on the welfare of animals during transport. https://consult.defra.gov.uk/transforming-farm-animal-health-and-welfare-team/improvements-to-animal-welfare-in-transport/supporting_documents/fawcopiniononthewelfareofanimalsduringtransport.pdf.

Fell, L. R., Colditz, I. G., Walker, K. H., & Watson, D. L. (1999). Associations between temperament, performance and immune function in cattle entering a commercial feedlot. *Australian Journal of Experimental Agriculture*, *39*(7), 795–802. https://doi.org/10.1071/Ea99027

Fernández, M., Ferreras, M. C., Giráldez, F. J., Benavides, J., & Pérez, V. (2020). Production significance of bovine respiratory disease lesions in slaughtered beef cattle. *Animals*, *10*(10), 1770. https://doi.org/10.3390/ani10101770

Fetrow, J., Nordlund, K. V., & Norman, H. D. (2006). Invited review: Culling: Nomenclature, definitions, and recommendations. *Journal of Dairy Science*, *89*(6), 1896–1905. https://doi.org/10.3168/jds.S0022-0302(06)72257-3

Fiems, L. O. (2012). Double muscling in cattle: Genes, husbandry, carcasses and meat. *Animals*, *2*(3), 472–506. https://doi.org/10.3390/ani2030472

Fiems, L. O., & De Brabander, D. L. (2009). Optimum growth rate of Belgian blue double-muscled replacement heifers. *South African Journal of Animal Science*, *39*(Suppl. 1), 6–10. https://doi.org/10.4314/sajas.v39i1.61179

Fiems, L. O., de Campeneere, S., van Caelenbergh, W., & Boucqué, C. V. (2001). Relationship between dam and calf characteristics with regard to dystocia in Belgian blue double-muscled cows. *Animal Science*, *72*(2), 389–394. https://doi.org/10.1017/S1357729800055880

Finch, V. A. (1986). Body temperature in beef cattle: Its control and relevance to production in the tropics. *Journal of Animal Science*, *62*(2), 531–542. https://doi.org/10.2527/jas1986.622531x

Fisher, A., Crowe, M., O'kiely, P., & Enright, W. (1997). Growth, behaviour, adrenal and immune responses of finishing beef heifers housed on slatted floors at 1.5, 2.0, 2.5 or 3.0 m^2 space allowance. *Livestock Production Science*, *51*(1–3), 245–254. https://doi.org/10.1016/S0301-6226(97)00052-3

Fisher, A., Crowe, M., Prendiville, D., & Enright, W. (1997). Indoor space allowance: Effects on growth, behaviour, adrenal and immune responses of finishing beef heifers. *Animal Science*, *64*(1), 53–62. https://doi.org/10.1017/S135772980001554X

Fisher, A. D., Knight, T. W., Cosgrove, G. P., Death, A. F., Anderson, C. B., Duganzich, D. M., & Mattews, L. R. (2001). Effects of surgical or banding castration on stress responses and behaviour of bulls. *Australian Veterinary Journal*, *79*(4), 279–284. https://doi.org/10.1111/j.1751-0813.2001.tb11981.x

Fjeldaas, T., Nafstad, O., Fredriksen, B., Ringdal, G., & Sogstad, Å. M. (2007). Claw and limb disorders in 12 Norwegian beef-cow herds. *Acta Veterinaria Scandinavica*, *49*(24), 1–11. https://doi.org/10.1186/1751-0147-49-24

Flower, F. C., & Weary, D. M. (2001). Effects of early separation on the dairy cow and calf:: 2. Separation at 1 day and 2 weeks after birth. *Applied Animal Behaviour Science*, *70*(4), 275–284. https://doi.org/10.1016/S0168-1591(00)00164-7

Flury, R., & Gygax, L. (2016). Daily patterns of synchrony in lying and feeding of cows: Quasi-natural state and (anti-) synchrony factors. *Behavioural Processes*, *133*, 56–61. https://doi.org/10.1016/j.beproc.2016.11.004
Fogsgaard, K. K., Bertelsen, M., & Christensen, J. W. (2019). Does shelter design matter? A note on the effect of two shelter types on shelter use by cattle during winter. *Journal of Veterinary Behavior*, *34*, 18–21. https://doi.org/10.1016/j.jveb.2019.07.009
Fogsgaard, K. K., & Christensen, J. W. (2018). Influence of space availability and weather conditions on shelter use by beef cattle during winter. *Applied Animal Behaviour Science*, *204*, 18–22. https://doi.org/10.1016/j.applanim.2018.04.007
Fordyce, G., Howitt, C. J., Holroyd, R. G., O'Rourke, P. K., & Entwistle, K. W. (1996). The performance of Brahman-shorthorn and Sahiwal-shorthorn beef cattle in the dry tropics of northern Queensland. 5. Scrotal circumference, temperament, ectoparasite resistance, and the genetics of growth and other traits in bulls. *Australian Journal of Experimental Agriculture*, *36*(1), 9–17. https://doi.org/10.1071/EA9960009
Foris, B., Vandresen, B., Sheng, K., Krahn, J., Weary, D. M., & von Keyserlingk, M. A. G. (2024). Automated, longitudinal measures of drinking behavior provide insights into the social hierarchy in dairy cows. *JDS Communications*, *5*(5), 411–415. https://doi.org/10.3168/jdsc.2023-0487
Forss, S., Ciria, A., Clark, F., Cl, G., Harrison, D., & Lee, S. (2024). A transdisciplinary view on curiosity beyond linguistic humans: Animals, infants, and artificial intelligence. *Biological Reviews*, *99*(3), 979–998. https://doi.org/10.1111/brv.13054
Francesconi, M., Pedruzzi, L., Bagnato, S., Goracci, J., Ripamonti, A., Mele, M., & Palagi, E. (2024). Social play and affiliation as possible coping strategies in a group of Maremmana beef cattle. *Journal of Ethology*, *42*(1), 41–52. https://doi.org/10.1007/s10164-023-00801-5
Futro, A., Masłowska, K., & Dwyer, C. M. (2015). Ewes direct most maternal attention towards lambs that show the greatest pain-related behavioural responses. *PLoS One*, *10*(7), e0134024. https://doi.org/10.1371/journal.pone.0134024
Gallo, C., Tabilo, B., Navarro, G., & Phillips, C. (2023). Minimum space requirements for cattle: An approach based on photographic records. *Veterinary Record*, *192*(9). https://doi.org/10.1002/vetr.2780
Gangl, M., Grulke, S., Serteyn, D., & Touati, K. (2006). Retrospective study of 99 cases of bone fractures in cattle treated by external coaptation or confinement. *Veterinary Record*, *158*(8), 264–268. https://doi.org/10.1136/vr.158.8.264
Garry, F. B. (2002). Indigestion in ruminants. In S. B. Mosby (Ed.), *Large animal internal medicine* (3rd ed., pp. 722–747). St. Louis.
Garza-Brenner, E., Sifuentes-Rincón, A. M., Randel, R. D., Paredes-Sánchez, F. A., Parra-Bracamonte, G. M., Arellano Vera, W., Rodríguez Almeida, F. A., & Segura Cabrera, A. (2017). Association of SNPs in dopamine and serotonin pathway genes and their interacting genes with temperament traits in Charolais cows. *Journal of Applied Genetics*, *58*, 363–371. https://doi.org/10.1007/s13353-016-0383-0
Gaughan, J., Bryden, W., Eigenberg, R., & Tait, L. (2004). Effect of shade on respiration rate and rectal temperature of Angus heifers. *Science Access*, *1*(1), 69–72. https://doi.org/10.1071/SA0401018
Gaughan, J., & Mader, T. (2014). Body temperature and respiratory dynamics in un-shaded beef cattle. *International Journal of Biometeorology*, *58*, 1443–1450. https://doi.org/10.1007/s00484-013-0746-8
Gaughan, J., Mader, T., Holt, S., Hahn, G., & Young, B. (2002). Review of current assessment of cattle and microclimate during periods of high heat load. *Animal Production in Australia*, *24*, 77–80.
Gaughan, J. B., Davis, M. S., & Mader, T. L. (2004). Wetting and the physiological responses of grain-fed cattle in a heated environment. *Australian Journal of Agricultural Research*, *55*(3), 253–260. https://doi.org/10.1071/AR03110
Gaughan, J. B., Mader, T. L., & Holt, S. M. (2008). Cooling and feeding strategies to reduce heat load of grain-fed beef cattle in intensive housing. *Livestock Science*, *113*(2), 226–233. https://doi.org/10.1016/j.livsci.2007.03.014
Gaughan, J. B., Mader, T. L., Holt, S. M., & Lisle, A. (2008). A new heat load index for feedlot cattle. *Journal of Animal Science*, *86*(1), 226–234. https://doi.org/10.2527/jas.2007-0305
Gautrais, J., Michelena, P., Sibbald, A., Bon, R., & Deneubourg, J.-L. (2007). Allelomimetic synchronization in merino sheep. *Animal Behaviour*, *74*(5), 1443–1454. https://doi.org/10.1016/j.anbehav.2007.02.020
Gebremedhin, K. G., Hillman, P. E., Lee, C. N., Collier, R. J., Willard, S. T., Arthington, J. D., & Brown-Brandl, T. M. (2008). Sweating rates of dairy cows and beef heifers in hot conditions. *Transactions of the ASABE*, *51*(6), 2167–2178. https://doi.org/10.13031/2013.25397
Gellatly, D., Marti, S., Pajor, E. A., Meléndez, D. M., Moya, D., Janzen, E. D., Yang, X., Milani, M. R. M., & Schwartzkopf-Genswein, K. S. (2021). Effect of a single subcutaneous injection of meloxicam on chronic indicators of pain and inflammatory responses in 2-month-old knife and band-castrated beef calves housed on pasture. *Livestock Science*, *244*, 104305. https://doi.org/10.1016/j.livsci.2020.104305
Gentry, W. W., Weiss, C. P., Meredith, C. M., McCollum, F. T., Cole, N. A., & Jennings, J. S. (2016). Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers. *Journal of Animal Science*, *94*(11), 4759–4770. https://doi.org/10.2527/jas.2016-0734
Georges, M., Drinkwater, R., King, T., Mishra, A., Moore, S. S., Nielsen, D., Sargeant, L. S., Sorensen, A., Steele, M. R., Zhao, X., Womack, J. E., & Hetzel, J. (1993). Microsatellite mapping of a gene affecting horn development in *Bos taurus*. *Nature Genetics*, *4*(2), 206–210. https://doi.org/10.1038/ng0693-206
Gibbons, J. M., Lawrence, A. B., & Haskell, M. J. (2009). Consistency of aggressive feeding behaviour in dairy cows. *Applied Animal Behaviour Science*, *121*(1), 1–7. https://doi.org/10.1016/j.applanim.2009.08.002
Gibbons, J. M., Lawrence, A. B., & Haskell, M. J. (2010). Measuring sociability in dairy cows. *Applied Animal Behaviour Science*, *122*(2–4), 84–91. https://doi.org/10.1016/j.applanim.2009.11.011
Gillandt, K., Stracke, J., Hohnholz, T., Waßmuth, R., & Kemper, N. (2018). A field study on the prevalence of and risk factors for endoparasites in beef suckler cow herds in Germany. *Agriculture*, *8*(9), 132. https://doi.org/10.3390/agriculture8090132
Gingerich, K., Choulet, V., & Miller-Cushon, E. (2020). Disbudding affects use of a shelter provided to group-housed dairy calves. *Journal of Dairy Science*, *103*(11), 10519–10529. https://doi.org/10.3168/jds.2020-18267
Gleerup, K. B., Andersen, P. H., Munksgaard, L., & Forkman, B. (2015). Pain evaluation in dairy cattle. *Applied Animal Behaviour Science*, *171*, 25–32. https://doi.org/10.1016/j.applanim.2015.08.023
Godden, S. (2008). Colostrum Management for Dairy Calves. *Veterinary Clinics of North America: Food Animal Practice*, *24*(1), 19–39. https://doi.org/10.1016/j.cvfa.2007.10.005
Goncherenko, G. A., Báez, F., Fedrigo, J. K., Santa Cruz, R., Claramunt, M., Mercadante, V. R. G., & Viñoles, C. (2024). Silvopastoral systems as a strategy to attenuate the negative effects of heat stress on productivity of beef cows grazing natural grassland. *Agroforestry Systems*, *98*(7), 1995–2011. https://doi.org/10.1007/s10457-024-01081-9
González, L. A., Manteca, X., Calsamiglia, S., Schwartzkopf-Genswein, K. S., & Ferret, A. (2012). Ruminal acidosis in feedlot cattle: Interplay between feed ingredients, rumen function and feeding behavior (a review). *Animal Feed Science and Technology*, *172*(1–2), 66–79. https://doi.org/10.1016/j.anifeedsci.2011.12.009
González, L. A., Schwartzkopf-Genswein, K. S., Caulkett, N. A., Janzen, E., McAllister, T. A., Fierheller, E., Schaefer, A. L., Haley, D. B., Stookey, J. M., & Hendrick, S. (2013). Pain mitigation after band castration of beef calves and its effects on performance, behavior, Escherichia coli, and salivary cortisol. *Journal of Animal Science*, *88*(2), 802–810. https://doi.org/10.2527/jas.2008-1752
Goonewardene, L., & Hand, R. (1991). Studies on dehorning steers in Alberta feedlots. *Canadian Journal of Animal Science*, *71*(4), 1241–1247. https://doi.org/10.4141/cjas91-147
Gottardo, F., Ricci, R., Fregolent, G., Ravarotto, L., & Cozzi, G. (2003). Welfare and meat quality of beef cattle housed on two types of floors with the same space allowance. *Italian Journal of Animal Science*, *2*(4), 243–253. https://doi.org/10.4081/ijas.2003.243

Gottardo, F., Ricci, R., Preciso, S., Ravarotto, L., & Cozzi, G. (2004). Effect of the manger space on welfare and meat quality of beef cattle. *Livestock Production Science*, *89*(2–3), 277–285. https://doi.org/10.1016/j.livprodsci.2004.01.002

Graf, B., & Senn, M. (1999). Behavioural and physiological responses of calves to dehorning by heat cauterization with or without local anaesthesia. *Applied Animal Behaviour Science*, *62*(2–3), 153–171. https://doi.org/10.1016/S0168-1591(98)00218-4

Graf, B. P. (1984). *Der Einfluss unterschiedlicher Laufstallsysteme auf Verhaltensmerkmale von Mastchsen* (p. 282). Eidgenössichen Technishen Hochschule, Zürich. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/138233/1/eth-36421-01.pdf

Grandin, T. (2000). Introduction: Management and economic factors of handling and transport. In *Livestock handling and transport* (2nd ed., pp. 1–14). CABI International. https://doi.org/10.1079/9780851994093.0001

Grandin, T. (2016). Evaluation of the welfare of cattle housed in outdoor feedlot pens. *Veterinary and Animal Science*, *1-2*, 23–28. https://doi.org/10.1016/j.vas.2016.11.001

Grandin, T. (2017). On-farm conditions that compromise animal welfare that can be monitored at the slaughter plant. *Meat Science*, *132*, 52–58. https://doi.org/10.1016/j.meatsci.2017.05.004

Grandin, T. (2021). How to improve livestock handling and reduce stress. *Improving Animal Welfare: A Practical Approach*, 84–112. https://doi.org/10.1079/9781780644677.0069

Green, A. C., Lidfors, L. M., Lomax, S., Favaro, L., & Clark, C. E. F. (2021). Vocal production in postpartum dairy cows: Temporal organization and association with maternal and stress behaviors. *Journal of Dairy Science*, *104*(1), 826–838. https://doi.org/10.3168/jds.2020-18891

Greenough, P. R. (1997). *Understanding herd lameness*. Schedule.

Gregory, N., & Grandin, T. (2007). Livestock presentation and welfare before slaughter. In *Animal welfare and meat production* (pp. 168–190). CABI Wallingford UK. https://doi.org/10.1079/9781845932152.0168

Griffin, D. (2014). The monster we don't see: Subclinical BRD in beef cattle. *Animal Health Research Reviews*, *15*(2), 138–141. https://doi.org/10.1017/S1466252314000255

Griffith, M., & Williams, G. (1996). Roles of maternal vision and olfaction in suckling-mediated inhibition of luteinizing hormone secretion, expression of maternal selectivity, and lactational performance of beef cows. *Biology of Reproduction*, *54*(4), 761–768. https://doi.org/10.1095/biolreprod54.4.761

Grignard, L., Boissy, A., Boivin, X., Garel, J. P., & Le Neindre, P. (2000). The social environment influences the behavioural responses of beef cattle to handling. *Applied Animal Behaviour Science*, *68*(1), 1–11. https://doi.org/10.1016/S0168-1591(00)00085-X

Grignard, L., Boivin, X., Boissy, A., & Le Neindre, P. (2001). Do beef cattle react consistently to different handling situations? *Applied Animal Behaviour Science*, *71*(4), 263–276. https://doi.org/10.1016/s0168-1591(00)00187-8

Grigoletto, L., Brito, L. F., Mattos, E. C., Eler, J. P., Bussiman, F. O., Silva, B. C. A., da Silva, R. P., Carvalho, F. E., Berton, M. P., Baldi, F., & Ferraz, J. B. S. (2019). Genome-wide associations and detection of candidate genes for direct and maternal genetic effects influencing growth traits in the Montana tropical® composite population. *Livestock Science*, *229*, 64–76. https://doi.org/10.1016/j.livsci.2019.09.013

Grobet, L., Royo Martin, L. J., Poncelet, D., Pirottin, D., Brouwers, B., Riquet, J., Schoeberlein, A., Dunner, S., Ménissier, F., Massabanda, J., Fries, R., Hanset, R., & Georges, M. (1997). A deletion in the bovine myostatin gene causes the double–muscled phenotype in cattle. *Nature Genetics*, *17*(1), 71–74. https://doi.org/10.1038/ng0997-71

Grobler, R., van Marle-Köster, E., & Visser, C. (2021). Challenges in selection and breeding of polled and scur phenotypes in beef cattle. *Livestock Science*, *247*, 104479. https://doi.org/10.1016/j.livsci.2021.104479

Grondahl-Nielsen, C., Simonsen, H. B., Lund, J. D., & Hesselholt, M. (1999). Behavioural, endocrine and cardiac responses in young calves undergoing dehorning without and with use of sedation and analgesia. *The Veterinary Journal*, *158*(1), 14–20. https://doi.org/10.1053/tvjl.1998.0284

Grout, A. S., Veira, D. M., Weary, D. M., von Keyserlingk, M. A. G., & Fraser, D. (2006). Differential effects of sodium and magnesium sulfate on water consumption by beef cattle1,2. *Journal of Animal Science*, *84*(5), 1252–1258. https://doi.org/10.2527/2006.8451252x

Gustin, P., Lomba, F., Bakima, J., Lekeux, P., & Van de Woestijne, K. P. (1987). Partitioning of pulmonary resistance in calves. *Journal of Applied Physiology*, *62*(5), 1826–1831. https://doi.org/10.1152/jappl.1987.62.5.1826

Gutiérrez-Gil, B., Ball, N., Burton, D., Haskell, M., Williams, J. L., & Wiener, P. (2008). Identification of quantitative trait loci affecting cattle temperament. *Journal of Heredity*, *99*(6), 629–638. https://doi.org/10.1093/jhered/esn060

Gutmann, A. K., Špinka, M., & Winckler, C. (2020). Do familiar group mates facilitate integration into the milking group after calving in dairy cows? *Applied Animal Behaviour Science*, *229*, 1–8. https://doi.org/10.1016/j.applanim.2020.105033

Guyot, H., Spring, P., Andrieu, S., & Rollin, F. (2007). Comparative responses to sodium selenite and organic selenium supplements in Belgian blue cows and calves. *Livestock Science*, *111*(3), 259–263. https://doi.org/10.1016/j.livsci.2007.04.018

Gygax, L., Mayer, C., Schulze Westerath, H., Friedli, K., & Wechsler, B. (2007). On-farm assessment of the lying behaviour of finishing bulls kept in housing systems with different floor qualities. *Animal Welfare*, *16*(2), 205–208. https://doi.org/10.1017/S0962728600031341

Gygax, L., Neisen, G., & Wechsler, B. (2010). Socio-spatial relationships in dairy cows. *Ethology*, *116*(1), 10–23. https://doi.org/10.1111/j.1439-0310.2009.01708.x

Gygax, L., Siegwart, R., & Wechsler, B. (2007). Effects of space allowance on the behaviour and cleanliness of finishing bulls kept in pens with fully slatted rubber coated flooring. *Applied Animal Behaviour Science*, *107*(1–2), 1–12. https://doi.org/10.1016/j.applanim.2006.09.011

Ha, J. J., Yang, K., Oh Dong, Y., Yi, J., & Kim, J. (2018). Rearing characteristics of fattening Hanwoo steers managed in different stocking densities. *Asian-Australasian Journal of Animal Sciences*, *31*(11), 1714–1720. https://doi.org/10.5713/ajas.17.0451

Hadley, G., Wolf, C., & Harsh, S. (2006). Dairy cattle culling patterns, explanations, and implications. *Journal of Dairy Science*, *89*(6), 2286–2296. https://doi.org/10.3168/jds.S0022-0302(06)72300-1

Halachmi, I., Klopčič, M., Polak, P., Roberts, D. J., & Bewley, J. M. (2013). Automatic assessment of dairy cattle body condition score using thermal imaging. *Computers and Electronics in Agriculture*, *99*, 35–40. https://doi.org/10.1016/j.compag.2013.08.012

Haley, D., Bailey, D., & Stookey, J. (2005). The effects of weaning beef calves in two stages on their behavior and growth rate. *Journal of Animal Science*, *83*(9), 2205–2214. https://doi.org/10.2527/2005.8392205x

Haley, D. B., Rushen, J., & de Passillé, A. M. (2000). Behavioural indicators of cow comfort: Activity and resting behaviour of dairy cows in two types of housing. *Canadian Journal of Animal Science*, *80*(2), 257–263. https://doi.org/10.4141/a99-084

Halipré, A. (1973). Étude du caractere culard. X. – sensibilité des bovins culards au stress thermique. *Annales de Génétique et de Sélection Animale*, *5*(4), 441–449. https://doi.org/10.1186/1297-9686-5-4-441

Hamrick, M. W., Pennington, C., & Byron, C. D. (2003). Bone architecture and disc degeneration in the lumbar spine of mice lacking GDF-8 (myostatin). *Journal of Orthopaedic Research*, *21*(6), 1025–1032. https://doi.org/10.1016/S0736-0266(03)00105-0

Handcock, R. N., Swain, D. L., Bishop-Hurley, G. J., Patison, K. P., Wark, T., Valencia, P., Corke, P., & O'Neill, C. J. (2009). Monitoring animal behaviour and environmental interactions using wireless sensor networks, GPS collars and satellite remote sensing. *Sensors*, *9*(5), 3586–3603. https://doi.org/10.3390/s90503586

Hannan, J., & Murphy, P. A. (1983). Comparative mortality and morbidity rates for cattle on slatted floors and in straw yards. In D. Smidt (Ed.), *Current topics in veterinary medicine and animal science* (pp. 139–140). Indicators Relevant to Farm Animal Welfare. Springer. https://doi.org/10.1007/978-94-009-6738-0_18

Hasegawa, N., Nishiwaki, A., Sugawara, K., & Ito, I. (1997). The effects of social exchange between two groups of lactating primiparous heifers on milk production, dominance order, behavior and adrenocortical response. *Applied Animal Behaviour Science*, *51*(1), 15–27. https://doi.org/10.1016/S0168-1591(96)01082-9
Haskell, M. J., Masłowska, K., Bell, D. J., Roberts, D. J., & Langford, F. M. (2013). The effect of a view to the surroundings and microclimate variables on use of a loafing area in housed dairy cattle. *Applied Animal Behaviour Science*, *147*(1–2), 28–33. https://doi.org/10.1016/j.applanim.2013.04.016
Haskell, M. J., Simm, G., & Turner, S. P. (2014). Genetic selection for temperament traits in dairy and beef cattle. *Frontiers in Genetics*, *5*, 368. https://doi.org/10.3389/fgene.2014.00368
Hatendi, P. R., Mulenga, F. M., Sibanda, S., & Ndlovu, P. (1996). The effect of diet and frequency of watering on the performance of growing cattle given food at maintenance. *Animal Science*, *63*(1), 33–38. https://doi.org/10.1017/S1357729800028253
Hauge, S. J., Kielland, C., Ringdal, G., Skjerve, E., & Nafstad, O. (2012). Factors associated with cattle cleanliness on Norwegian dairy farms. *Journal of Dairy Science*, *95*(5), 2485–2496. https://doi.org/10.3168/jds.2011-4786
Hay, K. E., Morton, J. M., Clements, A. C. A., Mahony, T. J., & Barnes, T. S. (2016). Associations between feedlot management practices and bovine respiratory disease in Australian feedlot cattle. *Preventive Veterinary Medicine*, *128*, 23–32. https://doi.org/10.1016/j.prevetmed.2016.03.017
Heinrich, A., Duffield, T. F., Lissemore, K. D., & Millman, S. T. (2010). The effect of meloxicam on behavior and pain sensitivity of dairy calves following cautery dehorning with a local anesthetic. *Journal of Dairy Science*, *93*(6), 2450–2457. https://doi.org/10.3168/jds.2009-2813
Held, S. D. E., & Špinka, M. (2011). Animal play and animal welfare. *Animal Behaviour*, *81*(5), 891–899. https://doi.org/10.1016/j.anbehav.2011.01.007
Hendricks, H. B., Aberle, E. D., Jones, D. J., & Martin, T. G. (1973). Muscle fiber type, rigor development and bone strength in double muscled cattle. *Journal of Animal Science*, *37*(6), 1305–1311. https://doi.org/10.2527/jas1973.3761305x
Herrero-García, G., Barroso, P., Preite, L., Relimpio, D., Vaz-Rodrigues, R., Balseiro, A., & Gortázar, C. (2024). Waterhole characteristics in tuberculosis positive and negative beef cattle farms from endemic regions in Spain. *Rangeland Ecology & Management*, *92*, 50–58. https://doi.org/10.1016/j.rama.2023.09.008
Herskin, M. S., & Nielsen, B. H. (2018). Welfare effects of the use of a combination of local Anesthesia and NSAID for disbudding analgesia in dairy calves-reviewed across different welfare concerns. Frontiers in veterinary. *Science*, *5*, 117. https://doi.org/10.3389/fvets.2018.00117
Herva, T., Huuskonen, A., Virtala, A.-M., & Peltoniemi, O. (2011). On-farm welfare and carcass fat score of bulls at slaughter. *Livestock Science*, *138*(1–3), 159–166. https://doi.org/10.1016/j.livsci.2010.12.019
Herve, L., Bareille, N., Cornette, B., Loiseau, P., & Assié, S. (2020). To what extent does the composition of batches formed at the sorting facility influence the subsequent growth performance of young beef bulls? A French observational study. *Preventive Veterinary Medicine*, *176*, 1–11. https://doi.org/10.1016/j.prevetmed.2020.104936
Hewson, C. J., Dohoo, I. R., Lemke, K. A., & Barkema, H. W. (2007). Canadian veterinarians' use of analgesics in cattle, pigs, and horses in 2004 and 2005. *Canadian Veterinary Journal*, *48*(2), 155–164. https://doi.org/10.4141/cjas68-021
Hickey, M., Earley, B., & Fisher, A. (2003). The effect of floor type and space allowance on welfare indicators of finishing steers. *Irish Journal of Agricultural and Food Research*, 89–100.
Hickey, M. C., Drennan, M., & Earley, B. (2003). The effect of abrupt weaning of suckler calves on the plasma concentrations of cortisol, catecholamines, leukocytes, acute-phase proteins and in vitro interferon-gamma production1. *Journal of Animal Science*, *81*(11), 2847–2855. https://doi.org/10.2527/2003.81112847x
Hickey, M. C., French, P., & Grant, J. (2002). Out-wintering pads for finishing beef cattle: Animal production and welfare. *Animal Science*, *75*(3), 447–458. https://doi.org/10.1017/S1357729800053212
Hidano, A., & Gates, M. C. (2019). Why sold, not culled? Analysing farm and animal characteristics associated with livestock selling practices. *Preventive Veterinary Medicine*, *166*, 65–77. https://doi.org/10.1016/j.prevetmed.2019.03.005
Hindman, M. S. (2023). Metabolic diseases in beef cattle. *Veterinary Clinics of North America: Food Animal Practice*, *39*(2), 337–353. https://doi.org/10.1016/j.cvfa.2023.02.011
Hoeben, D., Mijten, P., & de Kruif, A. (1997). Factors influencing complications during caesarean section on the standing cow. *Veterinary Quarterly*, *19*(2), 88–92. https://doi.org/10.1080/01652176.1997.9694748
Holland, B. (2012). *Preventing muddy conditions in feed lot pens*. SDSU Ext.
Holmes, J. H. G., Ashmore, C. R., & Robinson, D. W. (1973). Effects of stress on cattle with hereditary muscular hypertrophy. *Journal of Animal Science*, *36*(4), 684–694. https://doi.org/10.2527/jas1973.364684x
Hoppe, S., Brandt, H. R., Erhardt, G., & Gauly, M. (2008). Maternal protective behaviour of German Angus and Simmental beef cattle after parturition and its relation to production traits. *Applied Animal Behaviour Science*, *114*(3), 297–306. https://doi.org/10.1016/j.applanim.2008.04.008
Hoppe, S., Brandt, H. R., König, S., Erhardt, G., & Gauly, M. (2010). Temperament traits of beef calves measured under field conditions and their relationships to performance. *Journal of Animal Science*, *88*(6), 1982–1989. https://doi.org/10.2527/jas.2008-1557
Horvath, K. C., & Miller-Cushon, E. K. (2019). Characterizing grooming behavior patterns and the influence of brush access on the behavior of group-housed dairy calves. *Journal of Dairy Science*, *102*(4), 3421–3430. https://doi.org/10.3168/jds.2018-15460
Hubbard, A. J., Foster, M. J., & Daigle, C. L. (2021). Impact of social mixing on beef and dairy cattle—A scoping review. *Applied Animal Behaviour Science*, *241*, 1–10. https://doi.org/10.1016/j.applanim.2021.105389
Huber, J., Arnholdt, T., Möstl, E., Gelfert, C.-C., & Drillich, M. (2012). Pain management with flunixin meglumine at dehorning of calves. *Journal of Dairy Science*, *96*, 132–140. https://doi.org/10.3168/jds.2012-5483
Huertas, S. M., Gil, A. D., Piaggio, J. M., & van Eerdenburg, F. (2010). Transportation of beef cattle to slaughterhouses and how this relates to animal welfare and carcase bruising in an extensive production system. *Animal Welfare*, *19*(3), 281–285. https://doi.org/10.1017/S0962728600001664
Humer, E., Petri, R. M., Aschenbach, J. R., Bradford, B. J., Penner, G. B., Tafaj, M., Südekum, K. H., & Zebeli, Q. (2018). Invited review: Practical feeding management recommendations to mitigate the risk of subacute ruminal acidosis in dairy cattle. *Journal of Dairy Science*, *101*(2), 872–888. https://doi.org/10.3168/jds.2017-13191
Hurnik, J. F., Webster, A. B., & Siegel, P. B. (1995). *Dictionary of farm animal behavior* (2nd ed.). Iowa State University Press.
ICBF (Irish Cattle Breeding Federation). (2019). Polledness in Beef Breeds. https://www.icbf.com/polledness-in-beef-breeds/ [Accessed: 4 April 2024].
Idris, M., Sullivan, M., Gaughan, J. B., & Phillips, C. J. C. (2024). Behavioural responses of beef cattle to hot conditions. *Animals*, *14*(16), 2444. https://doi.org/10.3390/ani14162444
Iglesias, A., Casals, R., Quintana, B., Solé, A., Marti, S., & Devant, M. (2018). PSIX-4 cleaning frequency and straw bedding length alters behavior and animal and pen cleanliness of fattening bulls. *Journal of Animal Science*, *96*(Suppl. S3), 15. https://doi.org/10.1093/jas/sky404.034
ILCS (Irish Limousin Cattle Society), online. Limousin and the Myostatin Gene. ILCS July 2021 *Newsletter*. Available online: https://www.irishlimousin.com/wp-content/uploads/2021/07/ILCS-July-Newsletter.pdf
Ingvartsen, K. L., & Andersen, H. R. (1993). Space allowance and type of housing for growing cattle: A review of performance and possible relation to neuroendocrine function. *Acta Agriculturae Scandinavica Section A Animal Science*, *43*(2), 65–80. https://doi.org/10.1080/09064709309410147
Inspectra. (online). Inspection of meat and meat derivatives by artificial vision. https://inspectra-vision.com/en/meat-products/ [Accessed on 09 December 2024].

Institut de l'élevage, Unité mixte de technologie, and GenEval. (2024). Methods and results of the genetic evaluation IBOVAL 2024 for the beef cattle breeds. Paris. https://idele.fr/?eID=cmis_download&oID=workspace%3A%2F%2FSpacesStore%2F145cb17a-58e3-42ff-86a7-b4167f2c37df&cHash=b0ad1837ee33cb53b8203fba0ffc07bc.

Interbull Centre. (online). Beef calving. Interbull Centre. https://prep.interbull.org/display?formname=BEEF+Calving&fullpage=yes [Accessed: 5 December 2024].

Iraira, S. P., Madruga, A., Pérez-Juan, M., Ruíz-de-la-Torre, J. L., Rodríguez-Prado, M., Calsamiglia, S., Manteca, X., & Ferret, A. (2015). Performance, behaviour and meat quality of beef heifers fed concentrate and straw offered as total mixed ration or free-choice. *Spanish Journal of Agricultural Research*, *13*(4), 1–11. https://doi.org/10.5424/sjar/2015134-8003

Ishiwata, T., Uetake, K., Abe, N., Eguchi, Y., & Tanaka, T. (2006). Effects of an environmental enrichment using a drum can on behavioral, physiological and productive characteristics in fattening beef cattle. *Animal Science Journal*, *77*(3), 352–362. https://doi.org/10.1111/j.1740-0929.2006.00359.x

Ishiwata, T., Uetake, K., Kilgour, R. J., Eguchi, Y., & Tanaka, T. (2007). Oral Behaviors of beef steers in pen and pasture environments. *Journal of Applied Animal Welfare Science*, *10*(2), 185–192. https://doi.org/10.1080/10888700701313629

Islam, M., Lomax, S., Doughty, A., Islam, M., Thomson, P., & Clark, C. (2023). Revealing the diversity of internal body temperature and panting response for feedlot cattle under environmental thermal stress. *Scientific Reports*, *13*(1), 4879. https://doi.org/10.1038/s41598-023-31801-7

Jäger, M., Gauly, M., Bauer, C., Failing, K., Erhardt, G., & Zahner, H. (2005). Endoparasites in calves of beef cattle herds: Management systems dependent and genetic influences. *Veterinary Parasitology*, *131*(3–4), 173–191. https://doi.org/10.1016/j.vetpar.2005.05.014

Jamrozik, J., & Miller, S. P. (2014). Genetic evaluation of calving ease in Canadian Simmentals using birth weight and gestation length as correlated traits. *Livestock Science*, *162*, 42–49. https://doi.org/10.1016/j.livsci.2014.01.027

Jarvis, A. M., Selkirk, L., & Cockram, M. S. (1995). The influence of source, sex class and pre-slaughter handling on the bruising of cattle at two slaughterhouses. *Livestock Production Science*, *43*(3), 215–224. https://doi.org/10.1016/0301-6226(95)00055-P

Jemison, J. M., & Jones, C. (2002). Watering Systems for Livestock. University of Maine Cooperative Extension Bulletin #7129, 4 pp. https://projects.sare.org/wp-content/uploads/1161LNE96-079_0001.pdf

Jensen, M. B. (1999). Effects of confinement on rebounds of locomotor behaviour of calves and heifers, and the spatial preferences of calves. *Applied Animal Behaviour Science*, *62*(1), 43–56. https://doi.org/10.1016/S0168-1591(98)00208-1

Jensen, M. B., Vestergaard, K. S., & Krohn, C. C. (1998). Play behaviour in dairy calves kept in pens: The effect of social contact and space allowance. *Applied Animal Behaviour Science*, *56*(2–4), 97–108. https://doi.org/10.1016/S0168-1591(97)00106-8

Jensen, M. B., & Vestergaard, M. (2021). Invited review: Freedom from thirst—Do dairy cows and calves have sufficient access to drinking water? *Journal of Dairy Science*, *104*(11), 11368–11385. https://doi.org/10.3168/jds.2021-20487

Jensen, P. (2010). Domestication, selection, behaviour and welfare of animals – Genetic mechanisms for rapid responses. *Animal Welfare*, *19*(S1), 7–9. https://doi.org/10.1017/S0962728600002189

Jesse, F., Abba, Y., Sadiq, M. A., Umer, M., Chung, E. L. T., Bitrus, A. A., & Siti, L. (2016). A suspected case of suppurative frontal sinusitis in a Friesian heifer: Clinical management. *International Journal of Livestock Research*, *6*(8), 50–54. https://doi.org/10.5455/ijlr.20160816055652

Johanson, J. M., & Berger, P. J. (2003). Birth weight as a predictor of calving ease and perinatal mortality in Holstein cattle. *Journal of Dairy Science*, *86*(11), 3745–3755. https://doi.org/10.3168/jds.S0022-0302(03)73981-2

Johns, J., & Knierim, U. (2019). *Effects of herd, housing and management conditions on horn-induced alterations in cows. Proceedings of the 53rd congress of the ISAE, animal lives worth living, Bergen, Norway, 5–9 August 2019* (p. 266). Wageningen Academic Publishers. https://doi.org/10.3920/9789086868896_0201

Johns, J., Knierim, U., Mück, U., Sixt, D., Kremer, H.-J., & Poddey, E. (2019). Werkzeugkasten für die Haltung horntragender Milchkühe im Laufstall. https://orgprints.org/id/eprint/40225/1/Werkzeugkasten_Downloadversion_final_2019-10-15.pdf.

Johnsen, J. F., Ellingsen, K., Grøndahl, A. M., Bøe, K. E., Lidfors, L., & Mejdell, C. M. (2015). The effect of physical contact between dairy cows and calves during separation on their post-separation behavioural response. *Applied Animal Behaviour Science*, *166*, 11–19. https://doi.org/10.1016/j.applanim.2015.03.002

Johnson, A. K., Lonergan, S. M., Busby, W. D., Shouse, S. C., Maxwell, D. L., Harmon, J., & Honeyman, M. (2011). Comparison of steer behavior when housed in a deep-bedded hoop barn versus an open feedlot with shelter. *Journal of Animal Science*, *89*(6), 1893–1898. https://doi.org/10.2527/jas.2010-2877

Johnson, P. S., Patterson, H. H., & Haigh, R. (2004). *Effects of sulfates in water on performance of steers grazing rangeland* (p. 5). South Dakota State University. https://openprairie.sdstate.edu/sd_beefreport_2004/9

Kadel, M. J., Johnston, D. J., Burrow, H. M., Graser, H.-U., & Ferguson, D. M. (2006). Genetics of flight time and other measures of temperament and their value as selection criteria for improving meat quality traits in tropically adapted breeds of beef cattle. *Australian Journal of Agricultural Research*, *57*(9), 1029–1035. https://doi.org/10.1071/AR05082

Kambadur, R., Sharma, M., Smith, T. P. L., & Bass, J. J. (1997). Mutations in myostatin (GDF8) in double-muscled Belgian blue and Piedmontese cattle. *Genome Research*, *7*(9), 910–915. https://doi.org/10.1101/gr.7.9.910

Karhan, M., Troxler, J., & Paulsen, P. (2020). Cleanliness of Slaughter Cattle-a Pilot Study in Austria. *Wiener Tierärztliche Monatsschrift*, *107*(1/2), 40–48.

Kaurivi, Y. B., Laven, R., Hickson, R., Parkinson, T., & Stafford, K. (2020). Developing an animal welfare assessment protocol for cows in extensive beef cow–calf Systems in New Zealand. Part 1: Assessing the feasibility of identified animal welfare assessment measures. *Animals*, *10*(9), 1597. https://doi.org/10.3390/ani10091597

Keane, M. P., McGee, M., O'Riordan, E. G., Kelly, A. K., & Earley, B. (2017). Effect of space allowance and floor type on performance, welfare and physiological measurements of finishing beef heifers. *Animal*, *11*(12), 2285–2294. https://doi.org/10.1017/S1751731117001288

Keane, M. P., McGee, M., O'Riordan, E. G., Kelly, A. K., & Earley, B. (2018a). Effect of floor type on performance, lying time and dirt scores of finishing beef cattle: A meta-analysis. *Livestock Science*, *212*, 57–60. https://doi.org/10.1016/j.livsci.2018.03.012

Keane, M. P., McGee, M., O'Riordan, E. G., Kelly, A. K., & Earley, B. (2018b). Performance and welfare of steers housed on concrete slatted floors at fixed and dynamic (allometric based) space allowances. *Journal of Animal Science*, *96*(3), 880–889. https://doi.org/10.1093/jas/sky007

Keeling, L. J. (1994). Inter-bird distances and behavioural priorities in laying hens: The effect of spatial restriction. *Applied Animal Behaviour Science*, *39*(2), 131–140. https://doi.org/10.1016/0168-1591(94)90133-3

Kelln, B. M., Lardner, H. A., McKinnon, J. J., Campbell, J. R., Larson, K., & Damiran, D. (2011). Effect of winter feeding system on beef cow performance, reproductive efficiency, and system cost1. The professional animal. *Scientist*, *27*(5), 410–421. https://doi.org/10.15232/S1080-7446(15)30513-1

Ketelaar de Lauwere, C., & Smits, A. (1991). Spatial requirements of individually housed veal calves of 175 to 300 kg. *NewTrends in Veal Calf Production EAAP Publications*, *52*, 49 https://edepot.wur.nl/317675#page=51.

Khiaosa-Ard, R., & Zebeli, Q. (2018). Diet-induced inflammation: From gut to metabolic organs and the consequences for the health and longevity of ruminants. *Research in Veterinary Science*, *120*, 17–27. https://doi.org/10.1016/j.rvsc.2018.08.005

Kielland, C., Skjerve, E., & Zanella, A. J. (2009). Attitudes of veterinary students to pain in cattle. *Veterinary Record*, *165*(9), 254–258. https://doi.org/10.1136/vr.165.9.254

Kilgour, R. J. (2012). In pursuit of "normal": A review of the behaviour of cattle at pasture. *Applied Animal Behaviour Science*, *138*(1), 1–11. https://doi.org/10.1016/j.applanim.2011.12.002

Kilgour, R. J., Uetake, K., Ishiwata, T., & Melville, G. J. (2012). The behaviour of beef cattle at pasture. *Applied Animal Behaviour Science*, *138*(1), 12–17. https://doi.org/10.1016/j.applanim.2011.12.001

King, D. A., Schuehle Pfeiffer, C. E., Randel, R. D., Welsh, T. H., Jr., Oliphint, R. A., Baird, B. E., Curley, K. O., Jr., Vann, R. C., Hale, D. S., & Savell, J. W. (2006). Influence of animal temperament and stress responsiveness on the carcass quality and beef tenderness of feedlot cattle. *Meat Science*, *74*(3), 546–556. https://doi.org/10.1016/j.meatsci.2006.05.004

Kirchner, M., Kempkens, K., & Boxberger, J. (1987). Loading of the claws and the consequences for the design of slatted floor. Proceedings of the Seminar of the 2nd Technical Section of the C.I.G.R. [Commission Internationale du Génie Rural], University of Illinois, Urbana-Champaign, Illinois, USA, 1–8.

Kirchner, M. K., Schulze Westerath, H., Knierim, U., Tessitore, E., Cozzi, G., Pfeiffer, C., & Winckler, C. (2014). Application of the welfare quality® assessment system on European beef bull farms. *Animal*, *8*(5), 827–835. https://doi.org/10.1017/S1751731114000366

Kirk, A. A., & Tucker, C. B. (2023). Development and application of a scoring system for septum injuries in beef calves with and without a nose flap. Translational. *Animal Science*, *7*(1). doi:10.1093/tas/txad075

Kissell, L., Smith, G., Leavens, T., Baynes, R., Wu, H., & Riviere, J. (2012). Plasma pharmacokinetics and milk residues of flunixin and 5-hydroxy flunixin following different routes of administration in dairy cattle. *Journal of Dairy Science*, *95*(12), 7151–7157. https://doi.org/10.3168/jds.2012-5754

Kleen, J. L., Hooijer, G. A., Rehage, J., & Noordhuizen, J. P. T. M. (2003). Subacute Ruminal Acidosis (SARA): a review. *Journal of Veterinary Medicine Series A*, *50*(8), 406–414. https://doi.org/10.1046/j.1439-0442.2003.00569.x

Kleinhenz, M., Van Engen, N., Smith, J., Gorden, P., Ji, J., Wang, C., Perkins, S., & Coetzee, J. (2018). The impact of transdermal flunixin meglumine on biomarkers of pain in calves when administered at the time of surgical castration without local anesthesia. *Livestock Science*, *212*, 1–6. https://doi.org/10.1016/j.livsci.2018.03.016

Kleinhenz, M. D., Van Engen, N. K., Gorden, P. J., Ji, J., Walsh, P., & Coetzee, J. F. (2017). Effects of transdermal flunixin meglumine on pain biomarkers at dehorning in calves. *Journal of Animal Science*, *95*(5), 1993–2000. https://doi.org/10.2527/jas.2016.1138

Klemm, W. R., Sherry, C. J., Schake, L. M., & Sis, R. F. (1983). Homosexual behavior in feedlot steers: An aggression hypothesis. *Applied Animal Ethology*, *11*(2), 187–195. https://doi.org/10.1016/0304-3762(83)90127-X

Kneeland, J., Li, C., Basarab, J., Snelling, W. M., Benkel, B., Murdoch, B., Hansen, C., & Moore, S. S. (2004). Identification and fine mapping of quantitative trait loci for growth traits on bovine chromosomes 2, 6, 14, 19, 21, and 23 within one commercial line of *Bos taurus*. *Journal of Animal Science*, *82*(12), 3405–3414. https://doi.org/10.2527/2004.82123405x

Knierim, U., Irrgang, N., Roth, B., & Gorniak, T. (2009). Report on the assessment of dehorning and the keeping of horned dairy and beef cattle. *University of Kassel, Germany*, D221–D237.

Knierim, U., Irrgang, N., & Roth, B. A. (2015). To be or not to be horned—Consequences in cattle. *Livestock Science*, *179*, 29–37. https://doi.org/10.1016/j.livsci.2015.05.014

Knock, M., & Carroll, G. A. (2019). The potential of post-mortem carcass assessments in reflecting the welfare of beef and dairy cattle. *Animals*, *9*(11), 959. https://doi.org/10.3390/ani9110959

Knowles, T. G., Edwards, J. E., Bazeley, K. J., Brown, S. N., Butterworth, A., & Warriss, P. D. (2000). Changes in the blood biochemical and haematological profile of neonatal calves with age. *Veterinary Record*, *147*(21), 593–598. https://doi.org/10.1136/vr.147.21.593

Kohari, D., Kosako, T., Fukasawa, M., & Tsukada, H. (2007). Effect of environmental enrichment by providing trees as rubbing objects in grassland: Grazing cattle need tree-grooming. *Animal Science Journal*, *78*(4), 413–416. https://doi.org/10.1111/j.1740-0929.2007.00455.x

Kolkman, I., Aerts, S., Vervaecke, H., Vicca, J., Vandelook, J., De Kruif, A., Opsomer, G., & Lips, D. (2010). Assessment of differences in some indicators of pain in double muscled Belgian Blue cows following naturally calving vs caesarean section. *Reproduction in Domestic Animals*, *45*(1), 160–167. https://doi.org/10.1111/j.1439-0531.2008.01295.x

Kolkman, I., Hoflack, G., Aerts, S., Laevens, H., Lips, D., & Opsomer, G. (2012). Pelvic dimensions in phenotypically double-muscled Belgian blue cows. *Reproduction in Domestic Animals*, *47*(3), 365–371. https://doi.org/10.1111/j.1439-0531.2011.01881.x

Kondo, S., Kawakami, N., Kohama, H., & Nishino, S. (1984). Changes in activity, spatial pattern and social behavior in calves after grouping. *Applied Animal Ethology*, *11*(3), 217–228. https://doi.org/10.1016/0304-3762(84)90028-2

Kondo, S., Masato, S., Hiroaki, M., Susumu, N., & Yasushi, A. (1989). Spatial and social behavior of a beef-cattle group on grazing pasture and in dry-lot. *Hokkaido University Collection of Scholarly and Academic Papers*, *14*, 99–105.

Kondo, S., Sekine, J., Okubo, M., & Asahida, Y. (1989). The effect of group size and space allowance on the agonistic and spacing behavior of cattle. *Applied Animal Behaviour Science*, *24*(2), 127–135. https://doi.org/10.1016/0168-1591(89)90040-3

Kour, H., Patison, K. P., Corbet, N. J., & Swain, D. L. (2021). Recording cattle maternal behaviour using proximity loggers and tri-axial accelerometers. *Applied Animal Behaviour Science*, *240*, 105349. https://doi.org/10.1016/j.applanim.2021.105349

Krahn, J., Foris, B., Sheng, K., Weary, D. M., & von Keyserlingk, M. A. G. (2024). Effects of group size on agonistic interactions in dairy cows: A descriptive study. *Animal*, *18*(3), 1–8. https://doi.org/10.1016/j.animal.2024.101083

Krawczel, P., Klaiber, L., Butzler, R., Klaiber, L., Dann, H., Mooney, C., & Grant, R. (2012). Short-term increases in stocking density affect the lying and social behavior, but not the productivity, of lactating Holstein dairy cows. *Journal of Dairy Science*, *95*(8), 4298–4308. https://doi.org/10.3168/jds.2011-4687

Kretschmann, J., Früchtl, L., Fischer, M., Kaiser, M., Müller, H., Spilke, J., Mielenz, N., Möbius, G., Bittner-Schwerda, L., & Steinhöfel, I. (2021). Effect of a multimodal pain management protocol and age on wound healing after thermal disbudding of female German Holstein calves. *Schweizer Archiv Fur Tierheilkunde*, *163*(12), 836–850. https://doi.org/10.17236/sat00330

Krohn, C. C., Munksgaard, L., & Jonasen, B. (1992). Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments I. Experimental procedure, facilities, time budgets — Diurnal and seasonal conditions. *Applied Animal Behaviour Science*, *34*(1), 37–47. https://doi.org/10.1016/S0168-1591(05)80055-3

Kroll, L. K., Grooms, D. L., Siegford, J. M., Schweihofer, J. P., Daigle, C. L., Metz, K., & Ladoni, M. (2014). Effects of tail docking on behavior of confined feedlot cattle. *Journal of Animal Science*, *92*(10), 4701–4710. https://doi.org/10.2527/jas.2014-7583

Kubelka, L. (2016). *Survey of parasitoses in beef cattle from two geographical areas of The Czech Republic* (p. 79). Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Czech Republic. https://theses.cz/id/ks83jn/?lang=en

Kumar, N., Rao, T. K. S., Varghese, A., & Rathor, V. S. (2013). Internal parasite management in grazing livestock. *Journal of Parasitic Diseases*, *37*(2), 151–157. https://doi.org/10.1007/s12639-012-0215-z

Laden, S., Wohlt, J., Zajac, P., & Carsia, R. (1985). Effects of stress from electrical dehorning on feed intake, growth, and blood constituents of Holstein heifer calves. *Journal of Dairy Science*, *68*(11), 3062–3066. https://doi.org/10.3168/jds.S0022-0302(85)81203-0

Lambertz, C., Bowen, P. R., Erhardt, G., & Gauly, M. (2015). Effects of weaning beef cattle in two stages or by abrupt separation on nasal abrasions, behaviour, and weight gain. *Animal Production Science*, *55*(6), 786–792. https://doi.org/10.1071/AN14097

Langova, L., Novotna, I., Nemcova, P., Machacek, M., Havlicek, Z., Zemanova, M., & Chrast, V. (2020). Impact of nutrients on the hoof health in cattle. *Animals*, *10(10):1824*, 1–22. https://www.mdpi.com/2076-2615/10/10/1824

Laporte, I., Muhly, T. B., Pitt, J. A., Alexander, M., & Musiani, M. (2010). Effects of wolves on elk and cattle behaviors: Implications for livestock production and wolf conservation. *PLoS One*, *5*(8), e11954. https://doi.org/10.1371/journal.pone.0011954

Lardner, H., Braul, L., Schwartzkopf-Genswein, K., Schwean-Lardner, K., Damiran, D., & Darambazar, E. (2013). Consumption and drinking behavior of beef cattle offered a choice of several water types. *Livestock Science*, *157*(2–3), 577–585. https://doi.org/10.1016/j.livsci.2013.08.016

Lardner, H. A., Kirychuk, B. D., Braul, L., Willms, W. D., & Yarotski, J. (2005). The effect of water quality on cattle performance on pasture. *Australian Journal of Agricultural Research*, *56*(1), 97–104. https://doi.org/10.1071/AR04086

Lawrence, P., McGee, M., & Earley, B. (2022). Animal welfare index: An animal welfare evaluation of beef production farms in Ireland. *Journal of Applied Animal Research*, *50*(1), 643–655. https://doi.org/10.1080/09712119.2022.2126478

Le Neindre, P., Trillat, G., Sapa, J., Ménissier, F., Bonnet, J. N., & Chupin, J. M. (1995). Individual differences in docility in Limousin cattle. *Journal of Animal Science*, *73*(8), 2249–2253. https://doi.org/10.2527/1995.7382249x

Lean, I. J., Westwood, C. T., Golder, H. M., & Vermunt, J. J. (2013). Impact of nutrition on lameness and claw health in cattle. *Livestock Science*, *156*(1–3), 71–87. https://doi.org/10.1016/j.livsci.2013.06.006

Ledgerwood, D. N., Winckler, C., & Tucker, C. B. (2010). Evaluation of data loggers, sampling intervals, and editing techniques for measuring the lying behavior of dairy cattle. *Journal of Dairy Science*, *93*(11), 5129–5139. https://doi.org/10.3168/jds.2009-2945

Lee, C., Fisher, A. D., Colditz, I. G., Lea, J. M., & Ferguson, D. M. (2013). Preference of beef cattle for feedlot or pasture environments. *Applied Animal Behaviour Science*, *145*(3–4), 53–59. https://doi.org/10.1016/j.applanim.2013.03.005

Lees, A. M., Salvin, H. E., Colditz, I. G., & Lee, C. (2020). The influence of temperament on body temperature response to handling in Angus cattle. *Animals*, *10*(1), 172. https://doi.org/10.3390/ani10010172

Lees, A. M., Sejian, V., Wallage, A. L., Steel, C. C., Mader, T. L., Lees, J. C., & Gaughan, J. B. (2019). The impact of heat load on cattle. *Animals*, *9*(6), 322. https://doi.org/10.3390/ani9060322

Lees, A. M., Sullivan, M. L., Olm, J. C. W., Cawdell-Smith, A. J., & Gaughan, J. B. (2019). A panting score index for sheep. *International Journal of Biometeorology*, *63*(7), 973–978. https://doi.org/10.1007/s00484-019-01711-3

Lefcourt, A. M., & Elsasser, T. H. (1995). Adrenal responses of Angus × Hereford cattle to the stress of weaning. *Journal of Animal Science*, *73*(9), 2669–2676. https://doi.org/10.2527/1995.7392669x

Legesse, G., Small, J. A., Scott, S. L., Kebreab, E., Crow, G. H., Block, H. C., Robins, C. D., Khakbazan, M., & McCaughey, W. P. (2012). Bioperformance evaluation of various summer pasture and winter feeding strategies for cow-calf production. *Canadian Journal of Animal Science*, *92*(1), 89–102. https://doi.org/10.4141/cjas2011-082

Legrand, A. L., von Keyserlingk, M. A. G., & Weary, D. M. (2009). Preference and usage of pasture versus free-stall housing by lactating dairy cattle. *Journal of Dairy Science*, *92*(8), 3651–3658. https://doi.org/10.3168/jds.2008-1733

Lensink, B. J., Ofner-Schröck, E., Ventorp, M., Zappavigna, P., Flaba, J., Georg, H., & Bizeray-Filoche, D. (2013). Lying and walking surfaces for cattle, pigs and poultry and their impact on health, behaviour and performance. In *Livestock housing. Wageningen academic publishers* (pp. 75–92). https://doi.org/10.3920/978-90-8686-771-4_04

Leruste, H., Brscic, M., Heutinck, L. F. M., Visser, E. K., Wolthuis-Fillerup, M., Bokkers, E. A. M., Stockhofe-Zurwieden, N., Cozzi, G., Gottardo, F., Lensink, B. J., & van Reenen, C. G. (2012). The relationship between clinical signs of respiratory system disorders and lung lesions at slaughter in veal calves. *Preventive Veterinary Medicine*, *105*(1), 93–100. https://doi.org/10.1016/j.prevetmed.2012.01.015

Lévy, F., Guevara-Guzman, R., Hinton, M., Kendrick, K., & Keverne, E. (1993). Effects of parturition and maternal experience on noradrenaline and acetylcholine release in the olfactory bulb of sheep. *Behavioral Neuroscience*, *107*, 662–668. https://doi.org/10.1037/0735-7044.107.4.662

Li, S., Khafipour, E., Krause, D. O., Kroeker, A., Rodriguez-Lecompte, J. C., Gozho, G. N., & Plaizier, J. C. (2012). Effects of subacute ruminal acidosis challenges on fermentation and endotoxins in the rumen and hindgut of dairy cows. *Journal of Dairy Science*, *95*(1), 294–303. https://doi.org/10.3168/jds.2011-4447

Lidfors, L. (1989). The use of getting up and lying down movements in the evaluation of cattle environments. *Veterinary Research Communications*, *13*(4), 307–324. https://doi.org/10.1007/BF00420838

Ligon, J. M. (2014). *The effects of low stress cattle handling and weaning training on post-weaning weight gain and calf activity*. Master of Science in Biomedical and Veterinary Sciences. https://vtechworks.lib.vt.edu/server/api/core/bitstreams/13a670cb-a9ad-4982-a6aa-f16cf96d0887/content

Limousine. (online). La station nationale de qualification de Lanaud. Limousine. https://www.limousine.org/fichiers/Plaquettes/plaquette_station_lanaud.pdf [Accessed on 12 February 2025].

Lin, J. C., Moss, B. R., Koon, J. L., Flood, C. A., Smith, R. C., III, Cummins, K. A., & Coleman, D. A. (1998). Comparison of various fan, sprinkler, and mister systems in reducing heat stress in dairy cows. *Applied Engineering in Agriculture*, *14*(2), 177–182. https://doi.org/10.13031/2013.19370

Lindén, J., Taponen, S., Talvitie, V., Leppävuori, E., & Hänninen, L. (2023). Histopathological findings in a pilot study of dairy calves disbudded with hot cauterization or caustic paste. *Journal of Comparative Pathology*, *201*, 118–122. https://doi.org/10.1016/j.jcpa.2023.01.003

Llonch, L., Castillejos, L., & Ferret, A. (2020). Increasing the content of physically effective fiber in high-concentrate diets fed to beef heifers affects intake, sorting behavior, time spent ruminating, and rumen pH. *Journal of Animal Science*, *98*(6). https://doi.org/10.1093/jas/skaa192

Llonch, L., Marti, S., Fernandez, B., Prenafeta-Boldú, F. X., Verdú, M., Salsa, X., & Devant, M. (2022). PSXIII-3 effect of pen stocking density on animal performance, social behavior, and animal and pen dirtiness in Holstein bulls fed high-concentrate diets. *Journal of Animal Science*, *100*(Supplement_3), 203–204. https://doi.org/10.1093/jas/skac247.370

Llonch, L., Verdú, M., Guivernau, M., Viñas, M., Martí, S., Medinyà, C., Riera, J., Cucurull, J., & Devant, M. (2024). Dose effect of drinking water nitrate on health, feed intake, rumen fermentation and microbiota, and nitrogen excretion in Holstein heifers for a sustainable water use. *Sustainability*, *16*(20), 8814 https://www.mdpi.com/2071-1050/16/20/8814

Llonch, L., Verdú, M., Martí, S., Medinyà, C., Riera, J., Cucurull, J., & Devant, M. (2023). Drinking water chlorination in dairy beef fattening bulls: Water quality, potential hazards, apparent total tract digestibility, and growth performance. *Animal*, *17*(1), 1–12. https://doi.org/10.1016/j.animal.2022.100685

Llonch, L., Verdú, M., Martí, S., Medinyà, C., Riera, J., Cucurull, J., & Devant, M. (2024). Chlorine dioxide may be an alternative to acidification and chlorination for drinking water chemical disinfection in dairy beef bulls. *Animal*, *18*(9), 101244. https://doi.org/10.1016/j.animal.2024.101244

Llonch, P., Somarriba, M., Duthie, C. A., Troy, S., Roehe, R., Rooke, J., Haskell, M. J., & Turner, S. P. (2018). Temperament and dominance relate to feeding behaviour and activity in beef cattle: Implications for performance and methane emissions. *Animal*, *12*(12), 2639–2648. https://doi.org/10.1017/S1751731118000617

Loberg, J. M., Hernandez, C. E., Thierfelder, T., Jensen, M. B., Berg, C., & Lidfors, L. (2008). Weaning and separation in two steps—A way to decrease stress in dairy calves suckled by foster cows. *Applied Animal Behaviour Science*, *111*(3), 222–234. https://doi.org/10.1016/j.applanim.2007.06.011

Lomax, S., & Windsor, P. A. (2013). Topical anesthesia mitigates the pain of castration in beef calves1. *Journal of Animal Science*, *91*(10), 4945–4952. https://doi.org/10.2527/jas.2012-5984

Loneragan, G. H., Dargatz, D. A., Morley, P. S., & Smith, M. A. (2001). Trends in mortality ratios among cattle in US feedlots. *Journal of the American Veterinary Medical Association*, *219*(8), 1122–1127. https://doi.org/10.2460/javma.2001.219.1122

Lopes, F., Ferreira, J., Lôbo, R. B., & Rosa, G. (2017). Bayesian analyses of genetic parameters for growth traits in Nellore cattle raised on pasture. *Genetics and Molecular Research*, *16*(3), 1–10. https://doi.org/10.4238/gmr16039606

López, A., Arroquy, J. I., Hernández, O., Nasca, J. A., Juárez Sequeira, A. V., DiLorenzo, N., & Distel, R. A. (2021). A meta-analytical evaluation of the effects of high-salt water intake on beef cattle. *Journal of Animal Science*, *99*(8). https://doi.org/10.1093/jas/skab215

Losada-Espinosa, N., Estévez-Moreno, L. X., Bautista-Fernández, M., Galindo, F., Salem, A. Z. M., & Miranda-de la Lama, G. C. (2021). Cattle welfare assessment at the slaughterhouse level: Integrated risk profiles based on the animal's origin, pre-slaughter logistics, and iceberg indicators. *Preventive Veterinary Medicine*, *197*, 105513. https://doi.org/10.1016/j.prevetmed.2021.105513

Losada-Espinosa, N., Villarroel, M., María, G. A., & Miranda-de la Lama, G. C. (2018). Pre-slaughter cattle welfare indicators for use in commercial abattoirs with voluntary monitoring systems: A systematic review. *Meat Science*, *138*, 34–48. https://doi.org/10.1016/j.meatsci.2017.12.004

Losson, B., Lonneux, J.-F., & Lekimme, M. (1999). The pathology of Psoroptes ovis infestation in cattle with a special emphasis on breed difference. *Veterinary Parasitology*, *83*(3–4), 219–229. https://doi.org/10.1016/S0304-4017(99)00059-X

Love, W. J., Lehenbauer, T. W., Kass, P. H., Van Eenennaam, A. L., & Aly, S. S. (2014). Development of a novel clinical scoring system for on-farm diagnosis of bovine respiratory disease in pre-weaned dairy calves. *PeerJ*, *2*, e238. https://doi.org/10.7717/peerj.238

Lowe, D. E., Steen, R. W. J., & Beattie, V. E. (2001). Preferences of housed finishing beef cattle for different floor types. *Animal Welfare*, *10*(4), 395–404. https://doi.org/10.1017/S0962728600032668

Lowe, D. E., Steen, R. W. J., Beattie, V. E., & Moss, B. W. (1999). The effect of housing system on the behaviour, welfare and performance of beef cattle. *Proceedings of the British Society of Animal Science*, *1999*, 53. https://doi.org/10.1017/S1752756200002088

Loxton, I. D. L., Toleman, M. A., & Holmes, A. E. (1982). The effect of dehorning Brahman crossbred animals of four age groups on subsequent bodyweight gain. *Australian Veterinary Journal*, *58*(5), 191–193. https://doi.org/10.1111/j.1751-0813.1982.tb00650.x

Lundborg, G. K., Svensson, E. C., & Oltenacu, P. A. (2005). Herd-level risk factors for infectious diseases in Swedish dairy calves aged 0–90 days. *Preventive Veterinary Medicine*, *68*(2–4), 123–143. https://doi.org/10.1016/j.prevetmed.2004.11.014

Lutz, J., Burla, J. B., Gygax, L., Wechsler, B., Würbel, H., & Friedli, K. (2019). Horned and dehorned dairy cows differ in the pattern of agonistic interactions investigated under different space allowances. *Applied Animal Behaviour Science*, *218*, 104819. https://doi.org/10.1016/j.applanim.2019.05.008

Lynch, E., McGee, M., & Earley, B. (2019). Weaning management of beef calves with implications for animal health and welfare. *Journal of Applied Animal Research*, *47*(1), 167–175. https://doi.org/10.1080/09712119.2019.1594825

Lyons, N. A., Karvountzis, S., & Knight-Jones, T. J. D. (2013). Aspects of bovine caesarean section associated with calf mortality, dam survival and subsequent fertility. *The Veterinary Journal*, *197*(2), 342–350. https://doi.org/10.1016/j.tvjl.2013.01.010

Ma, B., Wei, W., Xia, Z.-F., Tang, H.-T., Zhu, S.-H., Wang, Y., Wang, G.-y., Cheng, D.-s., & Xiao, S.-c. (2007). Mass chemical burn casualty: Emergency management of 118 patients with alkali burn during a Matsa typhoon attack in Shanghai, China in 2005. *Burns*, *33*(5), 565–571. https://doi.org/10.1016/j.burns.2006.10.402

Mac, S. E., Lomax, S., Doughty, A. K., Thomson, P. C., & Clark, C. E. F. (2024). The impact of abrupt and Fenceline-weaning methods on cattle stress response, live weight gain, and behaviour. *Animals*, *14*(11), 1525. https://doi.org/10.3390/ani14111525

MacGregor, R. G., & Casey, N. H. (1999). Evaluation of carving interval and calving date as measures of reproductive performance in a beef herd. *Livestock Production Science*, *57*(2), 181–191. https://doi.org/10.1016/S0301-6226(98)00158-4

Mach, N., Bach, A., Realini, C. E., Font, I. F. M., Velarde, A., & Devant, M. (2009). Burdizzo pre-pubertal castration effects on performance, behaviour, carcass characteristics, and meat quality of Holstein bulls fed high-concentrate diets. *Meat Science*, *81*(2), 329–334. https://doi.org/10.1016/j.meatsci.2008.08.007

Macitelli, F., Braga, J., Gellatly, D., & da Costa, M. P. (2020). Reduced space in outdoor feedlot impacts beef cattle welfare. *Animal*, *14*(12), 2588–2597. https://doi.org/10.1017/S1751731120001652

Mader, T. (2014). Bill E. Kunkle interdisciplinary beef symposium: Animal welfare concerns for cattle exposed to adverse environmental conditions. *Journal of Animal Science*, *92*(12), 5319–5324. https://doi.org/10.2527/jas.2014-7950

Mader, T., Davis, M., & Gaughan, J. (2007). Effect of sprinkling on feedlot microclimate and cattle behavior. *International Journal of Biometeorology*, *51*, 541–551. https://doi.org/10.1007/s00484-007-0093-8

Mader, T. L. (2003). Environmental stress in confined beef cattle. *Journal of Animal Science*, *81*(14), E110–E119. https://doi.org/10.2527/2003.8114_suppl_2E110x

Mader, T. L. (2011). Mud effects on feedlot cattle. Nebraska Beef Cattle Reports, 613. Available online: https://digitalcommons.unl.edu/animalscinbcr/613

Mader, T. L., & Colgan, S. L. (2007). Pen density and straw bedding during feedlot finishing. *Nebraska Beef Cattle Reports*, *70* https://digitalcommons.unl.edu/animalscinbcr/70.

Mader, T. L., Davis, M. S., & Brown-Brandl, T. (2006). Environmental factors influencing heat stress in feedlot cattle. *Journal of Animal Science*, *84*(3), 712–719. https://doi.org/10.2527/2006.843712x

Mader, T. L., Gaughan, J. B., Johnson, L. J., & Hahn, G. L. (2010). Tympanic temperature in confined beef cattle exposed to excessive heat load. *International Journal of Biometeorology*, *54*, 629–635. https://doi.org/10.1007/s00484-009-0229-0

Mader, T. L., Holt, S. M., Hahn, G. L., Davis, M. S., & Spiers, D. E. (2002). Feeding strategies for managing heat load in feedlot cattle. *Journal of Animal Science*, *80*(9), 2373–2382. https://doi.org/10.1093/ansci/80.9.2373

Mader, T. L., Johnson, L. J., & Gaughan, J. B. (2010). A comprehensive index for assessing environmental stress in animals. *Journal of Animal Science*, *88*(6), 2153–2165. https://doi.org/10.2527/jas.2009-2586

Madsen, E. B., & Nielsen, K. (1985). A study of tail tip necrosis in young fattening bulls on slatted floors. *Nordisk Veterinaermedicin*, *37*(6), 349–357. https://europepmc.org/article/med/3835543

Maes, D., Sibila, M., Pieters, M., Haesebrouck, F., Segalés, J., & de Oliveira, L. G. (2023). Review on the methodology to assess respiratory tract lesions in pigs and their production impact. *Veterinary Research*, *54*(1), 8. https://doi.org/10.1186/s13567-023-01136-2

Magrin, L., Brscic, M., Armato, L., Contiero, B., Lotto, A., Cozzi, G., & Gottardo, F. (2020). Risk factors for claw disorders in intensively finished Charolais beef cattle. *Preventive Veterinary Medicine*, *175*, 1–8. https://doi.org/10.1016/j.prevetmed.2019.104864

Magrin, L., Brscic, M., Lora, I., Prevedello, P., Contiero, B., Cozzi, G., & Gottardo, F. (2021). Assessment of rumen mucosa, lung, and liver lesions at slaughter as benchmarking tool for the improvement of finishing beef cattle health and welfare. *Frontiers in Veterinary Science*, *7*, 622837. https://doi.org/10.3389/fvets.2020.622837

Magrin, L., Brscic, M., Lora, I., Rumor, C., Tondello, L., Cozzi, G., & Gottardo, F. (2017). Effect of a ceiling fan ventilation system on finishing young bulls' health, behaviour and growth performance. *Animal*, *11*(6), 1084–1092. https://doi.org/10.1017/S1751731116002482

Magrin, L., Gottardo, F., Brscic, M., Contiero, B., & Cozzi, G. (2019). Health, behaviour and growth performance of Charolais and Limousin bulls fattened on different types of flooring. *Animal*, *13*(11), 2603–2611. https://doi.org/10.1017/S175173111900106X

Magrin, L., Gottardo, F., Contiero, B., Brscic, M., & Cozzi, G. (2019). Time of occurrence and prevalence of severe lameness in fattening Charolais bulls: Impact of type of floor and space allowance within type of floor. *Livestock Science*, *221*, 86–88. https://doi.org/10.1016/j.livsci.2019.01.021

Magrin, L., Gottardo, F., Cozzi, G., & Bergsten, C. (2020). Wider slot in pens with fully slatted rubber mat flooring for fattening bulls: Effects on animal hygiene, health and welfare. *Livestock Science*, *234*, 103989. https://doi.org/10.1016/j.livsci.2020.103989

Mancke, M. R., Bortoluzzi, E. M., Dahmer, P., & White, B. J. (2025). The use of lidocaine-infused castration bands to castrate beef–dairy calves and its effect on animal welfare and performance. *Animals*, *15*(4), 538. https://doi.org/10.3390/ani15040538

Mankins, J. C. (1995). Technology readiness levels. White Paper, April, 6, 1995.

Manninen, M., Sankari, S., Jauhiainen, L., Kivinen, T., Anttila, P., & Soveri, T. (2008). Effects of outdoor winter housing and feeding level on performance and blood metabolites of suckler cows fed whole-crop barley silage. *Livestock Science*, *115*(2), 179–194. https://doi.org/10.1016/j.livsci.2007.07.014

Manninen, M., Sankari, S., Jauhiainen, L., Kivinen, T., & Soveri, T. (2007). Insulated, uninsulated and outdoor housing for replacement beef heifers on restricted grass silage-based diet in a cold environment. *Livestock Science*, *107*(2), 113–125. https://doi.org/10.1016/j.livsci.2006.09.009
Mao, W. H., Albrecht, E., Teuscher, F., Yang, Q., Zhao, R. Q., & Wegner, J. (2008). Growth- and breed-related changes of fetal development in cattle. *Asian-Australasian Journal of Animal Sciences*, *21*(5), 640–647. https://doi.org/10.5713/ajas.2008.70293
Marchant, J. N. (2002). Piglet- and stockperson-directed sow aggression after farrowing and the relationship with a pre-farrowing, human approach test. *Applied Animal Behaviour Science*, *75*(2), 115–132. https://doi.org/10.1016/S0168-1591(01)00170-8
Marchesini, G., Cortese, M., Mottaran, D., Ricci, R., Serva, L., Contiero, B., Segato, S., & Andrighetto, I. (2018). Effects of axial and ceiling fans on environmental conditions, performance and rumination in beef cattle during the early fattening period. *Livestock Science*, *214*, 225–230. https://doi.org/10.1016/j.livsci.2018.06.009
Marchitelli, C., Savarese, M. C., Crisà, A., Nardone, A., Marsan, P. A., & Valentini, A. (2003). Double muscling in Marchigiana beef breed is caused by a stop codon in the third exon of myostatin gene. *Mammalian Genome*, *14*, 392–395. https://doi.org/10.1007/s00335-002-2176-5
Marino, A., Braschi, C., Ricci, S., Salvatori, V., & Ciucci, P. (2016). Ex post and insurance-based compensation fail to increase tolerance for wolves in semi-agricultural landscapes of central Italy. *European Journal of Wildlife Research*, *62*(2), 227–240. https://doi.org/10.1007/s10344-016-1001-5
Marquette, G. A., McGee, M., Fisher, A. D., Stanger, K., Argüello, A., & Earley, B. (2021). Horn bud size of dairy-bred and suckler-bred calves at time of disbudding. *Irish Veterinary Journal*, *74*, 17. https://doi.org/10.1186/s13620-021-00196-0
Marquette, G. A., Ronan, S., & Earley, B. (2023a). Review: Castration – Animal welfare considerations. *Journal of Applied Animal Research*, *51*(1), 703–718. https://doi.org/10.1080/09712119.2023.2273270
Marquette, G. A., Ronan, S., & Earley, B. (2023b). Calf disbudding – Animal welfare considerations. *Journal of Applied Animal Research*, *51*(1), 616–623. https://doi.org/10.1080/09712119.2023.2264912
Marsden, K. (2023). *Livestock depredation and large carnivores in Europe: France - livestock damages and wolf* (p. 14). Adelphi GmbH. https://adelphi.de/system/files/document/lc-platform_livestock-depredation_france.pdf
Marti, S., Devant, M., Amatayakul-Chantler, S., Jackson, J. A., Lopez, E., Janzen, E. D., & Schwartzkopf-Genswein, K. S. (2015). Effect of anti-gonadotropin-releasing factor vaccine and band castration on indicators of welfare in beef cattle. *Journal of Animal Science*, *93*(4), 1581–1591. https://doi.org/10.2527/jas.2014-8346
Marti, S., Jelinski, M. D., Janzen, E. D., Jelinski, M. J., Dorin, C. L., Orsel, K., Pajor, E. A., Shearer, J., Millman, S. T., & Schwartzkopf-Genswein, K. S. (2021). A prospective longitudinal study of risk factors associated with cattle lameness in southern Alberta feedlots. *Canadian Journal of Animal Science*, *101*(4), 647–654. https://doi.org/10.1139/cjas-2020-0128
Marti, S., Meléndez, D. M., Pajor, E. A., Moya, D., Gellatly, D., Janzen, E. D., & Schwartzkopf-Genswein, K. S. (2018). Effect of a single dose of subcutaneous meloxicam prior to band or knife castration in 1-wk-old beef calves: II. Inflammatory response and healing. *Journal of Animal Science*, *96*(10), 4136–4148. https://doi.org/10.1093/jas/sky291
Marti, S., Meléndez, D. M., Pajor, E. A., Moya, D., Heuston, C. E. M., Gellatly, D., Janzen, E. D., & Schwartzkopf-Genswein, K. S. (2017). Effect of band and knife castration of beef calves on welfare indicators of pain at three relevant industry ages: II. Chronic pain. *Journal of Animal Sciences*, *95*(10), 4367–4380. https://doi.org/10.2527/jas2017.1763
Marti, S., Verdu, M., Medinya, C., Riera, J., & Devant, M. (2020). Increasing the number of water troughs do not increase water intake or improve calf performance. *Journal of Animal Science*, *98*(Suppl. 4), 389–390. https://doi.org/10.1093/jas/skaa278.686
Masebo, N. T., Marliani, G., Cavallini, D., Accorsi, P. A., Di Pietro, M., Beltrame, A., Gentile, A., & Jacinto, J. G. P. (2023). Health and welfare assessment of beef cattle during the adaptation period in a specialized commercial fattening unit. *Research in Veterinary Science*, *158*, 50–55. https://doi.org/10.1016/j.rvsc.2023.03.008
Matković, K., Šimić, R., Lolić, M., & Ostović, M. (2020). The effects of environmental enrichment on some welfare indicators in fattening cattle, housed at different stocking densities. *Veterinarski Arhiv*, *90*(6), 575–582. https://doi.org/10.24099/vet.arhiv.1170
Mattiello, S., Battini, M., De Rosa, G., Napolitano, F., & Dwyer, C. (2019). How can we assess positive welfare in ruminants? *Animals*, *9*(10), 758. https://doi.org/10.3390/ani9100758
Mauffré, V., Cardot, T., Belbis, G., Plassard, V., Constant, F., Bernard, S., Roch, N., Bohy, A., Nehlig, N., Ponter, A., Grimard, B., & Guilbert-Julien, L. (2021). Meloxicam administration in the management of postoperative pain and inflammation associated with caesarean section in beef heifers: Evaluation of reproductive parameters. *Theriogenology*, *175*, 148–154. https://doi.org/10.1016/j.theriogenology.2021.09.005
Mayes, B. T., Dundon, S. G., Cowley, F. C., Norman, L.-E. K., Morton, J. M., & Tait, L. A. (2025). Stocking density in intensive housing and the implications for beef cattle behaviour, stress physiology and liveweight. *Journal of Animal Science*, *103*, skaf034. https://doi.org/10.1093/jas/skaf034
McConnachie, E., Smid, A. M. C., Thompson, A. J., Weary, D. M., Gaworski, M. A., & von Keyserlingk, M. A. G. (2018). Cows are highly motivated to access a grooming substrate. *Biology Letters*, *14*, 1–4. https://doi.org/10.1098/rsbl.2018.0303
McGee, M., & Earley, B. (2019). Review: Passive immunity in beef-suckler calves. *Animal*, *13*(4), 810–825. https://doi.org/10.1017/S1751731118003026
McGettigan, C. E., McGee, M., O'Riordan, E. G., Kelly, A. K., & Earley, B. (2022). Effect of concrete slats versus rubber-covered slats on the performance, behaviour, hoof health, cleanliness of finishing beef steers and performance, cleanliness and hoof health of weanling cattle. *Livestock Science*, *266*, 2–11. https://doi.org/10.1016/j.livsci.2022.105106
McGrath, B. A., Fox, P. F., McSweeney, P. L. H., & Kelly, A. L. (2016). Composition and properties of bovine colostrum: A review. *Dairy Science & Technology*, *96*(2), 133–158. https://doi.org/10.1007/s13594-015-0258-x
McGuirk, S. M. (2008). Disease management of dairy calves and heifers. *The Veterinary Clinics of North America. Food Animal Practice*, *24*(1), 139–153. https://doi.org/10.1016/j.cvfa.2007.10.003
McHugh, N., Cromie, A., Evans, R., & Berry, D. (2014). Validation of national genetic evaluations for maternal beef cattle traits using Irish field data. *Journal of Animal Science*, *92*(4), 1423–1432. https://doi.org/10.2527/jas.2013-6658
Medugorac, I., Graf, A., Grohs, C., Rothammer, S., Zagdsuren, Y., Gladyr, E., Zinovieva, N., Barbieri, J., Seichter, D., Russ, I., Eggen, A., Hellenthal, G., Brem, G., Blum, H., Krebs, S., & Capitan, A. (2017). Whole-genome analysis of introgressive hybridization and characterization of the bovine legacy of Mongolian yaks. *Nature Genetics*, *49*(3), 470–475. https://doi.org/10.1038/ng.3775
Medugorac, I., Seichter, D., Graf, A., Russ, I., Blum, H., Göpel, K. H., Rothammer, S., Förster, M., & Krebs, S. (2012). Bovine Polledness - an autosomal dominant trait with allelic heterogeneity. *PLoS One*, *7*(6), e39477. https://doi.org/10.1371/journal.pone.0039477
Meischke, H., Ramsay, W., & Shaw, F. (1974). The effect of horns on bruising in cattle. *Australian Veterinary Journal*, *50*(10), 432–434. https://doi.org/10.1111/j.1751-0813.1974.tb06864.x
Meléndez, D., Marti, S., Pajor, E., Moya, D., Gellatly, D., Janzen, E., & Schwartzkopf-Genswein, K. (2018). Effect of a single dose of meloxicam prior to band or knife castration in 1-wk-old beef calves: I. Acute pain. *Journal of Animal Science*, *96*(4), 1268–1280. https://doi.org/10.1093/jas/sky034
Meléndez, D. M., Marti, S., Pajor, E. A., Moya, D., Gellatly, D., Janzen, E. D., & Schwartzkopf-Genswein, K. S. (2017). Effect of timing of subcutaneous meloxicam administration on indicators of pain after knife castration of weaned calves. *Journal of Animal Science*, *95*(12), 5218–5229. https://doi.org/10.2527/jas2017.1978
Meléndez, D. M., Marti, S., Pajor, E. A., Moya, D., Heuston, C. E. M., Gellatly, D., Janzen, E. D., & Schwartzkopf-Genswein, K. S. (2017). Effect of band and knife castration of beef calves on welfare indicators of pain at three relevant industry ages: I Acute Pain. *Journal of Animal Science*, *95*(10), 4352–4366. https://doi.org/10.2527/jas2017.1762

Meléndez, D. M., Marti, S., Pajor, E. A., Sidhu, P. K., Gellatly, D., Janzen, E. D., Schwinghamer, T. D., Coetzee, J. F., & Schwartzkopf-Genswein, K. S. (2019). Pharmacokinetics of oral and subcutaneous meloxicam: Effect on indicators of pain and inflammation after knife castration in weaned beef calves. *PLoS One*, *14*(5), e0217518. https://doi.org/10.1371/journal.pone.0217518

Meléndez, D. M., Marti, S., Pajor, E. A., Sidhu, P. K., Gellatly, D., Moya, D., Janzen, E. D., Coetzee, J. F., & Schwartzkopf-Genswein, K. S. (2018). Effect of meloxicam and lidocaine administered alone or in combination on indicators of pain and distress during and after knife castration in weaned beef calves. *PLoS One*, *13*(11), e0207289. https://doi.org/10.1371/journal.pone.0207289

Mench, J. A., Swanson, J. C., & Stricklin, W. R. (1990). Social stress and dominance among group members after mixing beef cows. *Canadian Journal of Animal Science*, *70*(2), 345–354. https://doi.org/10.4141/cjas90-046

Mendias, C. L., Marcin, J. E., Calerdon, D. R., & Faulkner, J. A. (2006). Contractile properties of EDL and soleus muscles of myostatin-deficient mice. *Journal of Applied Physiology*, *101*(3), 898–905. https://doi.org/10.1152/japplphysiol.00126.2006

Menke, C., Waiblinger, S., Fölsch, D. W., & Wiepkema, P. R. (1999). Social behaviour and injuries of horned cows in loose housing systems. *Animal Welfare*, *8*(3), 243–258. https://doi.org/10.1017/S0962728600021734

Menke, C. A. (1996). Laufstallhaltung mit behornten Milchkühen. Doctoral Thesis, Eidgenössische Technische Hochschule, (ETH) Zürich, Switzerland. http://hdl.handle.net/20.500.11850/142420

Mertens, D. R. (1997). Creating a system for meeting the fiber requirements of dairy cows. *Journal of Dairy Science*, *80*(7), 1463–1481. https://doi.org/10.3168/jds.S0022-0302(97)76075-2

Meschy, F. (2002). Recommandations d'apport en phosphore absorbé chez les ruminants. 9. Rencontres autour des Recherches sur les Ruminants. https://hal.inrae.fr/hal-02760998v1

Michenet, A., Barbat, M., Saintilan, R., Venot, E., & Phocas, F. (2016). Detection of quantitative trait loci for maternal traits using high-density genotypes of blonde d'Aquitaine beef cattle. *BMC Genetics*, *17*(1), 88. https://doi.org/10.1186/s12863-016-0397-y

Michenet, A., Saintilan, R., Venot, E., & Phocas, F. (2016). Insights into the genetic variation of maternal behavior and suckling performance of continental beef cows. *Genetics Selection Evolution*, *48*, 1–12. https://doi.org/10.1186/s12711-016-0223-z

Micol, D., Oury, M. P., Picard, B., Hocquette, J. F., Briand, M., Dumont, R., Egal, D., Jailler, R., Dubroeucq, H., & Agabriel, J. (2009). Effect of age at castration on animal performance, muscle characteristics and meat quality traits in 26-month-old Charolais steers. *Livestock Science*, *120*(1–2), 116–126. https://doi.org/10.1016/j.livsci.2008.05.002

Miller, G. A., Hyslop, J. J., Barclay, D., Edwards, A., Thomson, W., & Duthie, C.-A. (2019). Using 3D imaging and machine learning to predict liveweight and carcass characteristics of live finishing beef cattle. *Frontiers in Sustainable Food Systems*, *3*, 30. https://doi.org/10.3389/fsufs.2019.00030

Miller-Cushon, E. K., & DeVries, T. J. (2017). Feed sorting in dairy cattle: Causes, consequences, and management. *Journal of Dairy Science*, *100*(5), 4172–4183. https://doi.org/10.3168/jds.2016-11983

Minchin, W., Buckley, F., Kenny, D. A., Keane, M. G., Shalloo, L., & O'Donovan, M. (2009). Prediction of cull cow carcass characteristics from live weight and body condition score measured pre slaughter. *Irish Journal of Agricultural and Food Research*, *48*, 75–86. https://www.jstor.org/stable/25594965

Mintline, E., Stewart, M., Rogers, A., Cox, N., Verkerk, G., Stookey, J., Webster, J., & Tucker, C. (2013). Play behavior as an indicator of animal welfare: Disbudding in dairy calves. *Applied Animal Behaviour Science*, *144*(1–2), 22–30. https://doi.org/10.1016/j.applanim.2012.12.008

Mintline, E. M., Varga, A., Banuelos, J., Walker, K. A., Hoar, B., Drake, D., Weary, D. M., Coetzee, J. F., Stock, M. L., & Tucker, C. B. (2014). Healing of surgical castration wounds: A description and an evaluation of flunixin. *Journal of Animal Science*, *92*(12), 5659–5665. https://doi.org/10.2527/jas.2014-7885

Miranda-de la Lama, G. C., & Mattiello, S. (2010). The importance of social behaviour for goat welfare in livestock farming. *Small Ruminant Research*, *90*(1), 1–10. https://doi.org/10.1016/j.smallrumres.2010.01.006

Miretti, S., Martignani, E., Accornero, P., & Baratta, M. (2013). Functional effect of mir-27b on myostatin expression: A relationship in piedmontese cattle with double-muscled phenotype. *BMC Genomics*, *14*, 194. https://doi.org/10.1186/1471-2164-14-194

Mirra, A., Spadavecchia, C., Bruckmaier, R., Gutzwiller, A., & Casoni, D. (2018). Acute pain and peripheral sensitization following cautery disbudding in 1-and 4-week-old calves. *Physiology & Behavior*, *184*, 248–260. https://doi.org/10.1016/j.physbeh.2017.11.031

Mishra, S. (2021). Behavioural, physiological, neuro-endocrine and molecular responses of cattle against heat stress: An updated review. *Tropical Animal Health and Production*, *53*(3), 400. https://doi.org/10.1007/s11250-021-02790-4

Mitloehner, F., Morrow-Tesch, J., Bailey, J., & McGlone, J. (1999). Altering feeding times for feedlot cattle reduced dust generating behaviors. *Journal of Animal Science*, *77*(Suppl 1), 148.

Mitlöhner, F., Morrow, J., Dailey, J., Wilson, S., Galyean, M., Miller, M., & McGlone, J. (2001). Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. *Journal of Animal Science*, *79*(9), 2327–2335. https://doi.org/10.2527/2001.7992327x

Mohan Raj, A. B., Moss, B. W., McCaughey, W. J., McLauchlan, W., Kilpatrick, D. J., & McGaughey, S. J. (1991). Behavioural response to mixing of entire bulls, vasectomised bulls and steers. *Applied Animal Behaviour Science*, *31*(3–4), 157–168. https://doi.org/10.1016/0168-1591(91)90002-F

Morel-Journel, T., Assié, S., Vergu, E., Mercier, J.-B., Bonnet-Beaugrand, F., & Ezanno, P. (2021). Minimizing the number of origins in batches of weaned calves to reduce their risks of developing bovine respiratory diseases. *Veterinary Research*, *52*, 1–12. https://doi.org/10.1186/s13567-020-00872-z

Morgan, C. A., McIlvaney, K., Dwyer, C. M., & Lawrence, A. B. (2009). Assessing the welfare challenges to out-wintered pregnant suckler cows. *Animal*, *3*(8), 1167–1174. https://doi.org/10.1017/S1751731109004583

Mormède, P. (2005). Molecular genetics of behaviour: Research strategies and perspectives for animal production. *Livestock Production Science*, *93*(1), 15–21. https://doi.org/10.1016/j.livprodsci.2004.11.002

Morris, C. A., Cullen, N. G., Kilgour, R., & Bremner, K. J. (1994). Some genetic-factors affecting temperament in *Bos Taurus* cattle. *New Zealand Journal of Agricultural Research*, *37*(2), 167–175. https://doi.org/10.1080/00288233.1994.9513054

Morris, S., Kenyon, P., & Burnham, D. (2002). A comparison of two scales of body condition scoring in Hereford x Friesan beef breeding cows. *Proceedings of the New Zealand Grassland Association*, *64*, 121–123. https://doi.org/10.33584/jnzg.2002.64.2464

Mota, L. F. M., Lopes, F. B., Fernandes Júnior, G. A., Rosa, G. J. M., Magalhães, A. F. B., Carvalheiro, R., & Albuquerque, L. G. (2020). Genome-wide scan highlights the role of candidate genes on phenotypic plasticity for age at first calving in Nellore heifers. *Scientific Reports*, *10*(1), 6481. https://doi.org/10.1038/s41598-020-63516-4

Mõtus, K., Viltrop, A., & Emanuelson, U. (2018). Reasons and risk factors for beef calf and youngstock on-farm mortality in extensive cow-calf herds. *Animal*, *12*(9), 1958–1966. https://doi.org/10.1017/S1751731117003548

Mounier, L., Dubroeucq, H., Andanson, S., & Veissier, I. (2006). Variations in meat pH of beef bulls in relation to conditions of transfer to slaughter and previous history of the animals. *Journal of Animal Science*, *84*(6), 1567–1576. https://doi.org/10.2527/2006.8461567x

Mounier, L., Veissier, I., Andanson, S., Delval, E., & Boissy, A. (2006). Mixing at the beginning of fattening moderates social buffering in beef bulls. *Applied Animal Behaviour Science*, *96*(3–4), 185–200. https://doi.org/10.1016/j.applanim.2005.06.015

Mounier, L., Veissier, I., & Boissy, A. (2005). Behavior, physiology, and performance of bulls mixed at the onset of finishing to form uniform body weight groups. *Journal of Animal Science*, *83*(7), 1696–1704. https://doi.org/10.2527/2005.8371696x

Mount, L. (1974). *The role of the evaporative heat loss in thermoregulation of animals*. Contemporary Biology.

Moya, D., Mazzenga, A., Holtshausen, L., Cozzi, G., González, L. A., Calsamiglia, S., Gibb, D. G., McAllister, T. A., Beauchemin, K. A., & Schwartzkopf-Genswein, K. (2011). Feeding behavior and ruminal acidosis in beef cattle offered a total mixed ration or dietary components separately. *Journal of Animal Science*, *89*(2), 520–530. https://doi.org/10.2527/jas.2010-3045

Moya, D., Schwartzkopf-Genswein, K. S., & Veira, D. M. (2013). Standardization of a non-invasive methodology to measure cortisol in hair of beef cattle. *Livestock Science*, *158*(1), 138–144. https://doi.org/10.1016/j.livsci.2013.10.007

Mueller, M. L., Cole, J. B., Connors, N. K., Johnston, D. J., Randhawa, I. A., & Van Eenennaam, A. L. (2021). Comparison of gene editing versus conventional breeding to introgress the *POLLED* allele into the tropically adapted Australian beef cattle population. *Frontiers in Genetics*, *12*, 593154. https://doi.org/10.3389/fgene.2021.593154

Muir, W., Hubbell, J., Skarda, R., & Bednarski, R. (1995). Local anesthesia in cattle, sheep, goats, and pigs. In *Handbook of veterinary anesthesia* (pp. 53–77). Mosby.

Mulenga, F. M. (1994). *The effect of type of diet and frequency of watering on the performance of growing cattle fed at maintenance*. Faculty of Agriculture, University of Zimbabwe, Zimbabwe.

Müller, B. R., Soriano, V. S., Bellio, J. C. B., & Molento, C. F. M. (2019). Facial expression of pain in Nellore and crossbred beef cattle. *Journal of Veterinary Behavior*, *34*, 60–65. https://doi.org/10.1016/j.jveb.2019.07.007

Mummed, Y. Y. (2012). Milk yield estimation of Ogaden cattle breed based on methods of weigh–suckle–weigh and calves' growth. *Tropical Animal Health and Production*, *44*(4), 785–790. https://doi.org/10.1007/s11250-011-9968-0

Murphy, L. B. (1978). The practical problems of recognizing and measuring fear and exploration behaviour in the domestic fowl. *Animal Behaviour*, *26*, 422–431. https://doi.org/10.1016/0003-3472(78)90059-3

Murray, J. A. (1919). Meat production. *The Journal of Agricultural Science*, *9*(2), 174–181. https://doi.org/10.1017/S0021859600004767

Mwansa, P., Crews, D., Jr., Wilton, J., & Kemp, R. (2002). Multiple trait selection for maternal productivity in beef cattle. *Journal of Animal Breeding and Genetics*, *119*(6), 391–399. https://doi.org/10.1046/j.1439-0388.2002.00363.x

Nagaraja, T. G., & Titgemeyer, E. C. (2007). Ruminal acidosis in beef cattle: The current microbiological and nutritional outlook. *Journal of Dairy Science*, *90*(Suppl. E), E17–E38. https://doi.org/10.3168/jds.2006-478

Nagelmüller, S., Kirchgessner, N., Yates, S., Hiltpold, M., & Walter, A. (2016). Leaf length tracker: A novel approach to analyse leaf elongation close to the thermal limit of growth in the field. *Journal of Experimental Botany*, *67*(6), 1897–1906. https://doi.org/10.1093/jxb/erw003

Nakanishi, Y., Kawamura, T., Goto, T., & Umetsu, R. (1993). Comparative aspects of behavioural activities of beef cows before and after introducing a stranger at night. *Journal of the Faculty of Agriculture, Kyushu University*, *37*(3–4), 227–238. https://doi.org/10.5109/24014

Napolitano, F., Ute, K., Fernando, G., & De Rosa, G. (2009). Positive indicators of cattle welfare and their applicability to on-farm protocols. *Italian Journal of Animal Science*, *8*(Sup 1), 355–365. https://doi.org/10.4081/ijas.2009.s1.355

National Academies of Sciences Engineering Medicine. (2016). *Nutrient Requirements of Beef Cattle* (8th revised ed., p. 494). National Academies Press. https://doi.org/10.17226/19014

National guidelines for beef cattle feedlots in Australia. (2012). *Meat & Livestock Australia*. https://futurebeef.com.au/wp-content/uploads/National-guidelines-for-beef-cattle-feedlots-in-Australia-third-edition.pdf.

Neave, H. W., Jensen, E. H., Durrenwachter, M., & Jensen, M. B. (2024). Behavioral responses of dairy cows and their calves to gradual or abrupt weaning and separation when managed in full- or part-time cow-calf contact systems. *Journal of Dairy Science*, *107*(4), 2297–2320. https://doi.org/10.3168/jds.2023-24085

Neely, C., Thomson, D., Kerr, C., & Reinhardt, C. (2014). Effects of three dehorning techniques on behavior and wound healing in feedlot cattle. *Journal of Animal Science*, *92*(5), 2225–2229. https://doi.org/10.2527/jas.2013-7424

Neubauer, V., Humer, E., Kröger, I., Braid, T., Wagner, M., & Zebeli, Q. (2018). Differences between pH of indwelling sensors and the pH of fluid and solid phase in the rumen of dairy cows fed varying concentrate levels. *Journal of Animal Physiology and Animal Nutrition*, *102*(1), 343–349. https://doi.org/10.1111/jpn.12675

Nevard, R. P., Pant, S. D., Broster, J. C., Norman, S. T., & Stephen, C. P. (2023). Maternal behavior in beef cattle: The physiology, assessment and future directions—A review. *Veterinary Sciences*, *10*(1), 10. https://doi.org/10.3390/vetsci10010010

Neves, A. C., Júnior, J. C. S., Marucio, R. L., Midon, M., & Luna, S. P. (2017). Anesthetic effects of different volumes of lidocaine for spermatic cord block in cattle. *Veterinary Anaesthesia and Analgesia*, *44*(2), 375–378. https://doi.org/10.1016/j.vaa.2016.05.002

Newberry, R. C. (1995). Environmental enrichment: Increasing the biological relevance of captive environments. *Applied Animal Behaviour Science*, *44*(2–4), 229–243. https://doi.org/10.1016/0168-1591(95)00616-Z

Newberry, R. C., & Swanson, J. C. (2008). Implications of breaking mother–young social bonds. *Applied Animal Behaviour Science*, *110*(1–2), 3–23. https://doi.org/10.1016/j.applanim.2007.03.021

Newby, N. C., Duffield, T. F., Pearl, D. L., Leslie, K. E., LeBlanc, S. J., & von Keyserlingk, M. A. G. (2013). Short communication: Use of a mechanical brush by Holstein dairy cattle around parturition. *Journal of Dairy Science*, *96*(4), 2339–2344. https://doi.org/10.3168/jds.2012-6016

Newman, K. D., & Anderson, D. E. (2004). A retrospective study of risk factors that affect outcomes in bovine Cesarean sections (1998–2003). *American Association of Bovine Practitioners Conference Proceedings*, *37*, 290–291. https://doi.org/10.21423/aabppro20044973

Nicholson, M. J. (1989). Depression of dry-matter and water intake in Boran cattle owing to physiological, volumetric and temporal limitations. *Animal Production*, *49*(1), 29–34. https://doi.org/10.1017/S0003356100004220

Nielsen, S. S., Denwood, M. J., Forkman, B., & Houe, H. (2017). Selection of meat inspection data for an animal welfare index in cattle and pigs in Denmark. *Animals*, *7*(12), 94. https://doi.org/10.3390/ani7120094

Nisbet, H., Lambe, N., Miller, G., Doeschl-Wilson, A., Barclay, D., Wheaton, A., & Duthie, C.-A. (2024). Using in-abattoir 3-dimensional measurements from images of beef carcasses for the prediction of EUROP classification grade and carcass weight. *Meat Science*, *209*, 109391. https://doi.org/10.1016/j.meatsci.2023.109391

Niwa, M. V. G., Ítavo, L. C. V., Ítavo, C. C. B. F., Dias, A. M., dos Santos, D. G., Longhini, V. Z., da Costa, G. R., Vedovatto, M., Gurgel, A. L. C., de Moraes, G. J., & de Aquino Monteiro, G. O. (2023). Effect of physically effective neutral detergent fiber on nutrient intake and digestibility, ruminal and blood parameters, and ingestive behavior of confined beef cattle. *Tropical Animal Health and Production*, *55*(3), 224. https://doi.org/10.1007/s11250-023-03633-0

Nizzi, E., Dhumez, O., Hurtaud, C., & Boudon, A. (2025). Effect of temporal water restrictions on drinking behavior and time budget in lactating dairy cows according to their position in the social hierarchy within the herd. *Journal of Dairy Science*, *108*(2), 1824–1841. https://doi.org/10.3168/jds.2024-25226

Nizzi, E., Hurtaud, C., & Boudon, A. (2023). Interaction between drinker density and cow social dominance affects drinking behavior. *JDS Communications*. https://doi.org/10.3168/jdsc.2023-0479

Nkrumah, J. D., Crews, D. H., Jr., Basarab, J. A., Price, M. A., Okine, E. K., Wang, Z., Li, C., & Moore, S. S. (2007). Genetic and phenotypic relationships of feeding behavior and temperament with performance, feed efficiency, ultrasound, and carcass merit of beef cattle. *Journal of Animal Science*, *85*(10), 2382–2390. https://doi.org/10.2527/jas.2006-657

Nogues, E., von Keyserlingk, M. A. G., & Weary, D. M. (2021). Pain in the weeks following surgical and rubber ring castration in dairy calves. *Journal of Dairy Science*, *104*(12), 12881–12886. https://doi.org/10.3168/jds.2021-20127

Nordi, W. M., Marti, S., Gellatly, D., Meléndez, D. M., González, L. A., McAllister, T. A., Fierheller, E. E., Caulkett, N. A., Janzen, E., & Schwartzkopf-Genswein, K. S. (2019). Effect of preemptive flunixin meglumine and lidocaine on behavioral and physiological indicators of pain post-band and knife castration in 6-mo-old beef calves. *Livestock Science*, *230*, 103838. https://doi.org/10.1016/j.livsci.2019.103838

Norring, M., Mintline, E. M., & Tucker, C. B. (2017). The age of surgical castration affects the healing process in beef calves1. *Translational Animal Science*, *1*(3), 358–366. https://doi.org/10.2527/tas2017.0044

Norris, D., Ngambi, J. W., Mabelebele, M., Alabi, O. J., & Benyi, K. (2014). Genetic selection for docility: A review. *The Journal of Animal & Plant Sciences*, *24*(2), 374–379.

NRC (National Research Council). (2011). Guide for the care and use of laboratory animals. In *The National Academies Press* (8th ed., p. 246). US. https://doi.org/10.17226/12910

Ochroch, E. A., Mardini, I. A., & Gottschalk, A. (2003). What is the role of NSAIDs in pre-emptive analgesia? *Drugs*, *63*, 2709–2723. https://doi.org/10.2165/00003495-200363240-00002

Oehme, B., Geiger, S. M., Grund, S., Hainke, K., Munzel, J., & Mülling, C. K. W. (2018). Effect of different flooring types on pressure distribution under the bovine claw – An ex vivo study. *BMC Veterinary Research*, *14*(1), 259, pp. 1–9. https://doi.org/10.1186/s12917-018-1579-9

Olson, B., & Wallander, R. (2002). Influence of winter weather and shelter on activity patterns of beef cows. *Canadian Journal of Animal Science*, *82*(4), 491–501. https://doi.org/10.4141/A01-070

Olson, M. E., Ralston, B., Burwash, L., Matheson-Bird, H., & Allan, N. D. (2016). Efficacy of oral meloxicam suspension for prevention of pain and inflammation following band and surgical castration in calves. *BMC Veterinary Research*, *12*(1), 102. https://doi.org/10.1186/s12917-016-0735-3

OMIA (Online Mendelian Inheritance in Animals). (online). *OMIA:000683–9913 : Muscular hypertrophy (double muscling) in Bos taurus (taurine cattle)*. https://omia.org/OMIA000683/9913/.

Ontsouka, E. C., Albrecht, C., & Bruckmaier, R. M. (2016). Invited review: Growth-promoting effects of colostrum in calves based on interaction with intestinal cell surface receptors and receptor-like transporters. *Journal of Dairy Science*, *99*(6), 4111–4123. https://doi.org/10.3168/jds.2015-9741

Österman, S., & Redbo, I. (2001). Effects of milking frequency on lying down and getting up behaviour in dairy cows. *Applied Animal Behaviour Science*, *70*(3), 167–176. https://doi.org/10.1016/S0168-1591(00)00159-3

Ouapo, C. Z., Amosson, S. H., Guerrero, B. L., & Park, S. C. (2013). Cost analysis for the adoption of water truck and solid-set sprinkler systems for feedlot dust control. Proceedings of the Southern Agricultural Economics Association Annual Meeting, Orlando, Florida, pp. 18. https://doi.org/10.22004/ag.econ.143029

Pang, W., Earley, B., Sweeney, T., & Crowe, M. (2006). Effect of carprofen administration during banding or burdizzo castration of bulls on plasma cortisol, in vitro interferon-γ production, acute-phase proteins, feed intake, and growth. *Journal of Animal Science*, *84*(2), 351–359. https://doi.org/10.2527/2006.842351x

Pang, W. Y., Earley, B., Gath, V., & Crowe, M. A. (2008). Effect of banding or burdizzo castration on plasma testosterone, acute-phase proteins, scrotal circumference, growth, and health of bulls. *Livestock Science*, *117*(1), 79–87. https://doi.org/10.1016/j.livsci.2007.11.012

Pang, W. Y., Earley, B., Murray, M., Sweeney, T., Gath, V., & Crowe, M. A. (2011). Banding or Burdizzo castration and carprofen administration on peripheral leukocyte inflammatory cytokine transcripts. *Research in Veterinary Science*, *90*(1), 127–132. https://doi.org/10.1016/j.rvsc.2010.04.023

Paranhos da Costa, M. J. R., Menezes, J. V. T., Fernandes, L. S., & Valente, T. S. (2023). Behavioral and morphological traits of Nellore cattle that can influence calf survival and performance from birth to weaning. *Ruminants*, *3*(4), 347–359. https://doi.org/10.3390/ruminants3040029

Paredes-Sánchez, F. A., Sifuentes-Rincón, A. M., Lara-Ramírez, E. E., Casas, E., Rodríguez-Almeida, F. A., Herrera-Mayorga, E. V., & Randel, R. D. (2023). Identification of candidate genes and SNPs related to cattle temperament using a GWAS analysis coupled with an interacting network analysis. *Revista Mexicana de Ciencias Pecuarias*, *14*, 1–22. https://doi.org/10.22319/rmcp.v14i1.6077

Park, R. M., Foster, M., & Daigle, C. L. (2020). A scoping review: The impact of housing systems and environmental features on beef cattle welfare. *Animals*, *10*, 1–16. https://doi.org/10.3390/ani10040565

Park, R. M., Schubach, K. M., Cooke, R. F., Herring, A. D., Jennings, J. S., & Daigle, C. L. (2020). Impact of a cattle brush on feedlot steer behavior, productivity and stress physiology. *Applied Animal Behaviour Science*, *228*, 1–9. https://doi.org/10.1016/j.applanim.2020.104995

Parmigiani, S., Palanza, P., Rodgers, J., & Ferrari, P. F. (1999). Selection, evolution of behavior and animal models in behavioral neuroscience. *Neuroscience & Biobehavioral Reviews*, *23*(7), 957–970. https://doi.org/10.1016/s0149-7634(99)00029-9

Parola, F., Hillmann, E., Schütz, K. E., & Tucker, C. B. (2012). Preferences for overhead sprinklers by naïve beef steers: Test of two nozzle types. *Applied Animal Behaviour Science*, *137*(1–2), 13–22. https://doi.org/10.1016/j.applanim.2011.12.010

Parrini, S., Sirtori, F., Fabbri, M. C., Dal Prà, A., Crovetti, A., & Bozzi, R. (2022). Effects of a ceiling fan ventilation system and thi on young limousin bulls' social behaviour. *Animals*, *12*(10), 10.3390/ani12101259.

Parshutin, G. V., & Ippolitova, T. V. (1973). *Types of higher nervous activity, their definition and relationship with the productive qualities of animals* (p. 72). Kyrgyzstan.

Parsons, C., & Jensen, S. (2006). *Dehorning cattle. Western beef resource committee, cattle producers library*, Management Section CL750,. University of Idaho & Oregon State University.

Passos, L. T., Bettencourt, A. F., Ritt, L. A., Canozzi, M. E. A., & Fischer, V. (2023). Systematic review of the relationship between rumen acidosis and laminitis in cattle. *Research in Veterinary Science*, *161*, 110–117. https://doi.org/10.1016/j.rvsc.2023.06.001

Patterson, H. H., Johnson, P. S., Epperson, W. B., & Haigh, R. (2004). *Effect of total dissolved solids and sulfates in drinking water for growing steers* (p. 4). South Dakota State University. https://openprairie.sdstate.edu/sd_beefreport_2004/6

Patterson, H. H., Johnson, P. S., Ward, E. H., & Gates, R. N. (2004). *Effects of sulfates in water on performance of cow-calf pairs* (p. 5). South Dakota State University. https://openprairie.sdstate.edu/sd_beefreport_2004/10

Pausch, H., Flisikowski, K., Jung, S., Emmerling, R., Edel, C., Götz, K.-U., & Fries, R. (2011). Genome-wide association study identifies two major loci affecting calving ease and growth-related traits in cattle. *Genetics*, *187*(1), 289–297. https://doi.org/10.1534/genetics.110.124057

Payne, W. J. A. (1965). Specific problems of semi-arid environments. *Qualitas Plantarum et Materiae Vegetabiles*, *12*(3), 269–294. https://doi.org/10.1007/BF01105144

Pelley, M. C., Lirette, A., & Tennessen, T. (1995). Observations on the responses of feedlot cattle to attempted environmental enrichment. *Canadian Journal of Animal Science*, *75*(4), 631–632. https://doi.org/10.4141/cjas95-093

Pereira, A. M. F., Titto, E. L., Infante, P., Titto, C. G., Geraldo, A. M., Alves, A., Leme, T. M., Baccari, F., & Almeida, J. A. (2014). Evaporative heat loss in Bos taurus: Do different cattle breeds cope with heat stress in the same way? *Journal of Thermal Biology*, *45*, 87–95. https://doi.org/10.1016/j.jtherbio.2014.08.004

Petherick, J., Small, A., Reid, D., Colditz, I., & Ferguson, D. (2015). Welfare outcomes for 3- and 6-month-old beef calves in a tropical environment castrated surgically or by applying rubber rings. *Applied Animal Behaviour Science*, *171*, 47–57. https://doi.org/10.1016/j.applanim.2015.08.018

Petherick, J. C., & Phillips, C. J. (2009). Space allowances for confined livestock and their determination from allometric principles. *Applied Animal Behaviour Science*, *117*(1–2), 1–12. https://doi.org/10.1016/j.applanim.2008.09.008

Petrie, N., Mellor, D., Stafford, K., Bruce, R., & Ward, R. (1996a). Cortisol responses of calves to two methods of disbudding used with or without local anaesthetic. *New Zealand Veterinary Journal*, *44*(1), 9–14. https://doi.org/10.1080/00480169.1996.35924

Petrie, N., Mellor, D., Stafford, K., Bruce, R., & Ward, R. (1996b). Cortisol responses of calves to two methods of tail docking used with or without local anaesthetic. *New Zealand Veterinary Journal*, *44*(1), 4–8. https://doi.org/10.1080/00480169.1996.35923

Phillips, C., & Rind, M. (2002). The effects of social dominance on the production and behavior of grazing dairy cows offered forage supplements. *Journal of Dairy Science*, *85*(1), 51–59. https://doi.org/10.3168/jds.S0022-0302(02)74052-6

Phillips, C. J. C. (1993). Cattle behaviour. *The Journal of Agricultural Science*, *123*(3), 415–415. https://doi.org/10.1017/S0021859600070441
Phocas, F., Boivin, X., Sapa, J., Trillat, G., Boissy, A., & Le Neindre, P. (2006). Genetic correlations between temperament and breeding traits in Limousin heifers. *Animal Science*, *82*(6), 805–811. https://doi.org/10.1017/ASC200696
Phocas, F., & Laloë, D. (2004). Genetic parameters for birth and weaning traits in French specialized beef cattle breeds. *Livestock Production Science*, *89*(2–3), 121–128. https://doi.org/10.1016/j.livprodsci.2004.02.007
Phythian, C. J., Hughes, D., Michalopoulou, E., Cripps, P. J., & Duncan, J. S. (2012). Reliability of body condition scoring of sheep for cross-farm assessments. *Small Ruminant Research*, *104*(1), 156–162. https://doi.org/10.1016/j.smallrumres.2011.10.001
Plaizier, J. C., Krause, D. O., Gozho, G. N., & McBride, B. W. (2008). Subacute ruminal acidosis in dairy cows: The physiological causes, incidence and consequences. *The Veterinary Journal*, *176*(1), 21–31. https://doi.org/10.1016/j.tvjl.2007.12.016
Platz, S., Ahrens, F., Bahrs, E., Nüske, S., & Erhard, M. H. (2007). Association between floor type and behaviour, skin lesions, and claw dimensions in group-housed fattening bulls. *Preventive Veterinary Medicine*, *80*(2–3), 209–221. https://doi.org/10.1016/j.prevetmed.2007.02.007
Platz, S., Ahrens, F., Bendel, J., Meyer, H. H. D., & Erhard, M. H. (2008). What happens with cow behavior when replacing concrete slatted floor by rubber coating: A case study. *Journal of Dairy Science*, *91*(3), 999–1004. https://doi.org/10.3168/jds.2007-0584
Plusquellec, P., & Bouissou, M.-F. (2001). Behavioural characteristics of two dairy breeds of cows selected (Hérens) or not (Brune des Alpes) for fighting and dominance ability. *Applied Animal Behaviour Science*, *72*(1), 1–21. https://doi.org/10.1016/S0168-1591(00)00198-2
Pöllinger, A., & Zentner, A. (2016). *Rutschsicherheit von gummierten Laufgangböden* (pp. 25–32). Proceedings of the Nutztierschuztagung Raumberg-Gumpenstein.
Polsky, L., & von Keyserlingk, M. A. G. (2017). Invited review: Effects of heat stress on dairy cattle welfare. *Journal of Dairy Science*, *100*(11), 8645–8657. https://doi.org/10.3168/jds.2017-12651
Pratelli, A., Cirone, F., Capozza, P., Trotta, A., Corrente, M., Balestrieri, A., & Buonavoglia, C. (2021). Bovine respiratory disease in beef calves supported long transport stress: An epidemiological study and strategies for control and prevention. *Research in Veterinary Science*, *135*, 450–455. https://doi.org/10.1016/j.rvsc.2020.11.002
Price, E., Harris, J., Borgwardt, R., Sween, M., & Connor, J. (2003). Fenceline contact of beef calves with their dams at weaning reduces the negative effects of separation on behavior and growth rate. *Journal of Animal Science*, *81*(1), 116–121. https://doi.org/10.2527/2003.811116x
Purfield, D. C., Bradley, D. G., Evans, R. D., Kearney, F. J., & Berry, D. P. (2015). Genome-wide association study for calving performance using high-density genotypes in dairy and beef cattle. *Genetics Selection Evolution*, *47(1):47*, 1–13. https://doi.org/10.1186/s12711-015-0126-4
Raboisson, D., Trillat, P., & Cahuzac, C. (2016). Failure of passive immune transfer in calves: A meta-analysis on the consequences and assessment of the economic impact. *PLoS One*, *11*(3), e0150452. https://doi.org/10.1371/journal.pone.0150452
Randhawa, I. A. S., Burns, B. M., McGowan, M. R., Porto-Neto, L. R., Hayes, B. J., Ferretti, R., Schutt, K. M., & Lyons, R. E. (2020). Optimized genetic testing for Polledness in multiple breeds of cattle. *G3: Genes, Genomes, Genetics*, *10*(2), 539–544. https://doi.org/10.1534/g3.119.400866
Randhawa, I. A. S., McGowan, M. R., Porto-Neto, L. R., Hayes, B. J., & Lyons, R. E. (2021). Comparison of genetic merit for weight and meat traits between the polled and horned cattle in multiple beef breeds. *Animals*, *11*(3), 870. https://doi.org/10.3390/ani11030870
Ranjbar, S., Rabiee, A. R., Gunn, A., & House, J. K. (2016). Identifying risk factors associated with lameness in pasture-based dairy herds. *Journal of Dairy Science*, *99*(9), 7495–7505. https://doi.org/10.3168/jds.2016-11142
Rasch, P. J., Grabiner, M. D., Gregor, R. J., & Garhammer, J. (1989). *Kinesiology and applied anatomy*.
Rashid, M., & Rashid, R. S. (2004). Higher order repeat caesarean sections: How safe are five or more? *BJOG: An International Journal of Obstetrics & Gynaecology*, *111*(10), 1090–1094. https://doi.org/10.1111/j.1471-0528.2004.00244.x
Rault, J.-L. (2012). Friends with benefits: Social support and its relevance for farm animal welfare. *Applied Animal Behaviour Science*, *136*(1), 1–14. https://doi.org/10.1016/j.applanim.2011.10.002
Rauprich, A. B. E., Hammon, H. M., & Blum, J. W. (2000). Influence of feeding different amounts of first colostrum on metabolic, endocrine, and health status and on growth performance in neonatal calves. *Journal of Animal Science*, *78*(4), 896–908. https://doi.org/10.2527/2000.784896x
Raussi, S., Boissy, A., Andanson, S., Kaihilahti, J., Pradel, P., & Veissier, I. (2006). Repeated regrouping of pair-housed heifers around puberty affects their behavioural and HPA axis reactivities. *Animal Research*, *55*(2), 131–144. https://doi.org/10.1051/animres:2006004
Raussi, S., Boissy, A., Delval, E., Pradel, P., Kaihilahti, J., & Veissier, I. (2005). Does repeated regrouping alter the social behaviour of heifers? *Applied Animal Behaviour Science*, *93*(1–2), 1–12. https://doi.org/10.1016/j.applanim.2004.12.001
Raussi, S., Jauhiainen, L., Saastamoinen, S., Siivonen, J., Hepola, H., & Veissier, I. (2011). A note on overdispersion as an index of behavioural synchrony: A pilot study in dairy cows. *Animal*, *5*(3), 428–432. https://doi.org/10.1017/s1751731110001928
Réale, D., Reader, S. M., Sol, D., McDougall, P. T., & Dingemanse, N. J. (2007). Integrating animal temperament within ecology and evolution. *Biological Reviews*, *82*(2), 291–318. https://doi.org/10.1111/j.1469-185X.2007.00010.x
Redbo, I. (1990). Changes in duration and frequency of stereotypies and their adjoining behaviours in heifers, before, during and after the grazing period. *Applied Animal Behaviour Science*, *26*(1), 57–67. https://doi.org/10.1016/0168-1591(90)90087-T
Reedman, C. N., Duffield, T. F., DeVries, T. J., Lissemore, K. D., Adcock, S. J., Tucker, C. B., Parsons, S. D., & Winder, C. B. (2022). Effect of plane of nutrition and analgesic drug treatment on wound healing and pain following cautery disbudding in preweaning dairy calves. *Journal of Dairy Science*, *105*(7), 6220–6239. https://doi.org/10.3168/jds.2021-21552
Reiche, A.-M., Dohme-Meier, F., & Terlouw, E. M. C. (2020). Effects of horn status on behaviour in fattening cattle in the field and during reactivity tests. *Applied Animal Behaviour Science*, *231*, 1–9. https://doi.org/10.1016/j.applanim.2020.105081
Reinhardt, V., & Reinhardt, A. (1981). Cohesive relationships in a cattle herd (Bos Indicus). *Behaviour*, *77*(3), 121–150. https://doi.org/10.1163/156853981X00194
Renaudeau, D., Collin, A., Yahav, S., de Basilio, V., Gourdine, J. L., & Collier, R. J. (2012). Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal*, *6*(5), 707–728. https://doi.org/10.1017/S1751731111002448
Rezac, D. J., Thomson, D. U., Bartle, S. J., Osterstock, J. B., Prouty, F. L., & Reinhardt, C. D. (2014). Prevalence, severity, and relationships of lung lesions, liver abnormalities, and rumen health scores measured at slaughter in beef cattle1. *Journal of Animal Science*, *92*(6), 2595–2602. https://doi.org/10.2527/jas.2013-7222
Rhoads, M. L., Rhoads, R. P., VanBaale, M. J., Collier, R. J., Sanders, S. R., Weber, W. J., Crooker, B. A., & Baumgard, L. H. (2009). Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin[1]. *Journal of Dairy Science*, *92*(5), 1986–1997. https://doi.org/10.3168/jds.2008-1641
Ridge, E. E., Foster, M. J., & Daigle, C. L. (2020). Effect of diet on non-nutritive oral behavior performance in cattle: A systematic review. *Livestock Science*, *238*, 1–9. https://doi.org/10.1016/j.livsci.2020.104063
Robért, B. D., White, B. J., Renter, D. G., & Larson, R. L. (2011). Determination of lying behavior patterns in healthy beef cattle by use of wireless accelerometers. *American Journal of Veterinary Research*, *72*(4), 467–473. https://doi.org/10.2460/ajvr.72.4.467
Roberts, S., Hughes, H., Burdick Sanchez, N., Carroll, J., Powell, J., Hubbell, D., & Richeson, J. (2015). Effect of surgical castration with or without oral meloxicam on the acute inflammatory response in yearling beef bulls. *Journal of Animal Science*, *93*(8), 4123–4131. https://doi.org/10.2527/jas.2015-9160

Robertson, I. S., Kent, J. E., & Molony, V. (1994). Effect of different methods of castration on behaviour and plasma cortisol in calves of three ages. *Research in Veterinary Science*, *56*(1), 8–17. https://doi.org/10.1016/0034-5288(94)90189-9

Robles, I., Arruda, A. G., Nixon, E., Johnstone, E., Wagner, B., Edwards-Callaway, L., Baynes, R., Coetzee, J., & Pairis-Garcia, M. (2021). Producer and veterinarian perspectives towards pain management practices in the US cattle industry. *Animals*, *11*(1), 209. https://doi.org/10.3390/ani11010209

Roche, J. R., Dillon, P. G., Stockdale, C. R., Baumgard, L. H., & VanBaale, M. J. (2004). Relationships among international body condition scoring systems. *Journal of Dairy Science*, *87*(9), 3076–3079. https://doi.org/10.3168/jds.S0022-0302(04)73441-4

Roche, J. R., Friggens, N. C., Kay, J. K., Fisher, M. W., Stafford, K. J., & Berry, D. P. (2009). Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. *Journal of Dairy Science*, *92*(12), 5769–5801. https://doi.org/10.3168/jds.2009-2431

Roche, S. M., Renaud, D. L., Saraceni, J., Kelton, D. F., & DeVries, T. J. (2024). Invited review: Prevalence, risk factors, treatment, and barriers to best practice adoption for lameness and injuries in dairy cattle—A narrative review. *Journal of Dairy Science*, *107*(6), 3347–3366. https://doi.org/10.3168/jds.2023-23870

Rolfe, K. M., Snelling, W. M., Nielsen, M. K., Freetly, H. C., Ferrell, C. L., & Jenkins, T. G. (2011). Genetic and phenotypic parameter estimates for feed intake and other traits in growing beef cattle, and opportunities for selection. *Journal of Animal Science*, *89*(11), 3452–3459. https://doi.org/10.2527/jas.2011-3961

Rollin, B. E. (2006). Euthanasia and quality of life. *Journal of the American Veterinary Medical Association*, *228*(7), 1014–1016. https://doi.org/10.2460/javma.228.7.1014

Rosenberger, G., Dirksen, G., Gründer, H.-D., & Stöber, M. (1978). *Krankheiten des Rindes*.

Roughsedge, T., Amer, P., Thompson, R., & Simm, G. (2005). Genetic parameters for a maternal breeding goal in beef production. *Journal of Animal Science*, *83*(10), 2319–2329. https://doi.org/10.2527/2005.83102319x

Rouha-Muelleder, C., Absmanner, E., Kahrer, E., Zeiner, H., Scharl, T., Leisch, F., Stanek, C., & Troxler, J. (2012). Alternative housing systems for fattening bulls under Austrian conditions with special respect to rubberised slatted floors. *Animal Welfare*, *21*(1), 113–126. https://doi.org/10.7120/096272812799129394

Ruis-Heutinck, L. F. M., Smits, M. C. J., Smits, A. C., & Heeres, J. J. (2000). Effect of floor and floor area on behaviour and carpal joint lesions in beef bulls. Improving health and welfare in animal production. In H. J. Blokhuis, E. D. Ekkel, & B. Wechsler (Eds.), *Proceedings of sessions of the EAAP Commission on Animal Management & Health, The Hague (NL), 21–24 August 2000* (pp. 29–36). Wageningen Academic Publishers, No. 102.

Ruis-Heutnick, L. F. M., Smits, M. J. C., Smits, A. C., & Heere, J. J. (2000). *Effects of floor type and floor area on behaviour and carpal joint lesions in beef bulls* (pp. 29–36). Proceedings of the EAAP Commission on Animal Health and Management.

Rushen, J. (1987). A difference in weight reduces fighting when unacquainted newly weaned pigs first meet. *Canadian Journal of Animal Science*, *67*(4), 951–960. https://doi.org/10.4141/cjas87-100

Rushen, J. (1988). Assessment of fighting ability or simple habituation: What causes young pigs (Sus scrofa) to stop fighting? *Aggressive Behavior*, *14*(3), 155–167.

Rushen, J., & de Passille, A. M. (2012). Automated measurement of acceleration can detect effects of age, dehorning and weaning on locomotor play of calves. *Applied Animal Behaviour Science*, *139*, 169–174. https://doi.org/10.1016/j.applanim.2012.04.011

Saad, H. M., Thomas, M. G., Speidel, S. E., Peel, R. K., Frasier, W. M., & Enns, R. M. (2020). Differential response from selection for high calving ease vs. low birth weight in American Simmental beef cattle. *Journal of Animal Science*, *98*(7), skaa162. https://doi.org/10.1093/jas/skaa162

Sánchez, J. N., Félix-Leyva, B. J., Velázquez, D. Z., Rosiles, J. R., Montero, A., Strappini, A. C., Gallo, C., Robles-Estrada, J. C., Portillo-Loera, J. J., Diaz, D., & Dávila-Ramos, H. (2022). Prevalence, risk factors, and main characteristics of bruises in cattle: A meta-analysis in the American continent: A systematic review and meta-analysis. *Veterinaria México OA*, *9*, 1088. https://doi.org/10.22201/fmvz.24486760e.2022.1088

Sandelin, B., Brown, A., Jr., Johnson, Z., Hornsby, J., Baublits, R., & Kutz, B. (2005). Postpartum maternal behavior score in six breed groups of beef cattle over twenty-five years. *The Professional Animal Scientist*, *21*(1), 13–16. https://doi.org/10.15232/S1080-7446(15)31160-8

Sanders, A. H., Shearer, J. K., & De Vries, A. (2009). Seasonal incidence of lameness and risk factors associated with thin soles, white line disease, ulcers, and sole punctures in dairy cattle. *Journal of Dairy Science*, *92*(7), 3165–3174. https://doi.org/10.3168/jds.2008-1799

Sandøe, P., Theut, L., & Denwood, M. (2018). Breeding blues: An ethical evaluation of the plan to reduce calving difficulties in Danish blue cattle. In *Professionals in food chains: EurSafe* (pp. 134–140). Springer S & Grimm H, Wageningen Academic. https://doi.org/10.3920/978-90-8686-869-8_19

Sant'Anna, A. C., Baldi, F., Valente, T. S., Albuquerque, L. G., Menezes, L. M., Boligon, A. A., & Paranhos da Costa, M. J. R. (2015). Genetic associations between temperament and performance traits in Nellore beef cattle. *Journal of Animal Breeding and Genetics*, *132*(1), 42–50. https://doi.org/10.1111/jbg.12117

Sant'Anna, A. C., Paranhos da Costa, M. J. R., Baldi, F., & Albuquerque, L. G. (2013). Genetic variability for temperament indicators of Nellore cattle. *Journal of Animal Science*, *91*(8), 3532–3537. https://doi.org/10.2527/jas.2012-5979

Santo, N. K., von Borstel, U. K., & Sirovnik, J. (2020). The influence of maternal contact on activity, emotionality and social competence in young dairy calves. *Journal of Dairy Research*, *87*(S1), 138–143. https://doi.org/10.1017/S0022029920000527

Sanz-Fernandez, M. V., Daniel, J.-B., Seymour, D. J., Kvidera, S. K., Bester, Z., Doelman, J., & Martín-Tereso, J. (2020). Targeting the hindgut to improve health and performance in cattle. *Animals*, *10*, 1–18. https://doi.org/10.3390/ani10101817

Sarre, C., De Bleecker, K., Deprez, P., Levecke, B., Charlier, J., Vercruysse, J., & Claerebout, E. (2012). Risk factors for Psoroptes ovis mange on Belgian blue farms in Northern Belgium. *Veterinary Parasitology*, *190*(1), 216–221. https://doi.org/10.1016/j.vetpar.2012.05.026

Sarti, F. M., Ceccobelli, S., Lasagna, E., Di Lorenzo, P., Sbarra, F., Pieramati, C., Giontella, A., & Panella, F. (2019). Influence of single nucleotide polymorphisms in some candidate genes related to the performance traits in Italian beef cattle breeds. *Livestock Science*, *230*, 103834. https://doi.org/10.1016/j.livsci.2019.103834

Schafberg, R., & Swalve, H. H. (2015). The history of breeding for polled cattle. *Livestock Science*, *179*, 54–70. https://doi.org/10.1016/j.livsci.2015.05.017

Scheper, C. (2018). Hörnertragende Rinderzucht sichern – Status-Quo Analyse der Entwicklungen in der Zucht hornloser Milchrinder. https://orgprints.org/id/eprint/36519/1/1910_Abschlussbericht_Demeter_Horn-Zucht_fin_orgprints.pdf

Scheper, C., Wensch-Dorendorf, M., Yin, T., Dressel, H., Swalve, H., & König, S. (2016). Evaluation of breeding strategies for polledness in dairy cattle using a newly developed simulation framework for quantitative and Mendelian traits. *Genetics Selection Evolution*, *48*, 50. https://doi.org/10.1186/s12711-016-0228-7

Scheurwater, J., Jorritsma, R., Nielen, M., Heesterbeek, H., van den Broek, J., & Aardema, H. (2021). The effects of cow introductions on milk production and behaviour of the herd measured with sensors. *Journal of Dairy Research*, *88*(4), 374–380. https://doi.org/10.1017/S0022029921000856

Schiavon, S., Tagliapietra, F., Dal Maso, M., Bailoni, L., & Bittante, G. (2010). Effects of low-protein diets and rumen-protected conjugated linoleic acid on production and carcass traits of growing double-muscled Piemontese bulls. *Journal of Animal Science*, *88*(10), 3372–3383. https://doi.org/10.2527/jas.2009-2558

Schmidt, P. J., Yeates, N. T. M., & Murray, D. M. (1980). The effect of water restriction on some physiological responses of steers during enforced exercise in a warm environment. *Australian Journal of Agricultural Research*, *31*(2), 409–416. https://doi.org/10.1071/AR9800409

Schnaider, M. A., Heidemann, M. S., Silva, A. H. P., Taconeli, C. A., & Molento, C. F. M. (2022). Vocalization and other behaviors as indicators of emotional valence: The case of cow-calf separation and Reunion in beef cattle. *Journal of Veterinary Behavior*, *49*, 28–35. https://doi.org/10.1016/j.jveb.2021.11.011

Schneider, C. (2011). *Dimensionierung und Gestaltung von Laufställen für behornte Milchkühe unter Berücksichtigung des Herdenmanagements. Universität Kassel, FB 11, Ökologische Agrarwissenschaften* https://kobra.uni-kassel.de/handle/123456789/2011112339751

Schneider, L. (2020). Investigations on the behavior of fattening cattle in intensive housing systems. PhD Thesis, University of Veterinary Medicine Hannover, Institute for Animal Hygiene, Animal Welfare and Farm Animal Behavior. Hannover. 88 pp. https://elib.tiho-hannover.de/receive/tiho_mods_00001711

Schneider, L., Volkmann, N., Kemper, N., & Spindler, B. (2020). Feeding behavior of fattening bulls fed Six times per day using an automatic feeding system. Frontiers in veterinary. *Science*, *7*, 1–10. https://doi.org/10.3389/fvets.2020.00043

Schneider, L., Volkmann, N., Spindler, B., & Kemper, N. (2020a). Large group housing Systems in Fattening Bulls—Comparison of behavior and performance. *Frontiers in Veterinary Science*, *7*. https://doi.org/10.3389/fvets.2020.543335

Schneider, L., Volkmann, N., Spindler, B., & Kemper, N. (2020b). Synchronisation des Liegeverhaltens von Mastbullen bei verschiedenen Platzangeboten. *Tierärztliche Praxis. Ausgabe G, Grosstiere/Nutztiere*, *48*(5), 310–316. https://doi.org/10.1055/a-1235-8926

Schneider, M. J., Tait, R. G., Jr., Busby, W. D., & Reecy, J. M. (2009). An evaluation of bovine respiratory disease complex in feedlot cattle: Impact on performance and carcass traits using treatment records and lung lesion scores1,2. *Journal of Animal Science*, *87*(5), 1821–1827. https://doi.org/10.2527/jas.2008-1283

Schneider, P. L., Beede, D. K., & Wilcox, C. J. (1988). Effects of supplemental potassium and sodium chloride salts on ruminal turnover rates, Acid-Base and mineral status of lactating dairy cows during heat Stress2. *Journal of Animal Science*, *66*(1), 126–135. https://doi.org/10.2527/jas1988.661126x

Schoiswohl, J., Stanitznig, A., Smetanig, C., Kneissl, S., Thaller, D., Juffinger, A., Waiblinger, S., Palme, R., Tichy, A., Krametter-Froetscher, R., & Wittek, T. (2022). Comparison of alternative methods for thermal disbudding in calves. *Journal of Veterinary Behavior*, *51*, 35–42. https://doi.org/10.1016/j.jveb.2022.03.004

Schrader, L., Roth, H. R., Winterling, C., Brodmann, N., Langhans, W., Geyer, H., & Graf, B. (2001). The occurrence of tail tip alterations in fattening bulls kept under different husbandry conditions. *Animal Welfare*, *10*(2), 119–130. https://doi.org/10.1017/S0962728600023794

Schreiner, D. A., & Ruegg, P. L. (2002). Responses to tail docking in calves and heifers. *Journal of Dairy Science*, *85*(12), 3287–3296. https://doi.org/10.3168/jds.S0022-0302(02)74417-2

Schulze Westerath, H., Gygax, L., Mayer, C., & Wechsler, B. (2007). Leg lesions and cleanliness of finishing bulls kept in housing systems with different lying area surfaces. *The Veterinary Journal*, *174*(1), 77–85. https://doi.org/10.1016/j.tvjl.2006.05.010

Schulze Westerath, H., Laister, S., Winckler, C., & Knierim, U. (2009). Exploration as an indicator of good welfare in beef bulls: An attempt to develop a test for on-farm assessment. *Applied Animal Behaviour Science*, *116*(2–4), 126–133. https://doi.org/10.1016/j.applanim.2008.08.012

Schulze Westerath, H., Meier, T., Gygax, L., Wechsler, B., & Mayer, C. (2006). Effects of the inclination of the lying area in cubicles on the behaviour and dirtiness of fattening bulls. *Applied Animal Behaviour Science*, *97*(2–4), 122–133. https://doi.org/10.1016/j.applanim.2005.04.023

Schuster, F., Aldag, P., Frenzel, A., Hadeler, K. G., Lucas-Hahn, A., Niemann, H., & Petersen, B. (2020). CRISPR/Cas12a mediated knock-in of the polled Celtic variant to produce a polled genotype in dairy cattle. *Scientific Reports*, *10*, 13570. https://doi.org/10.1038/s41598-020-70531-y

Schütz, K. (2012). Effects of providing clean water on the health and productivity of cattle. Report for Northland Regional Council, no. RE400/2012/346. AgResearch, New Zealand. 23 pp. https://envirolink.govt.nz/assets/Envirolink/1051-NLRC142-Effects-of-providing-clean-water-on-the-health-and-productivity-of-cattle.pdf

Schütz, K., Clark, K., Cox, N., Matthews, L., & Tucker, C. (2010). Responses to short-term exposure to simulated rain and wind by dairy cattle: Time budgets, shelter use, body temperature and feed intake. *Animal Welfare*, *19*(4), 375–383. https://doi.org/10.1017/S0962728600001858

Schütz, K., Rogers, A., Poulouin, Y., Cox, N., & Tucker, C. (2010). The amount of shade influences the behavior and physiology of dairy cattle. *Journal of Dairy Science*, *93*(1), 125–133. https://doi.org/10.3168/jds.2009-2416

Schütz, K. E., Cave, V. M., Cox, N. R., Huddart, F. J., & Tucker, C. B. (2019). Effects of 3 surface types on dairy cattle behavior, preference, and hygiene. *Journal of Dairy Science*, *102*(2), 1530–1541. https://doi.org/10.3168/jds.2018-14792

Sellick, G. S., Pitchford, W. S., Morris, C. A., Cullen, N. G., Crawford, A. M., Raadsma, H. W., & Bottema, C. D. K. (2007). Effect of myostatin F94L on carcass yield in cattle. *Animal Genetics*, *38*(5), 440–446. https://doi.org/10.1111/j.1365-2052.2007.01623.x

Shahin, K. A., Berg, R. T., & Price, M. A. (1991). Muscle and bone distribution in mature normal and double muscled cows. *Livestock Production Science*, *28*(4), 291–303. https://doi.org/10.1016/0301-6226(91)90011-E

Shaw, F., Baxter, R., & Ramsay, W. (1976). The contribution of horned cattle to carcase bruising. *The Veterinary Record*, *98*(13), 255–257. https://doi.org/10.1136/vr.98.13.255

Sheedy, D. B., Aly, S. S., Tucker, C. B., & Lehenbauer, T. W. (2024). The history and future of the cornual nerve block for calf disbudding. *JDS Communications*, *5*(4), 305–309. https://doi.org/10.3168/jdsc.2023-0506

Shen, J. F., Chen, Q. M., Zhang, F. W., Hanif, Q., Huang, B. Z., Chen, N. B., Qu, K. X., Zhan, J. X., Chen, H., Jiang, Y., & Lei, C. Z. (2022). Genome-wide association study identifies quantitative trait loci affecting cattle temperament. *Zoological Research*, *43*(1), 14–25. https://doi.org/10.24272/j.issn.2095-8137.2021.176

Shephard, R., & Maloney, S. (2023). A review of thermal stress in cattle. *Australian Veterinary Journal*, *101*(11), 417–429. https://doi.org/10.1111/avj.13275

Shepley, E., Lensink, J., Leruste, H., & Vasseur, E. (2020). The effect of free-stall versus strawyard housing and access to pasture on dairy cow locomotor activity and time budget. *Applied Animal Behaviour Science*, *224*, 104928. https://doi.org/10.1016/j.applanim.2019.104928

Shepley, E., Lensink, J., & Vasseur, E. (2020). Cow in Motion: A review of the impact of housing systems on movement opportunity of dairy cows and implications on locomotor activity. *Applied Animal Behaviour Science*, *230*, 105026. https://doi.org/10.1016/j.applanim.2020.105026

Sibanda, S., Hatendi, P. R., Mulenga, F. M., & Ndlovu, P. (1997). The effect of diet and frequency of watering on rumen degradability and outflow rate of low-quality veld hay and dry-matter apparent digestibility in steers given food at maintenance. *Animal Science*, *65*(2), 159–164. https://doi.org/10.1017/S1357729800016453

Silanikove, N. (1992). Effects of water scarcity and hot environment on appetite and digestion in ruminants: A review. *Livestock Production Science*, *30*(3), 175–194. https://doi.org/10.1016/S0301-6226(06)80009-6

Silanikove, N. (1994). The struggle to maintain hydration and osmoregulation in animals experiencing severe dehydration and rapid rehydration: The story of ruminants. *Experimental Physiology: Translation and Integration*, *79*(3), 281–300. https://doi.org/10.1113/expphysiol.1994.sp003764

Silva, R. P., Espigolan, R., Berton, M. P., Stafuzza, N. B., Santos, F. S., Negreiros, M. P., Schuchmann, R. K., Rodriguez, J. D., Lôbo, R. B., Banchero, G., Pereira, A. S. C., Bergmann, J. A. G., & Baldi, F. (2020). Genetic parameters and genomic regions associated with calving ease in primiparous Nellore heifers. *Livestock Science*, *240*, 104183. https://doi.org/10.1016/j.livsci.2020.104183

Simonsen, H. B. (1979). Grooming behaviour of domestic cattle. *Nordisk Veterinaermedicin*, *31*(1), 1–5.

Sirovnik, J., Barth, K., de Oliveira, D., Ferneborg, S., Haskell, M. J., Hillmann, E., Jensen, M. B., Mejdell, C. M., Napolitano, F., Vaarst, M., Verwer, C. M., Waiblinger, S., Zipp, K. A., & Johnsen, J. F. (2020). Methodological terminology and definitions for research and discussion of cow-calf contact systems. *Journal of Dairy Research*, *87*(S1), 108–114. https://doi.org/10.1017/S0022029920000564

Skúladóttir, G., Phythian, C. J., Holmøy, I. H., Myhrene, G., Alvåsen, K., & Martin, A. D. (2022). Overview of the practices of on-farm emergency slaughter of cattle in the Nordic countries. *Acta Veterinaria Scandinavica*, *64*(1), 9. https://doi.org/10.1186/s13028-022-00627-0

Small, A., Fisher, A., Lee, C., & Colditz, I. (2020). Gap evaluation of pain alleviation research. *Australian Wool Innovation Limited* https://www.wool.com/globalassets/wool/sheep/research-publications/welfare/improved-pain-relief/project-final-report-on-gap-evaluation-of-pain-alleviation.pdf

Smid, A. M. C., Burgers, E. E. A., Weary, D. M., Bokkers, E. A. M., & von Keyserlingk, M. A. G. (2019). Dairy cow preference for access to an outdoor pack in summer and winter. *Journal of Dairy Science*, *102*(2), 1551–1558. https://doi.org/10.3168/jds.2018-15007

Smits, A. C., Plomp, M., & Goedegebuure, S. A. (1995). Vergelijking van gedrag, produktie en gezondheid van vleesstieren gehouden op betonnen en op met rubber beklede roostervloeren. IMAG-DLO, Rapport 94–26, Wageningen. 48 pp.

Sobande, A., & Eskandar, M. (2006). Multiple repeat caesarean sections: Complications and outcomes. *Journal of Obstetrics and Gynaecology Canada*, *28*(3), 193–197. https://doi.org/10.1016/S1701-2163(16)32105-3

Spoolder, H. A. M., Schöne, M., & Bracke, M. B. M. (2016). Initiatives to reduce mutilations in EU livestock production Wageningen UR (University & Research centre) livestock research, Wageningen, The Netherlands. *Livestock Research Report*, *940*, 86 https://edepot.wur.nl/374964

Stafford, K. J., & Mellor, D. J. (2005a). The welfare significance of the castration of cattle: A review. *New Zealand Veterinary Journal*, *53*(5), 271–278. https://doi.org/10.1080/00480169.2005.36560

Stafford, K. J., & Mellor, D. J. (2005b). Dehorning and disbudding distress and its alleviation in calves. *The Veterinary Journal*, *169*(3), 337–349. https://doi.org/10.1016/j.tvjl.2004.02.005

Stafford, K. J., Mellor, D. J., Todd, S. E., Bruce, R. A., & Ward, R. N. (2002). Effects of local anaesthesia or local anaesthesia plus a non-steroidal anti-inflammatory drug on the acute cortisol response of calves to five different methods of castration. *Research in Veterinary Science*, *73*(1), 61–70. https://doi.org/10.1016/S0034-5288(02)00045-0

Stahringer, R. C., Randel, R. D., & Neuendorff, D. A. (1990). Effects of naloxone and animal temperament on serum luteinizing-hormone and cortisol concentrations in seasonally Anestrous Brahman heifers. *Theriogenology*, *34*(2), 393–406. https://doi.org/10.1016/0093-691x(90)90531-W

Stanek, C., Frickh, J. J., & Karall, P. (2004). Claw condition and meat quality factors in fattening bulls in two different housing systems. Proceedings of the 13th International Symposium and 5th Conference on Lameness in Ruminants, Maribor, Slovenija, 11–15 February 2004. pp. 193–195.

Stavaux, D., Art, T., Mc Entee, K., Reznick, M., & Lekeux, P. (1994). Muscle fibre type and size, and muscle capillary density in young double-muscled blue Belgian cattle. *Journal of Veterinary Medicine Series A*, *41*(1–10), 229–236. https://doi.org/10.1111/j.1439-0442.1994.tb00089.x

Stěhulová, I., Lidfors, L., & Špinka, M. (2008). Response of dairy cows and calves to early separation: Effect of calf age and visual and auditory contact after separation. *Applied Animal Behaviour Science*, *110*(1), 144–165. https://doi.org/10.1016/j.applanim.2007.03.028

Stěhulová, I., Špinka, M., Šárová, R., Máchová, L., Kněz, R., & Firla, P. (2013). Maternal behaviour in beef cows is individually consistent and sensitive to cow body condition, calf sex and weight. *Applied Animal Behaviour Science*, *144*(3–4), 89–97. https://doi.org/10.1016/j.applanim.2013.01.003

Steiner, B., Zähner, M., & Keck, M. (2011). Rutschfestigkeit von Rinderstallböden-Folgerungen für neue Materialien. Proceedings of the Bautagung Raumberg-Gumpenstein 2011. *HBLFA Raumberg-Gumpenstein*, *7*.

Stewart, M., Shepherd, H. M., Webster, J. R., Waas, J. R., McLeay, L. M., & Schütz, K. E. (2013). Effect of previous handling experiences on responses of dairy calves to routine husbandry procedures. *Animal*, *7*(5), 828–833. https://doi.org/10.1017/s175173111200225x

Stilwell, G. (2024). RE: Feedlots in Portugal? Message to Christoph Winckler. 17 January 2024, Email.

Stilwell, G., Carvalho, R., Lima, M., & Broom, D. (2009). Effect of caustic paste disbudding, using local anaesthesia with and without analgesia, on behavior and cortisol of calves. *Applied Animal Behaviour Science*, *116*, 35–44. https://doi.org/10.1016/j.applanim.2008.06.008

Stilwell, G., Carvalho, R. C., Carolino, N., Lima, M. S., & Broom, D. M. (2010). Effect of hot-iron disbudding on behaviour and plasma cortisol of calves sedated with xylazine. *Research in Veterinary Science*, *88*(1), 188–193. https://doi.org/10.1016/j.rvsc.2009.06.012

Stilwell, G., Lima, M., & Broom, D. (2007). Comparing the effect of three different disbudding methods on behaviour and plasma cortisol of calves. *Revista Portuguesa Ciencias Veteriniarias*, *102*, 281–288.

Stilwell, G., Lima, M. S., & Broom, D. M. (2008). Effects of nonsteroidal anti-inflammatory drugs on long-term pain in calves castrated by use of an external clamping technique following epidural anesthesia. *American Journal of Veterinary Research*, *69*(6), 744–750. https://doi.org/10.2460/ajvr.69.6.744

Stilwell, G., Lima, M. S., Carvalho, R. C., & Broom, D. M. (2012). Effects of hot-iron disbudding, using regional anaesthesia with and without carprofen, on cortisol and behaviour of calves. *Research in Veterinary Science*, *92*(2), 338–341. https://doi.org/10.1016/j.rvsc.2011.02.005

Stokka, G. L., Lechtenberg, K., Edwards, T., MacGregor, S., Voss, K., Griffin, D., Grotelueschen, D. M., Smith, R. A., & Perino, L. J. (2001). Lameness in feedlot cattle. *Veterinary Clinics of North America: Food Animal Practice*, *17*(1), 189–207. https://doi.org/10.1016/S0749-0720(15)30062-1

Stoye, S., Porter, M. A., & Stamp Dawkins, M. (2012). Synchronized lying in cattle in relation to time of day. *Livestock Science*, *149*(1), 70–73. https://doi.org/10.1016/j.livsci.2012.06.028

Stracke, J., Andersson, R., Volkmann, N., Spindler, B., Schulte-Landwehr, J., Günther, R., & Kemper, N. (2022). Footpad monitoring: reliability of an automated system to assess footpad dermatitis in Turkeys (Meleagris gallopavo) During Slaughter. *Frontiers in Veterinary Science*, *9*, 888503. https://doi.org/10.3389/fvets.2022.888503

Strappini, A. C., Frankena, K., Metz, J. H. M., & Kemp, B. (2012). Intra- and inter-observer reliability of a protocol for post mortem evaluation of bruises in Chilean beef carcasses. *Livestock Science*, *145*(1), 271–274. https://doi.org/10.1016/j.livsci.2011.12.014

Sullivan, M., Cawdell-Smith, A., Mader, T., & Gaughan, J. (2011). Effect of shade area on performance and welfare of short-fed feedlot cattle. *Journal of Animal Science*, *89*(9), 2911–2925. https://doi.org/10.2527/jas.2010-3152

Surlis, C., Earley, B., McGee, M., Keogh, K., Cormican, P., Blackshields, G., Tiernan, K., Dunn, A., Morrison, S., Arguello, A., & Waters, S. M. (2018). Blood immune transcriptome analysis of artificially fed dairy calves and naturally suckled beef calves from birth to 7 days of age. *Scientific Reports*, *8*, 15461. https://doi.org/10.1038/s41598-018-33627-0

Sutherland, M. A., Huddart, F. J., & Stewart, M. (2019). Short communication: Evaluation of the efficacy of novel disbudding methods for dairy calves. *Journal of Dairy Science*, *102*(1), 666–671. https://doi.org/10.3168/jds.2018-15230

Sutherland, M. A., & Tucker, C. B. (2011). The long and short of it: A review of tail docking in farm animals. *Applied Animal Behaviour Science*, *135*(3), 179–191. https://doi.org/10.1016/j.applanim.2011.10.015

Svensson, C., Hultgren, J., & Oltenacu, P. A. (2006). Morbidity in 3–7-month-old dairy calves in south-western Sweden, and risk factors for diarrhoea and respiratory disease. *Preventive Veterinary Medicine*, *74*(2–3), 162–179. https://doi.org/10.1016/j.prevetmed.2005.11.008

Sweeten, J. (1982). *Feedlot dust control. Texas agricultural extension service, The Texas A&M University System*.

Talebi, A., von Keyserlingk, M. A. G., Telezhenko, E., & Weary, D. M. (2014). Reduced stocking density mitigates the negative effects of regrouping in dairy cattle. *Journal of Dairy Science*, *97*(3), 1358–1363. https://doi.org/10.3168/jds.2013-6921

Tallo-Parra, O., Manteca, X., Sabes-Alsina, M., Carbajal, A., & Lopez-Bejar, M. (2015). Hair cortisol detection in dairy cattle by using EIA: Protocol validation and correlation with faecal cortisol metabolites. *Animal*, *9*(6), 1059–1064. https://doi.org/10.1017/S1751731115000294

Taschke, A. C. (1995). *Ethologische, physiologische und histologische Untersuchungen zur Schmerzbelastung der Rinder bei der Enthornung [ethological, physiological and histological studies on the pain of cattle during dehorning]*. Doctoral Thesis,. University of Zurich.

Taschke, A. C., & Fölsch, D. W. (1997). Ethological, physiological and histological aspects of pain and stress in cattle when being dehorned. *Tierärztliche Praxis*, *25*(1), 19–27.

Taylor, C. R. (1966). The vascularity and possible thermoregulatory function of the horns in goats. *Physiological Zoology*, *39*(2), 127–139. https://doi.org/10.1086/physzool.39.2.30152426

Taylor, E., Dunston-Clarke, E., Brookes, D., Jongman, E., Linn, B., Barnes, A., Miller, D., Fisher, A., & Collins, T. (2023). Developing a welfare assessment protocol for Australian lot-fed cattle. *Frontiers in Animal Science*, *4*, 1256670. https://doi.org/10.3389/fanim.2023.1256670

Taylor, J. D., Fulton, R. W., Lehenbauer, T. W., Step, D. L., & Confer, A. W. (2010). The epidemiology of bovine respiratory disease: What is the evidence for preventive measures? *The Canadian Veterinary Journal*, *51*(12), 1351–1359.

Taylor, J. D., Gilliam, J. N., Mourer, G., & Stansberry, C. (2020). Comparison of effects of four weaning methods on health and performance of beef calves. *Animal*, *14*(1), 161–170. https://doi.org/10.1017/S1751731119001228

Taylor, K. M., Giersch, G. E. W., Caldwell, A. R., Epstein, Y., & Charkoudian, N. (2024). Relation of body surface area-to-mass ratio to risk of exertional heat stroke in healthy men and women. *Journal of Applied Physiology*, *136*(3), 549–554. https://doi.org/10.1152/japplphysiol.00597.2023

Teagasc. (2020). Castration- Best Practice. https://www.teagasc.ie/publications/2020/castration--best-practice.php [Accessed on 13 March 2025].

Teagasc. (2022). Options for culling cows this autumn. https://www.teagasc.ie/news--events/daily/dairy/options-for-culling-cows-this-autumn.php [Accessed on 12 February 2024].

Teiga-Teixeira, P., Dina, M., Juan, G.-D., & Esteves, A. (2021). Characterization of carcass bruises in cattle in Northern Portugal, a preliminary study. *Italian Journal of Animal Science*, *20*(1), 1168–1174. https://doi.org/10.1080/1828051X.2021.1957030

Telezhenko, E., Bergsten, C., Magnusson, M., & Nilsson, C. (2009). Effect of different flooring systems on claw conformation of dairy cows. *Journal of Dairy Science*, *92*(6), 2625–2633. https://doi.org/10.3168/jds.2008-1798

Tetens, J., Wiedemar, N., Menoud, A., Thaller, G., & Drögemüller, C. (2015). Association mapping of the *scurs* locus in polled Simmental cattle – Evidence for genetic heterogeneity. *Animal Genetics*, *46*(2), 224–225. https://doi.org/10.1111/age.12237

Theurer, M. E., White, B. J., Coetzee, J. F., Edwards, L. N., Mosher, R. A., & Cull, C. A. (2012). Assessment of behavioral changes associated with oral meloxicam administration at time of dehorning in calves using a remote triangulation device and accelerometers. *BMC Veterinary Research*, *8*, 1–8. https://doi.org/10.1186/1746-6148-8-48

Thomsen, P. T., Hansen, J. H., & Herskin, M. S. (2021). Dairy calves show behavioural responses to hot iron disbudding after local anaesthesia with procaine. *Veterinary Record*, *188*(4), e52. https://doi.org/10.1002/vetr.52

Thomsen, P. T., & Houe, H. (2023). Recording of culling reasons in Danish dairy cows. *Livestock Science*, *278*, 105359. https://doi.org/10.1016/j.livsci.2023.105359

Thomsen, P. T., Munksgaard, L., & Tøgersen, F. A. (2008). Evaluation of a lameness scoring system for dairy cows. *Journal of Dairy Science*, *91*(1), 119–126. https://doi.org/10.3168/jds.2007-0496

Thüer, S., Doherr, M. G., Wechsler, B., Mellema, S. C., Nuss, K., Kirchhofer, M., & Steiner, A. (2007). Einfluss der Lokalanästhesie auf Kurz- und Langzeitschmerzen verursacht durch drei unblutige. *Kastrationsmethoden beim Kalb Schweiz Arch Tierheilkd*, *149*(5), 201–211. https://doi.org/10.1024/0036-7281.149.5.201

Thüer, S., Mellema, S., Doherr, M. G., Wechsler, B., Nuss, K., & Steiner, A. (2007). Effect of local anaesthesia on short- and long-term pain induced by two bloodless castration methods in calves. *The Veterinary Journal*, *173*(2), 333–342. https://doi.org/10.1016/j.tvjl.2005.08.031

Ting, S. T. L., Earley, B., & Crowe, M. A. (2003). Effect of repeated ketoprofen administration during surgical castration of bulls on cortisol, immunological function, feed intake, growth, and behavior. *Journal of Animal Science*, *81*(5), 1253–1264. https://doi.org/10.2527/2003.8151253x

Ting, S. T. L., Earley, B., Hughes, J., & Crowe, M. A. (2003). Effect of ketoprofen, lidocaine local anesthesia, and combined xylazine and lidocaine caudal epidural anesthesia during castration of beef cattle on stress responses, immunity, growth, and behavior. *Journal of Animal Science*, *81*(5), 1281–1293. https://doi.org/10.2527/2003.8151281x

Ting, S. T. L., Earley, B., Veissier, I., Gupta, S., & Crowe, M. A. (2005). Effects of age of Holstein-Friesian calves on plasma cortisol, acute-phase proteins, immunological function, scrotal measurements and growth in response to Burdizzo castration. *Animal Science*, *80*(3), 377–386. https://doi.org/10.1079/ASC42150377

Titterington, F. M., Knox, R., Buijs, S., Lowe, D. E., Morrison, S. J., Lively, F. O., & Shirali, M. (2022). Human–animal interactions with bos taurus cattle and their impacts on on-farm safety: A systematic review. *Animals*, *12*(6), 776. https://doi.org/10.3390/ani12060776

Titterington, F. M., Knox, R., Morrison, S. J., & Shirali, M. (2022). Behavioural traits in *Bos taurus* cattle, their heritability, potential genetic markers, and associations with production traits. *Animals*, *12*(19), 2602. https://doi.org/10.3390/ani12192602

Toaff-Rosenstein, R. L., Velez, M., & Tucker, C. B. (2017). Technical note: Use of an automated grooming brush by heifers and potential for radiofrequency identification-based measurements of this behavior. *Journal of Dairy Science*, *100*(10), 8430–8437. https://doi.org/10.3168/jds.2017-12984

Tom, E., Rushen, J., Duncan, I., & De Passillé, A. (2002). Behavioural, health and cortisol responses of young calves to tail docking using a rubber ring or docking iron. *Canadian Journal of Animal Science*, *82*(1), 1–9. https://doi.org/10.4141/A01-053

Tomka, J. (2018). Genetic evaluation of calving difficulty in cattle: A review. *Slovak Journal of Animal Science*, *51*(3), 128–137.

Trachtman, A. R., Bergamini, L., Palazzi, A., Porrello, A., Capobianco Dondona, A., Del Negro, E., Paolini, A., Vignola, G., Calderara, S., & Marruchella, G. (2020). Scoring pleurisy in slaughtered pigs using convolutional neural networks. *Veterinary Research*, *51*(1), 51. https://doi.org/10.1186/s13567-020-00775-z

Tresoldi, G., Schütz, K. E., & Tucker, C. B. (2018). Cooling cows with sprinklers: Spray duration affects physiological responses to heat load. *Journal of Dairy Science*, *101*(5), 4412–4423. https://doi.org/10.3168/jds.2017-13806

Tschoner, T. (2021). Methods for pain assessment in calves and their use for the evaluation of pain during different procedures—A review. *Animals*, *11*(5), 1235. https://doi.org/10.3390/ani11051235

Tucker, C. B., Jensen, M. B., de Passillé, A. M., Hänninen, L., & Rushen, J. (2021). Invited review: Lying time and the welfare of dairy cows. *Journal of Dairy Science*, *104*(1), 20–46. https://doi.org/10.3168/jds.2019-18074

Tucker, C. B., Rogers, A. R., & Schütz, K. E. (2008). Effect of solar radiation on dairy cattle behaviour, use of shade and body temperature in a pasture-based system. *Applied Animal Behaviour Science*, *109*(2–4), 141–154. https://doi.org/10.1016/j.applanim.2007.03.015

Tunstall, J., Mueller, K., Grove-White, D., Oultram, J. W. H., & Higgins, H. M. (2021). Lameness in beef cattle: A cross-sectional descriptive survey of on-farm practices and approaches. *Frontiers in Veterinary Science*, *8*. https://doi.org/10.3389/fvets.2021.657299

Tuomisto, L., Huuskonen, A., Jauhiainen, L., & Mononen, J. (2019). Finishing bulls have more synchronised behaviour in pastures than in pens. *Applied Animal Behaviour Science*, *213*, 26–32. https://doi.org/10.1016/j.applanim.2019.02.007

Tuomisto, L., Mononen, J., Martiskainen, P., Ahola, L., & Huuskonen, A. K. (2015). Time budgets of finishing bulls housed in an uninsulated barn or at pasture. *Agricultural and Food Science*, *24*(3), 173–182. https://doi.org/10.23986/afsci.51116

Turner, S. P., Camerlink, I., Baxter, E. M., D'Eath, R. B., Desire, S., & Roehe, R. (2024). Breeding for pig welfare: Opportunities and challenges. *Advances in Pig Welfare*, 429–447. https://doi.org/10.1016/B978-0-323-85676-8.00003-1

Turner, S. P., & Lawrence, A. B. (2007). Relationship between maternal defensive aggression, fear of handling and other maternal care traits in beef cows. *Livestock Science*, *106*(2–3), 182–188. https://doi.org/10.1016/j.livsci.2006.08.002

Tuska, H. S. A., Residiwati, G., Verdru, K., Raes, A., Meesters, M., Six, R., Santoro, D., Budiono, P. O. B., Van Soom, A., & Opsomer, G. (2021). The impact of elective caesarean section on colostrum characteristics in double-muscled Belgian blue cows. *Theriogenology*, *167*, 120–125. https://doi.org/10.1016/j.theriogenology.2021.03.015

Twomey, A. J., Cromie, A. R., McHugh, N., & Berry, D. P. (2020). Validation of a beef cattle maternal breeding objective based on a cross-sectional analysis of a large national cattle database. *Journal of Animal Science*, *98*, 1–15. https://doi.org/10.1093/jas/skaa322

Ünal, Z., Kızıldeniz, T., Özden, M., Aktaş, H., & Karagöz, Ö. (2024). Detection of bruises on red apples using deep learning models. *Scientia Horticulturae*, *329*, 113021. https://doi.org/10.1016/j.scienta.2024.113021

Ungerfeld, R., Quintans, G., & Hötzel, M. J. (2016). Minimizing cows' stress when calves were early weaned using the two-step method with nose flaps. *Animal*, *10*(11), 1871–1876. https://doi.org/10.1017/S1751731116000793

Urie, N. J., Lombard, J. E., Shivley, C. B., Kopral, C. A., Adams, A. E., Earleywine, T. J., Olson, J. D., & Garry, F. B. (2018). Preweaned heifer management on US dairy operations: Part V. Factors associated with morbidity and mortality in preweaned dairy heifer calves. *Journal of Dairy Science*, *101*(10), 9229–9244. https://doi.org/10.3168/jds.2017-14019

Urso, P. M., Abe, T., Rfr, B., Sz, K., & Johnson, B. J. (2021). Review: The effects of dust on feedlot health and production of beef cattle. *Journal of Applied Animal Research*, *49*(1), 133–138. doi:10.1080/09712119.2021.1903476

Utley, P. R., Bradley, N. W., & Boling, J. A. (1970). Effect of restricted water intake on feed intake, nutrient digestibility and nitrogen metabolism in steers. *Journal of Animal Science*, *31*(1), 130–135. https://doi.org/10.2527/jas1970.311130x

Uygur, D., Gun, O., Kelekci, S., Ozturk, A., Ugur, M., & Mungan, T. (2005). Multiple repeat caesarean section: Is it safe? *European Journal of Obstetrics & Gynecology and Reproductive Biology*, *119*(2), 171–175. https://doi.org/10.1016/j.ejogrb.2004.07.022

Uytterhaegen, L., Claeys, E., Demeyer, D., Lippens, M., Fiems, L. O., Boucqué, C. Y., Van de Voorde, G., & Bastiaens, A. (1994). Effects of double-muscling on carcass quality, beef tenderness and myofibrillar protein degradation in Belgian blue White bulls. *Meat Science*, *38*(2), 255–267. https://doi.org/10.1016/0309-1740(94)90115-5

Valente, T. S., Ruiz, L. R. B., Macitelli, F., & Paranhos da Costa, M. J. R. (2022). Nose-flap devices used for two-stage weaning produce wounds in the nostrils of beef calves: Case report. *Animals*, *12*(11), 1452. https://doi.org/10.3390/ani12111452

Valkova, L., Vecerek, V., Voslarova, E., Kaluza, M., & Takacova, D. (2021). The welfare of cattle, sheep, goats and pigs from the perspective of traumatic injuries detected at slaughterhouse Postmortem inspection. *Animals*, *11*(5), 1406. https://doi.org/10.3390/ani11051406

Van Hoof, M. (2018). Ontwikkeling van een rendabel huisvesting- en managementconcept voor melkkoeien via de optimalisering van hun fysiologische en ethologische behoeften. Master Thesis, Veterinary medicine Universiteit Gent, Gent, Belgium. 54 pp. https://libstore.ugent.be/fulltxt/RUG01/002/481/323/RUG01-002481323_2018_0001_AC.pdf

Van Laer, E., Moons, C. P. H., Sonck, B., & Tuyttens, F. A. M. (2014). Importance of outdoor shelter for cattle in temperate climates. *Livestock Science*, *159*, 87–101. https://doi.org/10.1016/j.livsci.2013.11.003

van Leenen, K., Jouret, J., Demeyer, P., Van Driessche, L., De Cremer, L., Masmeijer, C., Boyen, F., Deprez, P., & Pardon, B. (2020). Associations of barn air quality parameters with ultrasonographic lung lesions, airway inflammation and infection in group-housed calves. *Preventive Veterinary Medicine*, *181*, 1–11. https://doi.org/10.1016/j.prevetmed.2020.105056

van Leenen, K., Jouret, J., Demeyer, P., Vermeir, P., Leenknecht, D., Van Driessche, L., De Cremer, L., Masmeijer, C., Boyen, F., Deprez, P., Cox, E., Devriendt, B., & Pardon, B. (2021). Particulate matter and airborne endotoxin concentration in calf barns and their association with lung consolidation, inflammation, and infection. *Journal of Dairy Science*, *104*(5), 5932–5947. https://doi.org/10.3168/jds.2020-18981

Van Os, J. M. C., Mintline, E. M., DeVries, T. J., & Tucker, C. B. (2018). Domestic cattle (*Bos taurus taurus*) are motivated to obtain forage and demonstrate contrafreeloading. *PLoS One*, *13*(3), 1–16. https://doi.org/10.1371/journal.pone.0193109

Vanezis, P. (2001). Interpreting bruises at necropsy. *Journal of Clinical Pathology*, *54*(5), 348. https://doi.org/10.1136/jcp.54.5.348

Varona, L., Moreno, C., & Altarriba, J. (2012). Genetic correlation of longevity with growth, post-mortem, docility and some morphological traits in the Pirenaica beef cattle breed. *Animal*, *6*(6), 873–879. https://doi.org/10.1017/S1751731111002072

Vasseur, E., Borderas, F., Cue, R. I., Lefebvre, D., Pellerin, D., Rushen, J., Wade, K. M., & de Passillé, A. M. (2010). A survey of dairy calf management practices in Canada that affect animal welfare. *Journal of Dairy Science*, *93*(3), 1307–1316. https://doi.org/10.3168/jds.2009-2429

Vasseur, E., Rushen, J., & De Passillé, A. (2014). Calf body temperature following chemical disbudding with sedation: Effects of milk allowance and supplemental heat. *Journal of Dairy Science*, *97*(8), 5185–5190. https://doi.org/10.3168/jds.2013-7519

Vecerek, V., Kozak, A., Malena, M., Tremlova, B., & Chloupek, P. (2003). Veterinary meat inspection of bovine carcasses in The Czech Republic during the period of 1995–2002. *Veterinární Medicína*, *48*(7), 183–189. https://doi.org/10.17221/5768-VETMED

Veissier, I., Boissy, A., dePassillé, A. M., Rushen, J., van Reenen, C. G., Roussel, S., Andanson, S., & Pradel, P. (2001). Calves' responses to repeated social regrouping and relocation1. *Journal of Animal Science*, *79*(10), 2580–2593. https://doi.org/10.2527/2001.79102580x

Venot, E., Guerrier, J., Lajudie, P., Dufour, V., Leudet, O., Boivin, X., Sapa, J., & Phocas, F. (2015). Mise en place d'une évaluation nationale du comportement des bovins allaitants à partir de données recueillies en ferme. In: Rencontres autour des Recherches sur les Ruminants. Institut de l'Elevage. https://hal.inrae.fr/hal-02744229

Verdú, M., Bach, A., & Devant, M. (2015). Effect of concentrate feeder design on performance, eating and animal behavior, welfare, ruminal health, and carcass quality in Holstein bulls fed high-concentrate diets. *Journal of Animal Science*, *93*(6), 3018–3033. https://doi.org/10.2527/jas.2014-8540

Verdú, M., Bach, A., & Devant, M. (2017). Effect of feeder design and concentrate presentation form on performance, carcass characteristics, and behavior of fattening Holstein bulls fed high-concentrate diets. *Animal Feed Science and Technology*, *232*, 148–159. https://doi.org/10.1016/j.anifeedsci.2017.07.003

Vermunt, J. (1990). *Lesions and structural characteristics of the claws of dairy heifers in two management systems* (p. 332). University of Saskatchewan, Canada.

Vermunt, J. J. (2008). The Caesarean Operation in Cattle: A Review. *Iranian Journal of Veterinary Surgery*, *10*(1), 82 https://www.magiran.com/p628533

Vial, F., & Reist, M. (2014). Evaluation of Swiss slaughterhouse data for integration in a syndromic surveillance system. *BMC Veterinary Research*, *10*(1), 33. doi:10.1186/1746-6148-10-33

Vial, F., Schärrer, S., & Reist, M. (2015). Risk factors for whole carcass condemnations in the Swiss slaughter cattle population. *PLoS One*, *10*(4), e0122717. https://doi.org/10.1371/journal.pone.0122717

Villot, C., Meunier, B., Bodin, J., Martin, C., & Silberberg, M. (2018). Relative reticulo-rumen pH indicators for subacute ruminal acidosis detection in dairy cows. *Animal*, *12*(3), 481–490. https://doi.org/10.1017/S1751731117001677

Vissac, B., Ménissier, F., Perreau, B., Manis, Y., & Marchand, H. (1973). Étude du caractère culard. VII. – Croissance et musculature des femelles, déséquilibre morphologique au vêlage. *Annales de Génétique et de Sélection Animale*, *5*, 23–38. https://doi.org/10.1186/1297-9686-5-1-23

Vissac, B., & Perreau, B. (1968). Étude Du Caractère Culard. II. Incidence Du Caractère Culard Sur La Morphologie Générale Des Bovins. *Annales de Zootechnie*, *17*(1), 77–101. https://doi.org/10.1051/animres:19680107

Vogt, A., Barth, K., Waiblinger, S., & König von Borstel, U. (2024). Can a gradual weaning and separation process reduce weaning distress in dam-reared dairy calves? A comparison with the 2-step method. *Journal of Dairy Science*, *107*(8), 5942–5961. https://doi.org/10.3168/jds.2024-23809

Volkmann, N., Stracke, J., Rauterberg, S. L., Spindler, B., & Kemper, N. (2021). Determination of static space requirements for finishing bulls based on image analysis. *Animal Welfare*, *30*(3), 307–314. https://doi.org/10.7120/09627286.30.3.007

von Keyserlingk, M. A. G., Olenick, D., & Weary, D. M. (2008). Acute Behavioral effects of regrouping dairy cows. *Journal of Dairy Science*, *91*(3), 1011–1016. https://doi.org/10.3168/jds.2007-0532

Wagner, J. J., & Engle, T. E. (2021). Invited review: Water consumption, and drinking behavior of beef cattle, and effects of water quality. *Applied Animal Science*, *37*(4), 418–435. https://doi.org/10.15232/aas.2021-02136

Waiblinger, S., Wagner, K., Hillmann, E., & Barth, K. (2020). Play and social behaviour of calves with or without access to their dam and other cows. *Journal of Dairy Research*, *87*(S1), 144–147. https://doi.org/10.1017/S0022029920000540

Walker, K. H., Fell, L. R., Reddacliff, L. A., Kilgour, R. J., House, J. R., Wilson, S. C., & Nicholls, P. J. (2007). Effects of yard weaning and training on the behavioural adaptation of cattle to a feedlot. *Livestock Science*, *106*(2), 210–217. https://doi.org/10.1016/j.livsci.2006.08.004
Walmsley, B., Lee, S., Parnell, P., & Pitchford, W. (2016). A review of factors influencing key biological components of maternal productivity in temperate beef cattle. *Animal Production Science*, *58*(1), 1–19. https://doi.org/10.1071/AN12428
Wang, J., Li, J., Wang, F., Xiao, J., Wang, Y., Yang, H., Li, S., & Cao, Z. (2020). Heat stress on calves and heifers: A review. *Journal of Animal Science and Biotechnology*, *11*(1), 79. https://doi.org/10.1186/s40104-020-00485-8
Ward, J. L., & Rebhun, W. C. (1992). Chronic frontal sinusitis in dairy cattle: 12 cases (1978–1989). *Journal of the American Veterinary Medical Association*, *201*(2), 326–328. https://doi.org/10.2460/javma.1992.201.02.326
Weary, D. M., Jasper, J., & Hötzel, M. J. (2008). Understanding weaning distress. *Applied Animal Behaviour Science*, *110*(1–2), 24–41. https://doi.org/10.1016/j.applanim.2007.03.025
Webb, L. E., van Reenen, C. G., Jensen, M. B., Schmitt, O., & Bokkers, E. A. (2015). Does temperament affect learning in calves? *Applied Animal Behaviour Science*, *165*, 33–39. https://doi.org/10.1016/j.applanim.2015.01.013
Webster, H., Morin, D., Jarrell, V., Shipley, C., Brown, L., Green, A., Wallace, R., & Constable, P. (2013). Effects of local anesthesia and flunixin meglumine on the acute cortisol response, behavior, and performance of young dairy calves undergoing surgical castration. *Journal of Dairy Science*, *96*(10), 6285–6300. https://doi.org/10.3168/jds.2012-6238
Webster, J. R., Stewart, M., Rogers, A. R., & Verkerk, G. A. (2008). Assessment of welfare from physiological and behavioural responses of New Zealand dairy cows exposed to cold and wet conditions. *Animal Welfare*, *17*(1), 19–26. https://doi.org/10.1017/S0962728600031948
Wechsler, B. (2011). Floor quality and space allowance in intensive beef production: A review. *Animal Welfare*, *20*(4), 497–503. https://doi.org/10.1017/S0962728600003134
Weeth, H., & Hunter, J. (1971). Drinking of sulfate-water by cattle. *Journal of Animal Science*, *32*(2), 277–281. https://doi.org/10.2527/jas1971.322277x
Welfare Quality. (2023a). Welfare Quality assessment protocol for cattle. Version 3.0. Welfare Quality Network. https://www.welfarequalitynetwork.net/media/1320/fattening-cattle-protocol.pdf
Welfare Quality. (2023b). Welfare Quality assessment protocol for cattle. Version 3.0. Welfare Quality Network. https://www.welfarequalitynetwork.net/media/1319/dairy-cattle-protocol.pdf
Weller, J. I., Ezra, E., & Ron, M. (2017). Invited review: A perspective on the future of genomic selection in dairy cattle. *Journal of Dairy Science*, *100*(11), 8633–8644. https://doi.org/10.3168/jds.2017-12879
Wierenga, H. K. (1990). Social dominance in dairy cattle and the influences of housing and management. *Applied Animal Behaviour Science*, *27*(3), 201–229. https://doi.org/10.1016/0168-1591(90)90057-K
Wiese, B. I., Campbell, J., Hendrick, S., & Penner, G. B. (2017). Ruminal pH, short-chain fatty acid concentrations, and serum acute phase protein concentrations during finishing for steers with and without rumen and liver pathology. *Canadian Journal of Animal Science*, *97*(4), 581–589. https://doi.org/10.1139/cjas-2016-0212
Wilcox, C. S., Schutz, M. M., Rostagno, M. R., Lay, D. C., Jr., & Eicher, S. D. (2013). Repeated mixing and isolation: Measuring chronic, intermittent stress in Holstein calves. *Journal of Dairy Science*, *96*(11), 7223–7233. https://doi.org/10.3168/jds.2013-6944
Wildemann, T. H. (2023). *Always restless? Effect of different housing systems on time budgets and restlessness in beef bulls*. Master Thesis, BOKU University, Austria.
Williams, L., Rowlands, G., & Russell, A. (1986). Effect of wet weather on lameness in dairy cattle. *The Veterinary Record*, *118*(10), 259–261. https://doi.org/10.1136/vr.118.10.259
Williams, L. R., Jackson, E. L., Bishop-Hurley, G. J., & Swain, D. L. (2016). Drinking frequency effects on the performance of cattle: A systematic review. *Journal of Animal Physiology and Animal Nutrition*, *101*(6), 1076–1092. https://doi.org/10.1111/jpn.12640
Willms, W. D., Kenzie, O. R., McAllister, T. A., Colwell, D., Veira, D., Wilmshurst, J. F., Entz, T., & Olson, M. E. (2002). Effects of water Quality on cattle performance. *Journal of Range Management*, *55*(5), 452–460. https://doi.org/10.2307/4003222
Wilson, A. M., Wright, T. C., Cant, J. P., & Osborne, V. R. (2022). Development of a novel stall design for dairy cattle: Part I. The effect of an increased slope on lying behavior, rumination, cleanliness, and preference. *Animal*, *16*(1), 100427. https://doi.org/10.1016/j.animal.2021.100427
Wilson, S., Morrow-Tesch, J., Straus, D., Cooley, J., Wong, W., Mitlohner, F., & McGlone, J. (2002). Airborne microbial flora in a cattle feedlot. *Applied and Environmental Microbiology*, *68*(7), 3238–3242. https://doi.org/10.1128/AEM.68.7.3238-3242.2002
Wilson, S. C., Mitlöhner, F. M., Morrow-Tesch, J., Dailey, J. W., & McGlone, J. J. (2002). An assessment of several potential enrichment devices for feedlot cattle. *Applied Animal Behaviour Science*, *76*(4), 259–265. https://doi.org/10.1016/S0168-1591(02)00019-9
Winchester, C., & Morris, M. (1956). Water intake rates of cattle. *Journal of Animal Science*, *15*(3), 722–740. https://doi.org/10.2527/jas1956.153722x
Winckler, C., Tucker, C. B., & Weary, D. M. (2015). Effects of under- and overstocking freestalls on dairy cattle behaviour. *Applied Animal Behaviour Science*, *170*, 14–19. https://doi.org/10.1016/j.applanim.2015.06.003
Winder, C. B., LeBlanc, S. J., Haley, D. B., Lissemore, K. D., Godkin, M. A., & Duffield, T. F. (2017). Clinical trial of local anesthetic protocols for acute pain associated with caustic paste disbudding in dairy calves. *Journal of Dairy Science*, *100*(8), 6429–6441. https://doi.org/10.3168/jds.2017-12724
Winder, C. B., Miltenburg, C. L., Sargeant, J. M., LeBlanc, S. J., Haley, D. B., Lissemore, K. D., Godkin, M. A., & Duffield, T. F. (2018). Effects of local anesthetic or systemic analgesia on pain associated with cautery disbudding in calves: A systematic review and meta-analysis. *Journal of Dairy Science*, *101*(6), 5411–5427. https://doi.org/10.3168/jds.2017-14092
Windig, J. J., Hoving-Bolink, R. A., & Veerkamp, R. F. (2015). Breeding for polledness in Holstein cattle. *Livestock Science*, *179*, 96–101. https://doi.org/10.1016/j.livsci.2015.05.021
Winks, L., Holmes, A., & O'Rourke, P. (1977). Effect of dehorning and tipping on liveweight gain of mature Brahman crossbred steers. *Australian Journal of Experimental Agriculture*, *17*(84), 16–19. https://doi.org/10.1071/EA9770016
Winterling, C., & Graf, B. (1994). *Ursachen und Einflußfaktoren von Schwanzspitzenveränderungen bei Mastrindern* (pp. 128–139). Aktuelle Arbeiten zur artgemäßen Tierhaltung. KTBL. https://www.ktbl.de/fileadmin/user_upload/Allgemeines/Download/DVG-Tagung/P_11370_small.pdf
Wittum, T. E., & Perino, L. J. (1995). Passive immune status at postpartum hour 24 and long-term health and performance of calves. *American Journal of Veterinary Research*, *56*(9), 1149–1154.
WOAH (World Organisation for Animal Health). (2018). Terrestrial Animal Health Code. Chapter 7.6 Killing of animals for disease control purposes. Paris. 27th edition. https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/2018/en_chapitre_aw_killing.htm
WOAH (World Organisation for Animal Health). (online). Terrestrial Animal Health Code. Chapter 7.9. Animal Welfare and Beef Cattle Production Systems. https://www.woah.org/fileadmin/Home/eng/Internationa_Standard_Setting/docs/pdf/A_Update_2012_Chapter_7.9._Beef_cattle.pdf
Wohlt, J. E., Allyn, M. E., Zajac, P. K., & Katz, L. S. (1994). Cortisol increases in plasma of Holstein heifer calves, from handling and method of electrical Dehorning1. *Journal of Dairy Science*, *77*(12), 3725–3729. doi:10.3168/jds.S0022-0302(94)77317-3
Wood-Gush, D. G. M., & Vestergaard, K. (1989). Exploratory behavior and the welfare of intensively kept animals. *Journal of Agricultural Ethics*, *2*, 161–169. https://doi.org/10.1007/BF01826929
Wright, C. L. (2007). Management of Water Quality for beef cattle. *Veterinary Clinics of North America: Food Animal Practice*, *23*(1), 91–103. https://doi.org/10.1016/j.cvfa.2006.12.002

Yang, C.-H., Ko, H.-L., Salazar, L. C., Llonch, L., Manteca, X., Camerlink, I., & Llonch, P. (2018). Pre-weaning environmental enrichment increases piglets' object play behaviour on a large scale commercial pig farm. *Applied Animal Behaviour Science*, *202*, 7–12. https://doi.org/10.1016/j.applanim.2018.02.004

Youngers, M., Thomson, D., Schwandt, E., Simroth, J., Bartle, S., Siemens, M., & Reinhardt, C. (2017). Case study: Prevalence of horns and bruising in feedlot cattle at slaughter. The professional animal. *Scientist*, *33*(1), 135–139. https://doi.org/10.15232/pas.2016-01551

Zamir, L., Baum, M., Bardenstein, S., Blum, S. E., Moran-Gilad, J., Perry Markovich, M., King, R., Lapid, R., Hamad, F., Even-Tov, B., & Elnekave, E. (2022). The association between natural drinking water sources and the emergence of zoonotic leptospirosis among grazing beef cattle herds during a human outbreak. *One Health*, *14*, 100372. https://doi.org/10.1016/j.onehlt.2022.100372

Zanardi, E., De Luca, S., Alborali, G. L., Ianieri, A., Varrà, M. O., Romeo, C., & Ghidini, S. (2022). Relationship between bruises on carcasses of beef cattle and transport-related factors. *Animals*, *12*(15), 1997. https://doi.org/10.3390/ani12151997

Zebunke, M., Puppe, B., & Langbein, J. (2013). Effects of cognitive enrichment on behavioural and physiological reactions of pigs. *Physiology & Behavior*, *118*, 70–79. https://doi.org/10.1016/j.physbeh.2013.05.005

Zimmerman, A. S. (2003). Sulphate salts affect water consumption: Drinking behaviour and welfare of beef cattle. In *MSc in agricultural sciences University of British Columbia, Department of Animal Science* (p. 70). https://doi.org/10.14288/1.0091287

Zobel, G., Schwartzkopf-Genswein, K. S., Genswein, B. M. A., & von Keyserlingk, M. A. G. (2011). Impact of agonistic interactions on feeding behaviours when beef heifers are fed in a competitive feeding environment. *Livestock Science*, *137*(1–3), 1–9. https://doi.org/10.1016/j.livsci.2010.09.022

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APPENDIX A

Protocol

The methodology described herein (Tables A.1–A.6) adhere to the Methodological guidance for the development of animal welfare mandates in the context of the Farm to Fork Strategy (EFSA AHAW Panel, 2022a) and the Guidance on risk assessment of animal welfare (EFSA AHAW Panel, 2012a).

TABLE A.1 Problem formulation (APRIO-Agent-Pathway-Receptor-Intervention-Output) for the assessment questions related to ToR 2(a-e).

Number as appeared in the mandate	Mandate element	Agent	Pathway	Receptor	Intervention	Output	Lower or higher order sub- questions
ToR 2	ToR 2a. Welfare assessment of housing conditions for beef cattle	Flooring (quality) Space allowance Water access (Number of drinkers etc) Nutrition and feeding High environmental temperatures Lack of environmental enrichment Lack of outdoor access Mixing of cattle	The theoretical relationship between the agents listed and the welfare consequences	Suckler calves, suckler cows/heifers, fattening cattle and breeding bulls.	The measures to prevent or mitigate the welfare consequences	Assessing the effect of the intervention(s) on welfare consequence(s)	What are the current practices? What are the welfare consequences for each of the agents (i.e. practices/hazards)? What are the ABMs (definition, interpretation, feasibility, sensitivity and specificity) useful for detecting and monitoring each WC? What are the interventions, to prevent or mitigate the welfare consequences, and what is their effect on the WCs experienced by the animals? Some examples of hazards/practices are: hard flooring, slippery flooring, lack of space, restricted water access, high environmental temperatures, lack of brushes, lack of access to a loafing area, an frequent mixing.
	TOR 2b. Welfare of fattening cattle kept at grass	Cold, wind, rain and underfoot conditions Nutrition and feeding Water access					Some examples of hazards/practices are: space allowance; shelter for fattening cattle on pasture;
	TOR 2c. The risk to the welfare of suckler cows and calves associated with the weaning of suckler calves.	Weaning of suckler calves					Some examples of hazards/practices are: weaning method(s), timing of weaning relative to housing

TABLE A.1 (Continued)

Number as appeared in the mandate	Mandate element	Agent	Pathway	Receptor	Intervention	Output	Lower or higher order sub- questions
	TOR 2d. The risk to welfare associated with the mutilation of cattle.	Castration Disbudding Dehorning Tail docking					Age of calves, provision of pain relief and anaesthesia and method of castration; age of calves, provision of pain relief and anaesthesia, concurrent castration and methods for disbudding; age of animals, provision of pain relief and of anaesthesia and method of dehorning; age of animals, provision of pain relief and of anaesthesia for tail docking.
	TOR 2e. The risk to welfare associated with breeding strategies and genetics.	Hypermuscularity Dystocia and caesarean sections Polledness Maternal ability Temperament					

TABLE A.2 The approach for conducting the assessment relating to ToR 2 (a-e).

ToR 2 (a-e)	Sub question	Evidence needed	Data Collection	Assessment methods to be used
	What are (and briefly describe) the current practices?	A brief description of each practice.	For ToR 2a (housing conditions) the EFSA experts will identify and briefly describe the housing systems and husbandry practices, using expert knowledge and citing literature where appropriate. This will allow the EFSA experts to conduct the welfare risk assessment on this topic. A description of housing systems will also be delivered via ToR 1 (Article 31: a request for a technical report describing housing systems and husbandry practices). Sources of data include survey/interviews, review reports and other grey literature (including reputable websites) and peer-reviewed literature if necessary. When the draft technical report from ToR 1 is available to the EFSA experts, more detail or practices not previously identified, relating to current housing practices may be incorporated into the Scientific Opinion. For ToRs 2 a–e current practices will be based on expert knowledge supported by citations to literature where necessary. For areas where expert knowledge is insufficient a literature review (grey literature and if necessary, peer-reviewed literature) will be conducted.	Qualitative description of the most relevant practices

(Continues)

TABLE A.2 (Continued)

ToR 2 (a-e)	Sub question	Evidence needed	Data Collection	Assessment methods to be used
	What are the welfare consequences for each of agents (i.e. practices/ hazards)?	The mandate requests the identification of the highly relevant (i.e. most important) welfare consequences for each of the defined practices or hazards.	The identification of the highly relevant WCs is executed via expert opinion. The opinion of the EFSA experts is elicited through an exercise of individual classification of welfare consequences (considering severity, prevalence and duration) in terms of relevance followed by group discussion to identify the highly relevant WC by consensus.	A short list of the most highly relevant welfare consequences for each of the defined practices or hazards is produced.
	What are the ABMs useful for detecting and monitoring each WC?	Evidence that the ABMs allow detecting and monitoring of the highly relevant WCs previously identified. To include definition, interpretation, feasibility, sensitivity and specificity	Expert opinion and scientific literature (including recent EFSA opinions)	The ABMs for the identification and monitoring of the highly relevant welfare consequences (previously identified) are described.
	What are the interventions, to prevent or mitigate the welfare consequences, and what is their effect on the WCs experienced by the animals (i.e. minimum space allowance)?	A demonstration or description of the effect of the interventions on the most relevant WCs (previously selected) as monitored by the ABMs (previously identified).	A literature review connecting the hazard/agents to the WC via the ABM and if needed expert opinion	The effect of the interventions will be described using narrative text, figures and tables as appropriate.

TABLE A.3 Problem formulation (APRIO-Agent-Pathway-Receptor-Intervention-Output) for the assessment questions related to ToR 2(f).

Number as appeared in the mandate	Mandate element	Agent	Pathway	Receptor	Intervention	Output	Lower or higher order sub-questions
ToR 2	**ToR 2f**. Decision making criteria for the euthanasia of end of career dairy and suckler cows that are kept for beef production.	Further farming of a cow in a poor welfare condition	The relationship between the agent listed and the welfare consequences	Cull dairy and beef cows	Killing of the cull cow	A set of criteria indicating the level of welfare impairment facilitating the decisions: (A) should the cull cow be killed or fattened (B) is the cull cow fit to be transported or should it be killed on farm.	What are the animal welfare criteria indicating whether a cull cow should be killed or fattened? What are the animal welfare criteria indicating whether a cull cow should be transported or killed on farm?

TABLE A.4 The approach for conducting the assessment relating to ToR 2(f).

ToR 2 (f)	Sub question	Evidence needed	Data collection	Assessment methods to be used
	What are the animal welfare criteria indicating whether a cull cow should be killed or fattened?	Evidence of welfare state that renders a cull cow unfit for further fattening (i.e. cause unnecessary suffering)	Literature review and expert opinion	Identify the relevant ABMs and assess the severity level for each.
	What are the animal welfare criteria indicating whether a cull cow should be transported or killed on farm?	Evidence of welfare state that renders a cull cow unfit for transport	Literature review and expert opinion	Identify the relevant ABMs and assess the severity level for each.

TABLE A.5 Problem formulation (APRIO-Agent-Pathway-Receptor-Intervention-Output) for the assessment questions related to TOR 3.

Number as appeared in the mandate	Mandate element	Agent	Pathway	Receptor	Intervention	Output	Lower or higher order sub-questions
ToR 3	The assessment of animal-based measures collected in slaughterhouses to monitor the level of animal welfare on farm for fattening cattle.	N/A	The theoretical relationship between the ABMs and the welfare consequences	Fattening cattle	N/A	A list of ABMs, to be collected at an abattoir/slaughterhouse, indicative of animal welfare on farm for fattening cattle.	What are the ABMs, to be collected at an abattoir/slaughterhouse, indicative of the level of animal welfare on farm for fattening cattle.

TABLE A.6 The approach for conducting the assessment relating to ToR 3.

TOR 3	Sub question	Evidence needed	Data Collection	Assessment methods to be used
	What are the ABMs, to be collected at an abattoir/slaughterhouse, indicative of the level of animal welfare on farm for fattening cattle.	Evidence of the relationship between ABMs collected at a slaughterhouse with the level of animal welfare on farm for fattening cattle.	A proposed list of ABMs (*ante-mortem* and *post- mortem*) and their descriptions have already been identified by EFSA experts based on the existing literature (Welfare Quality, 2023a; EFSA AHAW Panel, 2012). To gather information on the use of the ABMs in the proposed list, the ABMs were discussed by the EFSA AHAW network at the annual network meeting (EFSA, 2023).	From the ABMs already identified (see data collection) a semi-quantitative consensus exercise and literature review will be carried out to identify those ABMs that could best represent the level of animal welfare on farm for fattening cattle. The exercise consists of two steps: (i) Screening of ABMs; (ii) Selection of ABMs. Screening is carried out per each ABM considering relevance to animal welfare, relationship with on-farm welfare, existing data or literature, feasibility for large scale collection. Selection will be based on the welfare consequences associated the ABM, if the ABM is already used at slaughter, priority given from EFSA network and technology readiness.

APPENDIX B

Uncertainty assessment

B.1 | SOURCES OF UNCERTAINTY

The sources of uncertainty relevant to this Scientific Opinion generally relate to study external and internal validity. External validity is limited because of high variability between production systems and housing practices in different regions of the European Union. This means that the results from one particular study may not be generalisable to other farms, areas or countries. Internal validity may be limited because some studies are small, cross-sectional, may not have fully controlled for potential confounders and the measures used are rarely standardised. In this case, there is a low degree of certainty that causal relationships proposed are true effects. Additional research studies using robust study designs to establish causal relationships would be needed to provide unequivocal evidence of the impact of housing practices on beef welfare (see Table B.1 below).

TABLE B.1 Sources of uncertainty and their potential impact on the welfare assessment outcomes.

Topic	Sources of uncertainty	Impact on the assessment
Identification and description of the common housing practices	Large regional differences Variations between production systems (e.g. breeds, slaughter weight) Large variability within a system	Possible limited generalisability of the description of housing practices. Some of this uncertainty was reduced due to information on husbandry practices in different EU Member states provided by stakeholders through the EFSA Public call for evidence (December 2023–January 2024).
Assessment of welfare consequences (prevalence, severity, duration), ABMs and preventive measures	Regional differences (e.g. heat stress is more prevalent in southern regions) and diverse husbandry practices across regions Very limited data on prevalence of welfare consequences Scarcity of published evidence, which required extrapolation from other cattle categories (e.g. dairy or calves) or species (e.g. pigs) in some cases The selection of the highly relevant welfare consequences was done through group discussion and could vary slightly if the composition of the working group was diffcerent. Literature search characteristics (e.g. search performed mainly in the English language; not all synonyms may have been used in search terms; only one main database used (Web of Science – core collection) although the search was complemented with manual searches of the literature; grey literature not extensively searched)	Due to the sources of uncertainty listed, the number of relevant welfare consequences, ABMs may have been underestimated or overestimated.

B.2 | UNCERTAINTY ASSESSMENT OF CONCLUSIONS

As explained in the methodology section, the uncertainty relating to key conclusions was assessed through expert opinion. Working group experts were asked to provide their individual judgement on the certainty for each key conclusion according to three predefined certainty 'ranges' (Table 2, EFSA, 2019). A 'key' conclusion was defined as any conclusion containing elements that could potentially inform legislation on the welfare of beef cattle. For instance, a listing of WCs associated with lack of water access was not considered a key conclusion, but a conclusion on water availability and amounts to prevent prolonged thirst was. Group discussion took place during which experts had the opportunity to explain the rationale behind their judgement, and a consensus on the category better reflecting the overall certainty was reached (see Table B.2 below).

TABLE B.2 Uncertainty assessment of conclusions on housing.

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
Water access				
3	Nipple drinkers typically have low flow rates and do not allow natural drinking behaviour.	How certain are you that the proportion of beef cattle able to express natural drinking behaviour is lower when water is provided through nipple drinkers compared to water provided in troughs or bowls?	> 90%	
6	Competition for water increases leading to group stress particularly for subordinate cattle, when availability is restricted due to limited water flow, drinker size or number of drinkers. This can reduce water intake and increase the risk of injuries.	How certain are you that the proportion of beef cattle experiencing reduced water intake and injuries due to competition for accessing water is increased the more water availability is limited (water flow, drinker size or number of drinkers)?	> 90%	
7	For dairy cows, a minimal drinking places: animals ratio of one drinker per 10 cows or 6 cm of water trough space per cow is required to meet both their behavioural and physiological needs throughout summer and winter. Although specific data for beef cattle are lacking, this ratio is expected to suffice, given that dairy cows at the peak of lactation have higher water demands than beef cattle.	How certain are you that the proportion of beef cattle meeting their behavioural and physiological needs throughout summer and winter is greater when they are provided with a minimal drinking places: animal ratio of one drinker per 10 animals or 6 cm of water trough space per animal than when provided with less water access?	> 66%	Insufficient scientific evidence specifically on beef cattle. The information available was extrapolated from dairy cows.
8	Providing drinkers away from the lying area improves accessibility of drinkers.	How certain are you that the proportion of beef cattle having accessibility of drinkers is greater when providing drinkers outside the lying area than when they are not?	> 66%	Potential conflicts between accessibility of drinkers and feeding area. Lack of studies on effects on water accessibility depending on specific position of drinkers.
9	Reduced growth performance is associated with the ingestion of water contaminated with faeces containing elevated levels of pathogenic bacteria.	How certain are you that the proportion of beef cattle experiencing reduced growth is lower if the animals ingest non-contaminated water than if they ingest water contaminated with high levels of pathogenic bacteria?	> 90%	
Flooring – types of flooring, bedding and resting areas				
5	CSFs cause animals to change their normal lying down and standing up movements. This results in more time standing on CSFs than in RMs or bedded floors.	How certain are you that the proportion of beef cattle experiencing a reduction in time standing (as a result of change in their normal lying down and standing up movements) is greater if animals are housed on bedded floors than if they are housed on CSFs?	> 90%	
6	The risk of lameness is higher on CSFs than on bedded floors due to the hard slippery floors and gaps between the slats.	How certain are you that the proportion of beef cattle exposed to the risk of experiencing lameness is lower if animals are housed on bedded floors than if they are housed on CSFs due to hard and slippery floors and the gaps between the slats?	> 90%	
7	Resting problems are more frequent in CSFs and RMs compared to bedded floors with clean bedding.	How certain are you that the proportion of beef cattle experiencing resting problems is lower if animals are housed on bedded floors with clean bedding than when they are housed on CSFs and RMs?	> 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
8	In addition to allowing comfortable resting, clean straw bedding provides an opportunity to ingest fibre, chew and ruminate.	How certain are you that clean straw bedding provides an additional opportunity to ingest fibre, chew and ruminate compared to flooring systems with no or soiled bedding?	> 90%	
9	The risk of slipping and injury is higher on CSFs compared to RMs and bedded floors.	How certain are you that the proportion of beef cattle experiencing slipping and injuries is lower if they are housed on rubber mats and bedded floors than if they are housed on CSFs?	> 90%	
10	Restriction of movement due to slippery floors is mitigated by overlaying CSFs with rubber mats. The positive effect of RMs is more pronounced in heavier than in lighter cattle.	(1) How certain are you that the proportion of beef cattle experiencing restriction of movements is lower if animals are housed on CSFs overlayed with rubber mats than if they are housed on bare CSFs? (2) How certain are you that the positive effect of rubber mats is more pronounced in heavier than in lighter cattle?	1: > 90% 2: > 90%	
11	RM improve the resting of beef cattle compared to CSFs. The frequency of lying down interruptions or deviations from the normal getting up and lying down movements is lower on RMs compared to CSFs.	How certain are you that the frequency of lying down interruptions or deviations from the normal getting up and lying down movements is lower if beef cattle are housed on rubber coated floors compared to CSFs?	> 90%	
12	While rubber mats improve traction they do not provide as comfortable a lying area as straw bedding and cannot be considered equivalent to straw bedding.	How certain are you that rubber mats improve traction but provide less lying comfort than straw bedding, and therefore cannot be considered equivalent to it?	> 90%	
13	RM with low abrasiveness can lead to an increase in the occurrence of overgrown claws compared to CSFs.	How certain are you that the proportion of beef cattle experiencing overgrown claws at the toe level is lower if animals are housed on concrete flooring systems than if they are housed on rubber mats?	> 90%	
14	Cleanliness of flooring is an important factor in claw health in terms of infectious diseases and slipperiness of flooring surfaces. If concrete slatted floors are covered with rubber mats, the drainage area/void space may be reduced, leading to increased soiling.	(1) How certain are you that the proportion of beef cattle experiencing infectious claw disorders and slipping events is higher if animals are housed on soiled floors than if they are housed on clean flooring surfaces? (2) How certain are you that the proportion of beef cattle experiencing infectious claw disorders and slipping events is lower if animals are housed on adequately cleaned slatted floors than when not regularly cleaned, particularly when covered with rubber mats?	1: > 90% 2: > 90%	
15	The prevalence of skin lesions on the limbs and the tail is greater in cattle housed on CSFs compared to RMs and bedded floors.	How certain are you that the proportion of beef cattle experiencing skin lesions on the limbs and the tail is reduced if animals are housed on RMs and bedded floors than if they are housed on CSFs?	> 90%	

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
16	Due to the higher flooring traction, more sexual and comfort behaviour is shown in animals housed on RMs and bedded floors compared to CSFs.	How certain are you that animals housed on RMs and bedded floors experience more sexual and comfort behaviours than those housed on CSFs, due to higher flooring traction?	> 90%	
Nutrition and feeding strategies				
4	Feeding less grain (starch) and more structured fibre (peNDF) is the main mitigation strategy against SARA.	How certain are you that the proportion of beef cattle experiencing SARA is lower if the animals are fed with more structured fibre (peNDF) and less grain (starch)?	> 90%	
5	Increasing proportions of readily fermentable starch in the diet increase the risk of hoof problems as secondary consequences of subacute or acute ruminal and hind gut acidosis conditions.	How certain are you that the proportion of beef cattle experiencing hoof problems as secondary consequences of subacute or acute ruminal and hind gut acidosis conditions is higher with increasing proportions of readily fermentable starch in the diet?	> 90%	
7	Compared to yeast and phytogenic compounds, mineral buffers are more effective against rumen acidosis resulting from the ingestion of too much concentrate feeding. These compounds have only a modulatory effect on the fermentation process of the ruminal microbiome. No feed additive can compensate for an inadequate feeding management.	(1) How certain are you that a lower proportion of beef cattle will experience SARA when mineral buffers are provided to them compared to when other feed additives such as yeast and phytogenic compounds are provided? (2) How certain are you that yeast and phytogenic compounds have only a modulatory effect on the fermentation process of the ruminal microbiome? (3) How certain are you that independently from the type of feed additives such measures cannot compensate for an inadequate feeding management?	1: > 90% 2: > 50% 3: > 90%	(2) There is only limited evidence on the modulatory effect of these compounds
8	As beef cattle are typically fed forage-based diets before transfer to the fattening farms, a gradual increase from forage-based to concentrate-based diets during the early fattening period at fattening farms is crucial to prevent gastro-enteric disorders.	How certain are you that the proportion of beef cattle in early finishing period experiencing gastro-enteric disorders is lower when they are fed with a gradual increase from forage-based to concentrate-based diets than when they experience an abrupt change on diet?	> 90%	
9	*Ad libitum* feeding with a constant availability of feed in the manger mitigates group stress and reduces the risk of prolonged hunger.	How certain are you that the proportion of beef cattle experiencing group stress and prolonged hunger will be reduced when food is given *ad libitum?*	> 90%	
10	Competition and aggressive interactions in the feeding areas are lowered by the provision of a space at the manger sufficient to allow the simultaneous presence of all group mates.	How certain are you that beef cattle will experience less competition and aggressive interactions when provided with a space at the manger that is sufficient to allow simultaneous presence of all group mates than when being overstocked at the manger?	> 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
11	High-concentrate diets reduce chewing and rumination time compared to predominantly forage-based diets, and lead to stereotypic oral behaviours such as non-nutritive oral manipulation, tongue flicks and tongue rolling.	How certain are you that the proportion of beef cattle experiencing lower stereotypical oral behaviours (e.g. non-nutritive oral manipulation, tongue flicks or rolling) is greater when they are fed with predominantly forage-based diets than when they are fed with high-grain diets?	> 90%	
12	The ingestion of mouldy feeds increases the risk of impaired locomotion that results from a mycotoxin-induced immune suppression.	How certain are you that the proportion of beef cattle experiencing impaired locomotion is lower if animals ingest non-mouldy feeds than if they ingest mouldy feed?	> 90%	
High environmental temperatures				
4	Heat stress is likely to start when temperatures exceed the upper boundary of the thermal comfort zone (TCZ) but there are no precise estimates of such threshold for cattle. The risk of heat stress increases when temperatures exceed the upper critical temperature (UCT) threshold (~24–26°C).	How certain are you that the proportion of beef cattle experiencing heat stress increases when temperatures exceed the upper critical temperature threshold (~24–26°C) compared to when temperatures remain lower?	> 66%	Other factors such as solar radiation, wind speed and access to shade affect the risk of heat stress
6	Water demand under high environmental temperatures increases up to double of baseline needs. Increasing the fat content in the diet is a strategy to reduce the heat load but is insufficient under high environmental temperatures.	(1) How certain are you that the proportion of beef cattle experiencing a reduction in heat load is higher when they are fed with high-fat content diets compared to diets with lower fat content? (2) How certain are you that high-fat content diets used as the only strategy to mitigate heat is insufficient to reduce the heat load in beef cattle under high environmental temperature conditions?	1: > 50% 2: > 90%	(1) Limited scientific evidence (one paper on beef cattle with small sample size and not significant results, some evidence on dairy cattle).
7	Sprinklers are an effective cooling system as long as air humidity is not too high, but optimum placement and usage frequency has not yet been determined. Misters are an effective cooling system to be used in beef cattle farming, as long as air humidity is not too high and when the water droplets size is small enough to evaporate and the air movement is not too high. The use of sprinklers and misters in the bedded lying area carries the risks to increase the moisture of the bedding material leading to negative welfare consequences.	(1) How certain are you that under hot environmental conditions the proportion of beef cattle experiencing effective cooling is higher when sprinklers are used and air humidity is low, compared to when air humidity is high? (2) How certain are you that under hot environmental conditions the proportion of beef cattle experiencing effective cooling is higher when misters are used in conditions of low air humidity, small droplet size and moderate air movement, compared to when these conditions are not met? (3) How certain are you that the use of sprinklers or misters in the bedded lying area increases the proportion of cattle exposed to higher bedding moisture levels and subsequent negative welfare consequences, compared to when these systems are used outside the bedded area?	1: > 90% 2: > 66% 3: > 90%	(2) Insufficient scientific evidence in beef cattle, proven to be effective in other species.

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
8	The use of fans under hot environmental conditions reduces heat stress. Additionally, it keeps the bedding material drier promoting better cattle comfort. Further research is needed on type of fan design and fan placement that minimise air recirculation and maximise ventilation in beef cattle farming.	(1) How certain are you that the proportion of beef cattle experiencing reduced heat stress is higher when fans are used under hot environmental conditions compared to when fans are not used? (2) How certain are you that the use of fans contributes to drier bedding conditions and improved cattle comfort compared to environments where fans are not used?	1: > 90% 2: > 90%	
Lack of environmental enrichment				
3	Environmental enrichment in general reduces sensory understimulation and leads to increased activity.	(1) How certain are you that the proportion of beef cattle experiencing sensory understimulation is lower if their environment is provided with enrichment materials compared to situations where no enrichment is provided? (2) How certain are you that the proportion of beef cattle experiencing increased activity is greater if their environment is provided with enrichment materials compared to situations where no enrichment is provided?	1: > 90% 2: > 90%	
4	Abnormal behaviour like tongue rolling and excessive oral manipulation of inanimate objects occurs more frequently in intensive beef systems with high-concentrate diets than in pasture systems. Enrichment of intensive systems with long fibrous organic manipulable material that can be ingested, such as roughage, leads to a reduction of these behaviours. The provision of brushes as enrichment also contributes to a reduction of abnormal oral behaviour.	(1) How certain are you that the proportion of beef cattle experiencing tongue rolling and excessive oral manipulation of inanimate objects is lower in animals kept in pasture systems than in those kept in intensive systems and fed with high-concentrate diets? (2) How certain are you that the proportion of beef cattle experiencing abnormal oral behaviour in intensive systems is lower if long fibrous organic manipulable material that can be ingested (e.g. roughage) are provided as enrichment compared to situations where no enrichment is provided? (3) How certain are you that the proportion of beef cattle experiencing abnormal oral behaviour in intensive systems is lower if brushes are provided as enrichment compared to situations where no enrichment is provided?	1: > 90% 2: > 90% 3: > 66%	(3) Evidence from dairy studies on brush use available but limited beef studies on brush use exist
6	Free choice between different components of the diet also enriches the environment of beef cattle, allowing more behavioural freedom and better adaptation to individual physiological needs. However, more research is needed on the welfare effects of free-choice feeding in intensive systems, with particular focus on the risks of metabolic disorders.	How certain are you that the proportion of beef cattle experiencing more behavioural freedom and better adaptation to individual physiological need is greater if animals are provided with the opportunity to choose between different components of the diets compared to situations where diet choice is limited or not provided?	> 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
7	Exploration for the purpose of information gathering allows the experience of positive emotions and is stimulated also by non-organic enrichment material, although these effects are linked to the degree of novelty, which call for frequently changing stimuli.	How certain are you that the proportion of beef cattle experiencing positive emotions through exploration is higher when cattle are provided with non-organic enrichment materials, compared to when no enrichment is provided?	> 90%	
8	Beef cattle have a high motivation to use brushes or rubbing objects for comfort behaviour, which induces positive emotions and alleviates stress and soiling.	How certain are you that the proportion of beef cattle experiencing positive emotions and reduced stress and soiling is higher when provided with brushes or rubbing objects, compared to situations where such enrichment materials are not available?	> 90%	
9	The provision of brushes can further help to reduce agonistic interaction and thus group stress, although more research is needed to confirm this effect. Insufficient knowledge is also available on the possible effects of the provision of brushes on mounting behaviour.	How certain are you that the proportion of beef cattle experiencing group stress through higher agonistic interactions is reduced if animals are provided with brushes than if they are not?	> 66%	Evidence from dairy studies on brush use available but limited research on beef
10	The simultaneous provision of different enrichment objects that target different behavioural motivations has a greater overall effect on activity levels than single enrichments, but to date this has not been addressed in adult cattle research.	How certain are you that the proportion of beef cattle experiencing higher overall activity levels is greater when different enrichment objects are provided simultaneously compared to when any single enrichments are offered?	> 66%	Research on simultaneous provision of enrichment limited to calves
11	Limited access to enrichment objects or rapidly diminishing material increases social competition. Research is necessary on a minimum number of enrichment devices in relation to the number of animals.	How certain are you that the proportion of beef cattle experiencing social competition is greater when there is limited access to enrichment objects or rapidly diminishing material, compared to situations where sufficient numbers of enrichment devices are provided per animal?	> 90%	
12	Very limited research has yet explicitly addressed the effects of environmental enrichment on play behaviour in beef cattle, but the provision of novel objects promotes play.	How certain are you that the proportion of beef cattle engaging in play behaviour is higher when animals are provided with novel objects, compared to situations where they are not?	> 66%	Evidence on play behaviour in adult animals from dairy studies is available, but limited beef studies
Lack of outdoor access				
3	Outdoor conditions provide more environmental complexity and changing sensory stimulation (e.g. sunlight, wind, rain or olfactory stimuli) than indoor conditions. While very little research is available on the importance of such stimulation to beef cattle, in general, free choice between different environmental conditions lowers the risk of sensory understimulation.	How certain are you that the proportion of beef cattle experiencing the sensory understimulation is lower when animals are provided with free choice between different environmental conditions, compared to situations where such freedom of choice is restricted or not provided??	> 90%	
4	Outdoor access that includes pasture promotes exploration and foraging behaviour.	How certain are you that the proportion of beef cattle engaging in exploration and foraging behaviours is higher when animals are provided with outdoor access including pasture, compared to when they are not?	> 90%	

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
5	Freely accessible outdoor loafing areas with well-managed underfoot conditions provide enlarged space and opportunity for locomotion and play.	How certain are you that the proportion of beef cattle engaging more in locomotion-related behaviours is higher when animals are provided with additional outdoor areas compared to all indoor systems?	> 90%	
6	An easily accessible outdoor loafing area allows lower-ranking individuals in particular to withdraw and avoid unwanted interactions with dominant individuals, thereby helping to reduce group stress.	How certain are you that the proportion of beef cattle experiencing group stress is lower when animals are provided with an easily accessible additional outside area adjacent to the barn compared to situations where such an area is not available?	> 90%	
7	A shaded outdoor area next to the barn provides cattle the opportunity to move outside if inside conditions are too hot or humid, mitigating heat stress.	How certain are you that the proportion of beef cattle experiencing heat stress is lower when animals are provided with a shaded area outside next to the barn when it is too hot or humid inside compared to situations where such a loafing area is not provided?	> 66%	No studies specifically investigating this but highly plausible hypothesis
Mixing of cattle				
6	Mixing animals that have met before leads to fewer agonistic interactions.	How certain are you that the proportion of beef cattle experiencing agonistic interactions after mixing is lower when mixing is performed among animals that have previously met compared to animals that have not met before?	> 66%	Evidence from heifers only
7	Animals with previous experiences of mixing are less disturbed by regrouping.	How certain are you that the proportion of beef cattle experiencing stress at regrouping is lower when the animals have had previous experience of mixing compared to animals that never had experience of mixing?	> 66%	Evidence from heifers only
8	Mixing animals at a young age results in fewer agonistic interactions than in more mature subjects.	How certain are you that the proportion of beef cattle experiencing agonistic interactions after mixing is lower when animals are mixed at a young age compared to when more mature subjects are mixed?	> 90%	
9	Agonistic and sexual interactions immediately following mixing are less frequent between bulls of heterogeneous body weight than between bulls of homogeneous weight. There are currently no grounds to suggest that homogeneous weights at the beginning of fattening are beneficial to minimise agonistic and sexual behaviour.	How certain are you that the proportion of beef cattle experiencing agonistic and sexual interactions is lower between bulls of heterogeneous body weight compared to bulls of homogeneous body weight?	> 66%	Conclusion based on a study only (Mounier et al., 2005)
10	Higher space allowance, increased manger space, *ad libitum* feeding and easy access to feeders and drinkers reduce social stress in new groups of cattle after mixing.	How certain are you that the proportion of beef cattle experiencing social stress in groups after mixing is lower when animals are provided with more space and lower competition for food compared to situations where space is limited and food competition is higher?	> 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
12	Mixing animals from different farms contributes to higher respiratory disease prevalence due to a mix of different microbiomes and the social stress.	How certain are you that the proportion of beef cattle experiencing respiratory disease is lower when mixing is performed between animals from the same farm, compared to when animals from different farms are mixed?	> 90%	
13	Mixing is frequently associated with aggressive interactions, which increase the risk of integument damage and bone lesions. The risk of injuries is higher in horned cattle, even though physical interactions appear to be less frequent than between hornless cattle.	How certain are you that the proportion of beef cattle experiencing integument damage or bone lesions after mixing is higher in horned cows compared to hornless cows?	> 90%	
Minimum space allowance				
3	There is little research on the effects of space allowance > 6 m^2/animal on the welfare of housed cattle, but providing larger space allowances generally increases lying time and allows for more inter-individual spacing, as well as more movement opportunities.	How certain are you that the proportion of beef cattle showing increased lying time, higher inter-individual spacing and more movements increases with increasing space allowance?	> 90%	
4	An increase in space allowance up to 4 m^2/animal is not associated with a reduction in aggressive behaviour. There is not sufficient evidence on the exact space allowance value above which a reduction in aggressive behaviour is observed.	How certain are you that an increase in space allowance up to 4 m^2/animal is not associated with a reduction in aggressive behaviour?	> 66%	Some of the studies not finding a decrease in agonistic behaviour up to 42/m have a low sample size.
Welfare of cattle kept on pasture				
3	The likelihood of experiencing cold stress depends on external factors such as temperature, rain and wind, as well as on fat and coat coverage, size and acclimatisation.	How certain are you that the proportion of cattle experiencing cold stress varies depending on external factors such as temperature, rain and wind, as well as fat and coat coverage, size and acclimatisation?	> 90%	
4	Outwintered cattle exposed to low temperatures, especially in combination with rain or wind, increasingly use shelter and eat more. If shelter is insufficient and lying area is not dry, cattle increase standing time, reduce lying time and reduce eating when this behaviour increases the risk of cold stress.	How certain are you that outwintered cattle increase standing time, reduce lying time and reduce eating when shelter is insufficient and lying area is not dry?	> 90%	
5	Cattle prefer natural over artificial shelter when available.	How certain are you that cattle prefer natural over artificial shelter?	> 66%	It depends on the type and effectiveness of shelter. Limited scientific evidence.
6	Cold stress is likely to start when temperatures fall below the lower boundary of the thermal comfort zone (TCZ) but there are no precise estimates of such threshold for cattle. The risk of cold stress increases when temperatures fall below the low critical temperature (LCT) threshold. For adult cattle in inclement weather, the LCT is approximately 0°C and in still, dry conditions between −10° and −21°.	How certain are you that the LCT for adult cattle in inclement weather is approximately 0°C and in still, dry conditions is between −10° and −21°?	> 66%	It may depend on other factors such as acclimatisation and breed effects (e.g. coat length).

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
7	Lying is a important behaviour for resting and rumination and is reduced when the ground is wet and/or muddy. There is limited information about the impact of muddy pastures on lameness in beef cattle.	(1) How certain are you that the duration spent lying shown by beef cattle is reduced when the ground is wet or muddy, compared to when it is not? (2) How certain are you that muddy pasture contributes to lameness in beef cattle?	1: > 90% 2: > 90%	
8	Poor weather and ground conditions present a challenge in ensuring sufficient monitoring of outwintered animals, increasing their risk of welfare consequences when problems arise.	How certain are you that the increased difficulty in monitoring outwintered cattle due to poor weather leads to a higher risk of suffering when problem arise?	> 90%	
10	Hazards related to grazing are nutrient deficiencies (especially trace minerals), parasitic and metabolic diseases, and intoxications.	How certain are you that grazing is associated with hazards such as nutrient deficiencies (especially trace minerals) as well as parasitic, metabolic and intoxications?	> 90%	
12	Cattle on pasture, especially in extensive settings, are at higher risk of handling stress when not habituated to such human interactions.	How certain are you that cattle on pasture in extensive systems are at higher risk to experience handling stress when they are not habituated to human interactions?	> 90%	
14	Cattle in barren grazing paddocks benefit from trees or brushes and other natural or artificial grooming opportunities.	How certain are you that cattle in barren grazing paddocks benefit from natural or artificial grooming opportunities and other enrichments?	> 90%	
15	During times of high heat load, cattle at pasture are at risk of heat stress especially when no shade is available.	How certain are you that cattle at pasture experience heat stress especially when no shade is available during times of high heat load?	> 90%	
Welfare of cattle in outdoor feedlots				
2	The duration of lying is reduced and cattle movement impeded when pen surface is muddy.	How certain are you that lying and locomotion behaviour are reduced when the pen surface is muddy compared to when it is dry?	> 90%	
3	Muddy conditions increase the risk of lameness mainly due to infections.	How certain are you that muddy feedlot conditions increase the risk of infectious lameness in cattle compared to dry conditions?	> 90%	
4	The risk of dust-related respiratory disorders caused is increased when the soil moisture is low (less than ~25%).	How certain are you that the proportion of beef cattle developing dust-related respiratory disorders is higher when soil moisture is low (e.g. less than ~25%)?	> 66%	It is supported by only a single study (Sweeten, 1982) and the presence of additional influencing factors cannot be excluded.
5	Access to palatable, clean and safe water is necessary at all times to prevent thirst and group stress, and to mitigate heat stress, especially during high environmental temperatures.	How certain are you that the risk of thirst, group stress and heat stress in beef cattle in outdoor feedlots is increase under high environmental temperatures?	> 90%	
6	Under high environmental temperatures, the lack of sufficiently large shaded area for use by all animals increases the risk of heat stress.	How certain are you that the proportion of feedlot cattle experiencing heat stress is lower when they are provided with a sufficiently large shaded area for use by all animals?	> 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
Weaning				
2	The WCs selected as highly relevant for suckler cows and calves as a result of weaning are separation stress, handling stress and group stress if weaning and separation are combined with regrouping, as well as inability to express maternal behaviour in cows and inability to perform sucking behaviour in calves. These are expressed by increased vocalisation, exploration and pacing (locomotory behaviour) along with reduced feeding and lying in weaned calves. Additionally, very early weaned calves (e.g. at 75 days of age) exhibit increased cross-sucking.	How certain are you that very early weaned calves, such as those weaned at 75 days of age, exhibit increased cross-sucking behaviour?	> 66%	Only one study investigating this is available.
3	The later the calves are weaned the better prepared they are physiologically and behaviourally to cope with the dietary and social changes. In addition, gastro-intestinal function is enhanced by promoting early intake of solid feed intake and familiarisation with post-weaning diets.	How certain are you that encouraging early solid feed intake and familiarisation with post-weaning feeds enhances gastro-intestinal function of calves?	> 90%	
4	A decoupling of weaning and separation by either fenceline weaning or nose flaps allows visual, auditive and physical cow-calf contact (more restricted in fenceline weaning) while preventing sucking behaviour before total separation occurs. These two-stage weaning methods contribute to a reduction of separation stress, compared to abrupt weaning.	How certain are you that the two-stage weaning methods reduce separation stress compared to abrupt weaning?	> 66%	Inconsistent results across studies, although the majority of studies showed positive effects.
5	Nose flaps, as they are currently used, carry an injury risk to the nasal septum.	How certain are you that the current use of nose flaps carries a risk of causing injuries to the nasal septum in calves?	> 90%	
6	Creep weaning methods are associated with less handling and separation stress compared to abrupt weaning.	How certain are you that creep weaning methods are associated with less handling and separation stress compared to abrupt weaning?	> 90%	
7	The presence of familiar peer calves provides social support or social buffering and reduces separation stress during weaning.	How certain are you that the presence of familiar peer calves reduces separation stress during weaning in calves by providing social support or buffering?	> 66%	The social buffering effect is a well-accepted principle, but there are no specific studies in the context of weaning of calves.
8	Additional husbandry changes (e.g. relocation from pasture to housing, dietary changes, regrouping, transportation and marketing) often occur around weaning and increase negative welfare impacts on the calves.	How certain are you that changes in husbandry conditions around weaning time increase the negative welfare impacts on calves?	> 90%	
9	When calves are weaned from the dams both are handled. Strategies to reduce handling stress during weaning are little investigated. However, a decrease in handling stress is achieved by increased contact with handlers before weaning, gentle handling and maintaining contact with familiar conspecifics during the weaning process to allow social buffering.	(1) How certain are you that increasing contact with handlers before weaning reduces handling stress? (2) How certain are you that using gentle handling during weaning reduces handling stress? (3) How certain are you that maintaining contact with familiar conspecifics during weaning reduces handling stress by allowing social buffering?	1: > 90% 2: > 90% 3: > 66%	(3) The social buffering effect is a well-accepted principle, but there are no specific studies in the context of handling of weaned calves.

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
Castration				
5	It is not completely clear whether there are differences in the intensity of pain perception around the procedure depending on age at castration but, due to the smaller size of the wound, healing is quicker in younger animals.	How certain are you that wound healing is quicker in younger animals due to the smaller size of the wound, even though differences in pain perception intensity around the time of castration depending on age remain unclear?	> 90%	
6	Castration carried out between 1 and 8 weeks of age is associated with a faster healing of the wound compared to older age. Very limited research is available on the welfare consequences of castration in neonatal (<1 week) calves, so conclusions cannot be drawn for this age group.	(1) How certain are you that castration performed between 1 and 8 weeks of age results in faster wound healing compared to castration at older calves? (2) How certain are you that the current lack of research on neonatal calves (<1 week) limits the ability to draw conclusions about the welfare consequences of castration at that age?	1: > 90% 2: > 90%	
7	When very young animals experience pain, there is a risk for central sensitisation.	How certain are you that experiencing pain at a very young age increases the risk of central sensitisation in calves?	> 50%	Only evidence from disbudding.
11	Depending on the method of castration, pain is shown at different times. Surgical and Burdizzo castrations are characterised by a high frequency of behaviours indicative of pain around the procedure, followed by a lower frequency of such pain behaviours during healing over 4 to 9 weeks. Rubber ring and band castration are characterised by pain around the procedure, followed by prolonged pain over 6 to 9 weeks.	(1) How certain are you that surgical and Burdizzo castrations are characterised by high frequency behaviours indicative of pain around the time of the procedure, followed by lower frequency of such behaviours during healing over 4 to 9 weeks? (2) How certain are you that rubber ring and band castration are characterised by pain around the procedure, followed by prolonged pain over 6 to 9 weeks?	1: > 90% 2: > 90%	
12	The use of pharmacological pain mitigation (NSAIDs and anaesthesia) reduces the frequency of behavioural responses indicative of pain around castration. Despite pain mitigation, these behaviours can be observed more frequently in calves older than 6 months of age than in younger calves.	(1) How certain are you that the frequency of behavioural responses indicative of pain is lower when pain mitigation (NSAIDs and anaesthesia) is used compared to when they are not used? (2) How certain are you that the frequency of behavioural responses indicative of pain is higher when the castration procedure is performed on calves younger than 6 months compared to older calves?	1: > 90% 2: > 90%	
13	The combination of local anaesthesia and NSAIDs leads to a higher reduction of behaviours indicative of pain than using anaesthesia or NSAIDs alone.	How certain are you that the proportion of calves experiencing pain is lower when local anaesthesia and NSAIDs are used in combination compared to when anaesthesia is used alone?	> 90%	
14	Research indicates that lidocaine leads to a higher reduction of behaviours indicative of pain than other local anaesthetics, and that meloxicam reduces post-surgical inflammation. There is a lack of studies directly comparing modes, timing of administration and duration of treatment at different ages.	How certain are you that the proportion of beef calves showing pain-related behaviours is lower when lidocaine is used compared to other local anaesthetics, and that post-surgical inflammation is reduced when meloxicam is administered compared to when it is not?	> 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
Disbudding and dehorning				
6	Dehorning carries considerably higher welfare risks (such as bleeding, sinus infections or bone fractures) than disbudding, and is related to more handling stress and longer wound healing times.	How certain are you that the proportion of beef cattle experiencing high levels of handling stress and pain is lower during disbudding than during dehorning?	> 90%	
7	Properly administered local anaesthesia and post-surgical analgesia reduce pain around the procedure in all disbudding and dehorning methods.	How certain are you that the proportion of beef cattle experiencing pain around the procedures of all disbudding or dehorning methods is lower when local anaesthesia and post-surgical analgesia are properly applied than when they are not applied?	> 90%	
8	Even if applying local anaesthesia and post-surgical analgesia, long-lasting pain develops (for several weeks).	How certain are you that long-lasting pain, potentially lasting several weeks, develops even when local anaesthesia and post-surgical analgesia are applied?	> 66%	Limited number of long term studies.
9	Signs if persistent sensitisation towards mechanical stimulation or pressure near the site of the procedure have been reported in calves, potentially worse for calves disbudded at a very young age (e.g. at 3 days) (certainty > 66%). Research is needed to clarify this.	How certain are you that calves disbudded at a very young age (e.g. at 3 days) are more likely to show persistent sensitisation to mechanical stimulation or pressure near the disbudding site compared to calves disbudded at an older age?	> 66%	Limited number of studies investigating this and partly conflicting results.
12	Sedation reduces overt signs of handling stress during disbudding and dehorning. Insufficient research is available on possible negative welfare effects of sedation, including increased stress due to sedative effects.	How certain are you that the proportion of beef cattle showing overt signs of handling stress is lower when sedation is used during disbudding and dehorning?	> 90%	
13	Surgical disbudding carries higher welfare risks, such as bleeding or infection, than hot-iron and caustic paste disbudding and elicits more responses indicative of pain.	How certain are you that the proportion of beef cattle experiencing welfare risks, such as bleeding or infection and showing more responses indicative of pain, is lower when disbudding is performed using hot-iron or caustic paste compared to surgical disbudding?	> 90%	
14	Caustic paste disbudding carries further welfare risks, such as unintentional caustic burns of the eye or other body parts, than hot-iron disbudding. Caustic paste elicits substantial pain and is associated with prolonged healing times (e.g. 18 weeks) due to deeper wounds than those caused by thermocautery. Moreover, in contrast to hot-iron disbudding, it requires the separation from the cow and from other calves to avoid burning them. For hot-iron disbudding, there are numerous brands of disbudders on the market, but there is insufficient information on the welfare consequences of different heat capacities, tip sizes and application times.	(1) How certain are you that the proportion of beef cattle experiencing welfare risks, such as unintentional caustic burns of the eye or other body parts, is lower when hot-iron disbudding is used compared to caustic paste disbudding? (2) How certain are you that caustic paste disbudding elicits substantial pain and leads to prolonged healing times (e.g. 18 weeks) due to causing deeper wounds than thermocautery?	1. > 90% 2. > 90%	

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
Tail docking				
4	Band/rubber ring tail docking results in behaviours indicative of pain such as head movements directed towards the tail, and more and shorter resting bouts.	How certain are you that the proportion of beef cattle showing pain-related behaviours, such as head movements towards the tail and more frequent and shorter resting bouts, is higher after band/rubber ring tail docking compared to when tail docking is not performed?	> 90%	
5	Hot-iron docking leads to less intense reactions indicative of pain than band/rubber ring tail docking.	How certain are you that hot-iron docking results in less intense pain-related reactions compared to band/rubber ring tail docking?	> 66%	Limited scientific evidence
7	The evidence for the effectiveness of epidural local anaesthesia is inconclusive, but due to the smaller lesion inflicted and the lesser innervation, docking of the tendinous tail tip leads to less severe welfare impairments than docking of parts of the tail with vertebrae.	How certain are you that docking the tendinous tail tip results in less severe welfare impairments compared to docking parts of the tail with vertebrae?	> 90%	
8	The primary rationale for tail docking in beef cattle is to prevent tail-tip injuries and necrosis, but these problems can be mitigated by management measures such as adequate space allowance and floor conditions.	How certain are you that adequate space allowance and floor conditions effectively mitigate tail-tip injuries and necrosis in beef cattle, reducing the need for tail docking?	> 90%	
Polledness				
1	The introgression of polledness in horned cattle breeds is an alternative to disbudding and dehorning procedures to mitigate soft tissue lesions and integument damage.	How certain are you that the proportion of beef cattle experiencing welfare consequences such as soft tissue lesions and integument damage is lower when the introgression of polledness is used as an alternative to disbudding and dehorning?	> 90%	
5	Horns play a role in thermal regulation and protection against predators, and they are used for comfort behaviour (self-scratching). Their functional importance depends on specific husbandry conditions (e.g. high/low environmental temperatures, indoor/outdoor conditions, presence of brushes).	(1) How certain are you that the proportion of beef cattle experiencing impaired thermal regulation is higher when horns are absent compared to when they are present? (2) How certain are you that the proportion of beef cattle vulnerable to predators is higher when horns are absent compared to where they are present?	1: > 66% 2: > 66%	(1) weak evidence in reduction of heat stress (2) weak evidence
7	When physical agonistic interactions occur, the presence of horns increases the risk of injuries. However, conditions leading to reduced competition for resources, that enable cattle to avoid dominant conspecifics and provide for stable social relationships, have been demonstrated to reduce group stress and decrease agonistic interactions and related injuries in herds of horned cattle.	(1) How certain are you that the presence of horns increases the risk of injuries caused by agonistic interactions among cattle? (2) How certain are you that reduced competitive conditions for resources help cattle avoid dominant conspecifics, thereby decreasing group stress, frequency of agonistic interactions and related injuries?	1: > 90% 2: > 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
8	Soft tissue lesions resulting from agonistic interactions are often not as visible in polled cattle compared to horned cattle. However, this does not mean than they do not occur. For this reason, polled cattle will also benefit from housing conditions leading to reduced competition.	(1) How certain are you that soft tissue lesions due to agonistic interactions in polled cattle are often not externally visible? (2) How certain are you that polled cattle would also benefit from reduced competitive conditions in terms of soft tissue lesions?	1: > 90% 2: > 90%	
9	Genetic associations with other traits are largely unknown. The establishment of genetic polledness in beef cattle populations carries a risk of losing desirable genetic traits such as disease resistance or adaptability.	How certain are you that the loss of genetic variability associated with the introgression of polled genotype in beef cattle carries a risk of losing desirable genetic traits such as disease resistance or adaptability?	> 50%	This is based on a theoretical consideration taking the limited size of the population of animals with polledness genes into account.
Temperament				
1	Efforts to select beef cattle displaying less fearful and aggressive temperament mitigate welfare issues resulting from flightiness and aggression.	How certain are you that genetic selection for less fearful and aggressive temperament in beef cattle mitigates welfare issues caused by flightiness and aggression?	> 90%	
2	Selection for calmer temperament (in terms of reduced flightiness) and simultaneously for increased maternal ability may also cause an increase in maternal defensiveness due to reduced fearfulness towards humans, which leads to increased difficulty in assisting the calf.	How certain are you that the simultaneous selection for calmer temperament and increased maternal ability in beef cattle leads to greater maternal defensiveness due to reduced fearfulness towards humans?	> 66%	Limited number of studies.
4	Identification of genes and genomic regions is useful for enhancing selection for docile and calm temperament in beef cattle.	How certain are you that identifying genes and genomic regions related to docile and calm temperament is useful for enhancing selection in beef cattle?	> 66%	Not clear how efficient this approach is due to the polygenic nature of this trait.
6	Outcomes of behavioural tests to assess temperament are not consistent across studies.	How certain are you that the outcomes of behavioural tests to assess temperament are not consistent across scientific studies?	> 90%	
Hypermuscolarity				
1	Double-muscled (DM) animals experience high rates of dystocia due to a mismatch between calf size and the pelvic conformation of dams, necessitating C-sections. For example, elective C-sections are carried out in approximately 90% of calvings in DM Belgian Blue cows.	How certain are you that the proportion of beef cattle experiencing dystocia, due to calf size and pelvic conformation mismatches, is higher if they are double-muscled than if they are not?	> 90%	
2	Double-muscled animals are at greater risk of heat stress, locomotory disorders (including lameness), metabolic disorders and fatigue resulting from a smaller heart and smaller lungs compared to non-DM animals.	How certain are you that the proportion of beef cattle at risk of experiencing heat stress, locomotory disorders (including lameness), metabolic disorders and fatigue is higher if they are double-muscled than if they are not?	> 90%	
7	Welfare consequences of hypermuscularity are mitigated by selecting for improved anatomical features such as pelvic conformation and internal organ size.	How certain are you that selecting for improved anatomical features, such as pelvic conformation and internal organ size, mitigates the welfare consequences of hypermuscularity in beef cattle?	> 50%	Very limited evidence on internal organ size.

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
Dystocia and C-sections				
1	Dystocia may have serious consequences on cow welfare (e.g. soft tissue lesions and integument damage, handling stress, prolonged hunger) and calf welfare (e.g. increased mortality rate, gastro-enteric disorders, respiratory disorders).	(1) How certain are you that dystocic births have serious welfare consequences for cows (e.g. soft tissue lesions and integument damage, handling stress, prolonged hunger)? (2) How certain are you that dystocic births have serious welfare consequences for calves (e.g. increased mortality rate, gastro-enteric disorders, respiratory disorders)?	1: > 90% 2: > 90%	
2	Planned C-section is a commonly used surgery to minimise the risks of dystocia and its effects on cows and calves. This procedure is associated with negative welfare consequences for cows.	How certain are you that also planned C-sections cause negative welfare consequences for cows?	> 90%	
3	It is likely that repeated C-sections lead to a higher risk of bleeding, infection and adhesions based on findings from human studies.	How certain are you that repeated C-sections in cattle lead to a higher risk of bleeding, infection and adhesions, as suggested by findings from human studies?	> 50%	No studies on cattle, only extrapolation from human studies.
4	Selection for calving ease, reduced calf size and weight, and reduced stillbirths is currently implemented in beef cattle. Genetic improvement has been achieved by these selection strategies in most breeds.	How certain are you that genetic improvement has been achieved by selecting for calving ease, reduced calf size and weight in most beef cattle breeds?	> 90%	
5	Including heifers' and dams' pelvic conformation in the selection traits leads to a faster genetic improvement.	How certain are you that the inclusion of heifers' and dams' pelvic dimensions in selection traits accelerates genetic improvement compared to selection strategies that do not consider pelvic dimensions?	> 66%	Not enough evidence available yet
Maternal ability				
2	Breeding for maternal ability mitigates the welfare consequences of poor maternal care or inadequate milk production.	How certain are you that breeding for maternal ability mitigates consequences of poor maternal care or inadequate milk production?	> 90%	
3	Selection for maternal ability can lead to inadvertently selecting for increased maternal aggressive temperament, a trait with potentially negative implications for handler and calf safety.	How certain are you that selecting for maternal ability in beef cattle inadvertently increases maternal aggressive temperament, with negative implications for the safety of handlers and calves?	> 50%	Not yet demonstrated in beef cattle
ABMs at slaughter				
2	The ABMs listed in (1) are the most suitable and promising ABMs for collection at slaughterhouses to monitor the level of welfare on farm for fattening cattle (i.e. fattening bulls, heifers and steers) although they have only to a very limited extent been evaluated under field conditions.	How certain are you that the listed ABMs in (1) are the most suitable and promising ABMs for collection at slaughterhouses to monitor the level of welfare on farm for fattening cattle?	> 90%	

(Continues)

TABLE B.2 (Continued)

N.	Conclusions	Uncertainty question	Certainty range	Reasoning for low certainty
8	The TRL of automated monitoring of the ABMs at slaughterhouses is currently low. Automated methods for carcass fatness classification are the most advanced.	How certain are you that automated methods for carcass fatness classification are more advanced compared to other automated monitoring methods for ABMs in slaughterhouses?	> 90%	

APPENDIX C

Literature searches

Sections 3.2.1–3.3 – Housing conditions (indoors) and space allowance

A broad literature search was carried out to identify scientific evidence on the elements to identify relevant peer-reviewed publications on the highly relevant welfare consequences identified. Restrictions on the different categories of cattle were applied by including synonyms that are commonly used both in scientific publications and grey literature.

The bibliographic database Web of Science (Core Collection) was used to retrieve relevant records, which were exported as Microsoft Excel files (.xlsx) along with associated metadata (e.g. title, authors, abstract). Duplicate entries were removed, and titles and abstracts were screened for relevance. If relevance could not be determined from the title and abstract alone, the full text was reviewed. Additional relevant publications known to the working group but not identified in the initial search were also included in the literature review. All relevant references were subsequently compiled in an EndNote 21 library to create the list of references of the Scientific Opinion. Details of the search strings used are provided below.

Water access

Search date: 11 March 2024

Defined time period: 2012 to 2024

Search string: (TI = (water* OR drink* OR thirst) AND TS = ("beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer* OR bull* OR heifer* OR calves OR cattle OR cow*) AND TS = ("water intake" OR "water flow*" OR "drinking behav*") AND TS = (indoor OR hous* OR pen* OR husbandry) NOT TS = (zebu OR lamb* OR goat* OR sheep OR pig* OR equi* OR horse* OR buffalo* OR bison* OR camel*))

Results: 33. Result after screening for relevance: 17.

Flooring

Search date: 12 March 2024

Defined time period: 2012 to 2024

Search string: (TI = (floor* OR bed* OR "resting area*" OR slat*) AND TS = ("beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer* OR bull* OR heifer* OR calf OR calves OR cattle OR cow*) AND TS = (indoor OR hous* OR pen* OR husbandry) NOT TS = (zebu OR lamb* OR goat* OR sheep OR pig* OR equi* OR horse* OR buffalo* OR bison* OR camel*))

Results: 204. Result after screening for relevance: 33.

Nutrition and feeding

Search date: 12 March 2024

Defined time period: 2012 to 2024

Search string: (TI = (diet* OR feed* OR nutrit* OR "oral behav*" OR "chewing behav*" OR forag* OR concentrat* OR "feed intake") AND TI = ("beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer* OR bull* OR heifer* OR calves OR cattle OR cow*) AND TI = (behav* OR welfare) AND TS = (indoor OR hous* OR pen* OR husbandry) AND TS = ("ruminal acidosis" OR silage* OR straw OR roughage OR "totally mixed ration" OR fiber*) NOT TS = (zebu OR lamb* OR goat* OR sheep OR pig* OR equi* OR horse* OR buffalo* OR bison* OR camel*))

Results: 98. Result after screening for relevance: 35.

High environmental temperature

Search date: 13 March 2024

Defined time period: 2012 to 2024

Search string: (TS = (cattle "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS = (heat OR "high temperature$" OR warm OR "heat stress") AND TS = (husbandry OR indoor OR hous* OR pen$) AND TS = (behavi* OR welfare) NOT TS = (zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Results: 101. Result after screening for relevance: 16.

Lack of environmental enrichment

Search date: 14 March 2024

Defined time period: 2012 to 2024

Search string: (TS = (cattle "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS = (enrichment OR "environmental enrichment") AND TS = (explorat* OR groom*

OR forag* OR "comfort behavi*" OR play) AND TS = (behavi* OR welfare) NOT TS = (zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Results: 30. Result after screening for relevance: 15.

Lack of outdoor access

Search date: 15 March 2024

Defined time period: 2012 to 2024

Search string: (TS = (cattle OR "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS = (outdoor OR "loafing area" OR feedlot) AND TS = (access OR restriction OR exploration) AND TS = (behavi* OR welfare) NOT TS = (zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Result = 109. Result after screening for relevance: 18.

Mixing of cattle

Search date: 15 March 2024

Defined time period: 2012 to 2024

Search string: (TS = (cattle "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS = (mix* OR regroup* OR "social mixing" OR "group change") AND TS = (social OR stress OR aggression OR separation) AND TS = (behavi* OR welfare) NOT TS = (zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Result = 222. Result after screening for relevance: 19.

Space allowance

Search date: 17 December 2024

Defined time period: 2012 to 2024

Search string: (TI = (cattle OR "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TI = ("space allowance$" OR "stocking densit*" OR spac* OR spat* OR area$) NOT TI = (dairy OR milk) AND TS = (cattle OR "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS = (husbandry OR indoor OR hous* OR pen$) AND TS = ("space allowance$" OR "stocking densit*" OR spac* OR spat* OR area$) AND TS = (behavi*) NOT TS = (zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Result = 19. Result after screening for relevance: 10.

Section 3.4 – Cattle kept outside

Welfare of cattle kept on pasture

Search date: 19 December 2024

Defined time period: 2012 to 2024

Search string: (TI = (cattle OR "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TI = (pasture$ OR grazing OR grass* OR outwinter* OR outdoor OR shelter* OR shade) NOT TI = (dairy OR feedlot OR milk) AND TS = (cattle OR "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS = (pasture$ OR grazing OR grass* OR outwinter* OR outdoor OR shelter* OR shade) AND TS = (behavi*) NOT TS = (zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Result = 341. Result after screening for relevance: 133.

Welfare of cattle kept in outdoor feedlots

Search date: 19 December 2024

Defined time period: 2012 to 2024

Search string: TS = (cattle OR "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS = (feedlot$) AND TS = (behavi* AND welfare) NOT TS = (zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Result = 133. Result after screening for relevance: 38.

Section 3.5 – Weaning

Search date: 23 November 2024

Defined time period: 2012 to 2024

Search string: (TI=(wean*) AND TS=("suckler cal*" OR "suckler cow$" OR "beef cal*" OR "dairy-beef cal*" OR "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR cow$) AND TS=("creep weaning" OR "creep feeding" OR "fence$line weaning" OR "abrupt weaning" OR "gradual weaning" OR "yard weaning" OR "nose$flaps") NOT TS=(dairy OR veal OR zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Result=27. Result after screening for relevance: 17.

Section 3.6 – Mutilations

Castration

Search date: 20 December 2024

Defined time period: 2012 to 2024

Search string: (TI=(cattle OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$" OR calf OR calves) AND TS=(*castrat*) AND TS=(pain OR anaesthe* OR "pain killer" OR analgesi* OR medical OR surgical OR surgery OR "topical treatment"))

Result=238. Result after screening for relevance: 115.

Disbudding and dehorning

Search date: 20 December 2024

Defined time period: 2012 to 2024

Search string: (TS=(cattle "beef cattle" OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$") AND TS=(disbud* OR dehorn* OR mutilat*) AND TS=(behavi* OR welfare) NOT TS=(zebu OR lamb* OR goat$ OR sheep OR pig$ OR equi* OR horse$ OR buffalo* OR bison$ OR camel$))

Result=58. Result after screening for relevance: 28.

Tail docking

Search date: 20 December 2024

Defined time period: 2012 to 2024

Search string: (TI=(cattle OR "fattening cattle" OR "finishing cattle" OR steer$ OR bull$ OR heifer$ OR "suckler cal*" OR "suckler cow$" OR calf OR calves) AND TS=("tail dock*"))

Result=21. Result after screening for relevance: 5.

Section 3.7 –Breeding and genetics

For the description of breeding strategies and genetics, an extensive literature review was performed using the bibliographic database 'Scopus'. Document type other than research and review articles and in a language other than English were excluded. Furthermore, the subject areas of "Biochemistry, Genetics and Molecular Biology", "Agricultural and Biological Sciences", "Veterinary" and "Multidisciplinary" were selected as inclusion criteria. The five lists of peer-reviewed documents (one for each topic of ToR3) were exported to Excel files together with the relevant metadata (e.g. title, authors, abstract), then merged and duplicates removed.

Polledness

Defined time period: 2010 to 2023

Search string: TS=(beef AND cattle) AND (polledness OR polled OR hornless) AND (genetic OR gene OR epistasis OR epistat* OR welfare)

Result=38. Result after screening for relevance: 3.

Temperament

Defined time period: 2010 to 2023

Search string: TS=(beef AND cattle) AND (temperament OR docility OR proactivity OR reactivity OR coping OR workability OR character) AND (behaviour OR behavior OR ethology OR ethogram OR welfare) AND (genetic OR gene OR trait OR phenotype) AND NOT (steak OR consumer OR sensory OR market)

Result=53. Result after screening for relevance: 10.

Hypermuscularity

Defined time period: 2010 to 2023

Search string: TS = (beef AND cattle) AND (Hypermuscuolarity OR (muscle AND hypertrophy) OR "muscular hypertrophy" OR "double muscl*" OR "double-muscl*" OR myostatin OR mutation) AND (genetic OR inherited OR welfare) AND NOT (virus OR disease OR antibiotic)

Result = 205. Result after screening for relevance: 7.

Dystocia and Caesarean section

Defined time period: 2010 to 2023

Search string: TS = (beef AND cattle) AND ((calving AND ease) OR (birth AND ease OR "fetal malpresentation" OR "foetal malpresentation") OR (caesarean OR cesarean OR dystoc* OR obstetric* OR "surgical delivery")) AND (genetic OR phenotype OR trait OR genomic OR selection OR welfare)

Result = 88. Result after screening for relevance: 12.

Maternal ability

Defined time period: 2010 to 2023

Search string: TS = (beef AND cattle) AND maternal AND (genetic* OR trait OR selection) AND (instinct OR ability OR behaviour OR attitude OR ethology)

Result = 50. Result after screening for relevance: 9.

Section 3.8 – Cull cows

Search date: 10 February 2025

Defined time period: 2012 to 2024

Search string: (TS = (cow$) AND TS = (cull*) AND TS = (welfare OR behavi*))

Result = 255. Result after screening for relevance: 21.

Section 3.9 – Slaughter ABMs

For the description of the ABMs collected in slaughterhouses to monitor the level of welfare on farm for fattening cattle an extensive literature review was conducted on the 23rd of July 2024, using the bibliographic database 'Web of Science' (all databases). The records retrieved from Web of Science were exported to Excel files together with the relevant metadata (e.g. title, authors, abstract) and duplicates were removed. Titles and abstracts were screened for relevance. Full text publications were screened if title and abstract did not allow assessing the relevance of a paper.

Body condition

Defined time period: 2010 to 23-07-2024

Search string: (TS = ("beef cattle" OR "fattening cattle" OR "steer$" OR "bull$" OR "Heifer$") AND TS = ("body") AND TS = ("condition" OR "score" OR "composition") AND TS = ("slaughter*" OR "abattoir" OR "slaughter plant" OR "slaughter line" OR "slaughter factory") AND TS = ("welfare" OR "health" OR "protection" OR "inspection" OR "meat") NOT TS = ("zebu" OR "post-mortem" OR "postmortem" OR "post mortem" OR "genetic" OR "genomic" OR "transport*" OR "lamb$" OR "pig$" OR "equi*" OR "calves" OR "buffalo" Or "acid*" OR "ethiopia" OR "thailand" OR "china" OR "serum" or "plasma" OR "korean" OR "mexico" OR "mexican" OR "milk" OR "nellore" OR "vitamin$"))

NOT Languages: Korean or Chinese or Lithuanian

NOT Countries/regions: Japan or Thailand or Kenia or South Korea or Tunisia or Cambodia or Brazil or New Zealand or Uruguay or Colombia or Dem Rep Congo or Mexico or Indonesia

NOT document types: Patent or Meeting or Awarded Grant

Result = 93. Result after screening for relevance: 9

Carcass fatness

Defined time period: 2010 to 23-07-2024

Search string: (TS = ("beef cattle" OR "fattening cattle" OR "steer$" OR "bull$" OR "Heifer$") AND TS = ("carcass*" OR "carcase$") AND TS = ("fatness" OR "fat" OR "SEUROP" OR "EUROP" OR "grid") AND TS = ("slaughter*" OR "abattoir" OR "slaughter plant" OR "slaughter line" OR "slaughter factory") AND TS = ("welfare" OR "health" OR "protection" OR "meat") NOT TS = ("society" OR "consumer$" OR "economic$" OR "citizen$" OR "zebu" OR "post-mortem" OR "postmortem" OR "post mortem" OR "genetic" OR "genomic" OR "transport*" OR "lamb$" OR "pig$" OR "equi*" OR "calves" OR "buffalo" Or "acid*" OR "ethiopia" OR "thailand" OR "china" OR "serum" or "plasma" OR "korean" OR "mexico" OR "mexican" OR "milk" OR "nellore" OR "vitamin$" OR "south africa" OR "africa*" OR "brazil*"))

NOT Languages Korean or Czech or Polish or Russian or Croatian or Japanese or Serbo Croatian or Lithuanian or Turkish or Ukrainian

NOT Countries/Regions: Sudan or South Africa or RS or Peru or Colombia or Uruguay or South Korea or Peoples R China or Japan or Brasil or Mexico or Tunisia or Venezuela or Chile or Brazil or New Zealand

NOT document types: Patent, meeting, dataset

Result = 105. Result after screening for relevance: 3.

Carcass condemnation

Defined time period: 2010 to 23-07-2024

Search string: (TS = ("beef cattle" OR "fattening cattle" OR "steer$" OR "bull$" OR "Heifer$") AND TS = ("carcass*" OR "carcase$" OR "viscera") AND TS = ("condemnation" OR "trimming" OR "trimmed" OR "condemned") AND TS = ("slaughter" OR "abattoir" OR "slaughter plant" OR "slaughter line" OR "slaughter factory") AND TS = ("welf*" OR "health" OR "protection" OR "inspection" OR "meat") NOT TS = ("econom*" OR "value"))

Results = 81 Result after screening for relevance: 4

Lung lesions

Defined time period: all years

Search string: (TS = ("beef cattle" OR "fattening cattle" OR "steer$" OR "bull$" OR "Heifer$") AND TS = ("lung$") AND TS = ("lesion*" OR "respiratory" OR "wound*" OR "pneumonia" OR "pleuritis" OR "discoloration") AND TS = ("slaughter*" OR "abattoir" OR "slaughter plant" OR "slaughter line" OR "slaughter factory" OR "necroscopy") AND TS = ("welfare" OR "health" OR "protection" OR "inspection") NOT TS = ("econom*" OR "value"))

Result = 104. Result after screening for relevance:

Skin lesions – bruises (PM), wounds and bursitis (AM)

Defined time period: 2001 to 23-07-2024

Search string: (TS = ("beef cattle" OR "fattening cattle" OR "steer$" OR "bull$" OR "Heifer$") AND TS = ("bruise$" OR "bursitis" OR "bursa$" OR "punctiform spot*" OR "scratch*" OR "wound*" OR "damage" OR "rupture*" OR "injur*") AND TS = ("slaughter" OR "abattoir" OR "slaughter plant" OR "slaughter line" OR "slaughter factory") AND TS = ("welf*" OR "health" OR "protection" OR "inspection" OR "meat") NOT TS = ("horse" OR "transport" OR "liver" OR "stunning" OR "econom*"))

Result = 174. Result after screening for relevance: 1

Body cleanliness

Defined time period: all years

Search string: TS = ("beef cattle" OR "fattening cattle" OR "steer$" OR "bull$" OR "heifer$") AND TS = ("body") AND TS = ("cleanliness" OR "dirtiness" OR "manure" OR "manure on the body") AND TS = ("ante mortem" OR "ante-mortem" OR "slaughter" OR "abattoir" OR "slaughter plant" OR "slaughter line" OR "slaughter factory") AND TS = ("welf*" OR "health" OR "protection" OR "inspection" OR "meat"))

Result = 33. Result after screening for relevance: 5

APPENDIX D

Instructions for accessing submissions from the Public call for evidence

The submissions referenced in this Scientific Opinion are identified under the label 'EFSA Public call for evidence 2024', followed by the prefix 'PC-0742' which denotes the unique identifier of the Public call for evidence on the welfare of beef cattle on farm. This prefix is further followed by a number indicating the specific topic of the call the submission refers, alongside the name of the organisation that provided each submission.

The data provided by each stakeholder through the Public call for evidence is publicly available at the following webpage: https://open.efsa.europa.eu/consultations/a0cTk00000024kHIAQ.

The submissions specifically referenced in this Scientific Opinion are listed in Table D.1.

- For submissions in the form of comments, open the webpage linked above and use the 'Download all comments' button to download all comments in a single file. Once downloaded, the relevant comment can be identified by searching for the corresponding Comment Number listed in the table.
- For submissions in the form of attachments, open the webpage linked above and use the PC ID and the organisation's name as listed in the table to locate the relevant submission. Additional details on where to find the attached file are provided in the 'Submission Location Details' column. These details can be retrieved on a page view displaying 20 results per page. If this column is left empty, it means that no file was attached to the submission.

TABLE D.1 Summary of submissions received in response to the EFSA Public call for evidence, 2024 and cited in the present document.

Public call for evidence ID	Stakeholders submitting information on beef farming practices	Comment number	Attached file location on open EFSA link, if provided* ('20/page' view)
PC-0742 4	Four Paws	33	Page 2
PC-0742 14	Association of Veterinary Consultants (AVC)	221	Page 10
PC-0742 14	Czech Beef Cattle Assosiation	50	Page 3
PC-0742 19	Czech Beef Cattle Assosiation	55	Page 3
PC-0742 19	Landwirtschaftskammer Nordrhein-Westfalen	89	–
PC-0742 21	Landwirtschaftskammer Nordrhein-Westfalen	90	–
PC-0742 19	EFFAB-FABRE TP	165	Page 9
PC-0742 20	EFFAB-FABRE TP	166	Page 9
PC-0742 19	Deutscher Tierschutzbund e.V.	163	Page 8
PC-0742 17	Deutscher Tierschutzbund e.V.	161	Page 8
PC-0742 17	Irish Farmers Association (IFA)	187	–
PC-0742 21	Irish Farmers Association (IFA)	191	–
PC-0742 18	Netherlands Food and Consumer Product Safety Authority	16	Page 1
PC-0742 18	Compassion in World Farming Brussels (CIWF EU)	143	–
PC-0742 18	Belbeef	27	Page 2

*Not all the attachments provided were used in this Scientific Opinion but they are mentioned for completeness.

APPENDIX E

Behavioural model

Space model for three animals

The information here presented (see Figures E.1–E.11 below) is aimed at complementing the information in the main text. Please refer to the main text for an explanation of the model assumptions, and calculations for groups of 8 animals.

For three animals, the necessary space is estimated as:

Number of animals:	$N = 3$
Short side:	$a = 0.866 \times d_{min} + w$ with 0.866 = Ö 3/4
Long side:	$\lambda \times a = d_{min} + w$
Area of the pen:	$A = \lambda \times a^2 = (d_{min} + w) \times (0.866 \times d_{min} + w)$
Area per aniamal:	$Z(3) = A/N = (d_{min} + w) \times (0.866 \times d_{min} + w)/3$
Side ratio:	$\lambda = (\lambda \times a)/a = (d_{min} + w)/(0.866 \times d_{min} + w)$

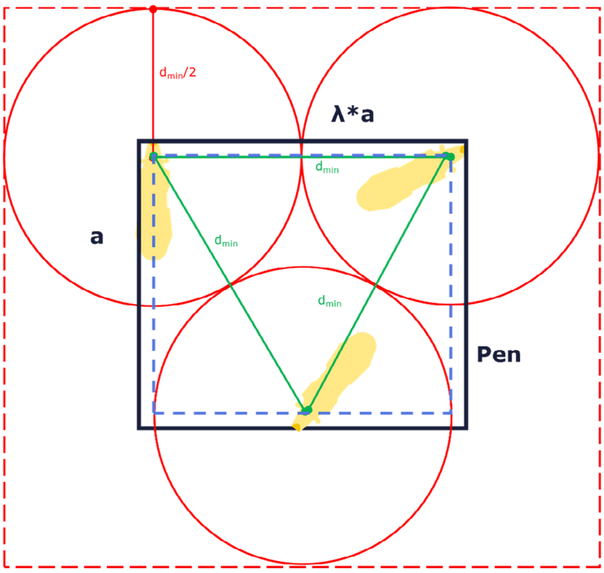

FIGURE E.1 Distribution of three animals in a pen following the model assumptions, i.e. an even distribution of cattle having all the same distance between heads to their neighbours and a head-to-head minimum inter-individual distance.

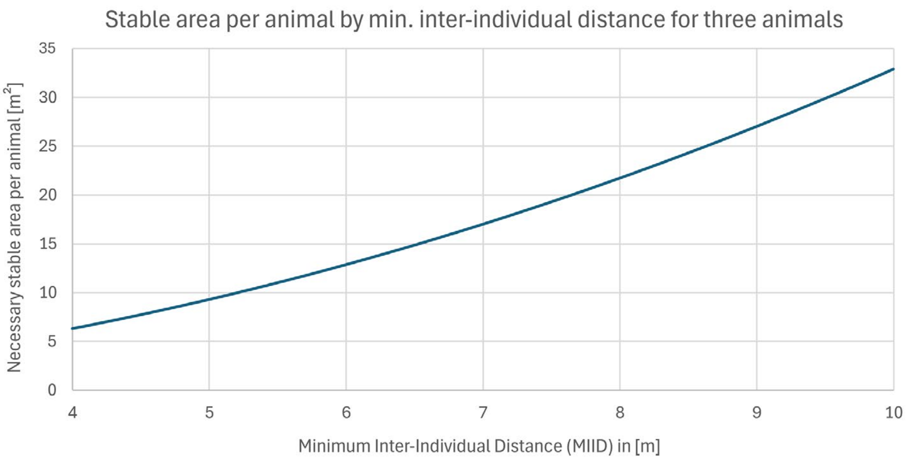

FIGURE E.2 Estimation of the relationship between minimum inter-individual distance and necessary m^2/animal assuming a rectangular pen.

The optimal ratio of length of the pen is for the minimum inter-individual distance from 4 to 10 m is between 1.13 and 1.14.

Extension to large groups of cattle

FIGURE E.3 Planimetric surface of animals denoting *w* (with) and *l* (length) of the animal.

Beside the pure planimetric surface in individual pens the size of pens for tree animals can be seen as the minimum area per animal, as most of the space needed for the inter-individual distance is beyond the boundaries of the pen (red areas in Figure E.4):

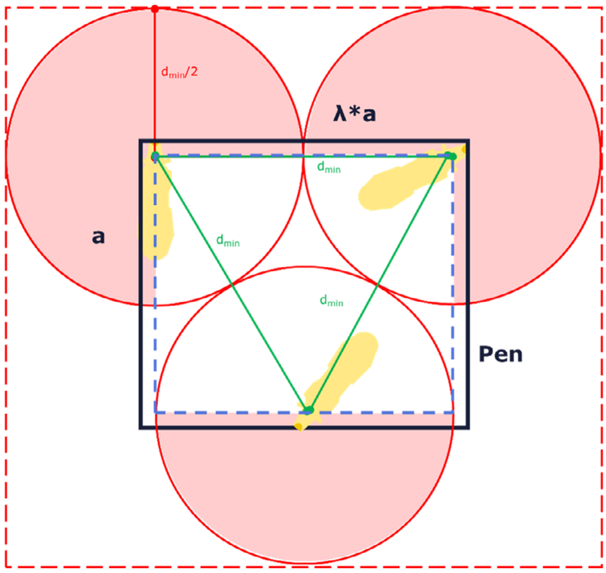

FIGURE E.4 Distribution of three animals in a pen following the model assumptions, i.e. an even distribution of cattle having all the same distance between heads to their neighbours and a head-to-head minimum inter-individual distance. The highlighted red areas represent the additional inter-individual space required beyond the physical boundaries of the pen.

For an infinitive group of animals this 'advantage' would disappear, and each animal would need a full circle with the diameter d_{min}. Additionally, 10% of space is needed for the optimal allocation of circles in an area:

Area per cattle: $Z(\infty) = \pi \times (d_{min}/2)^2/0.9069$

with the correction factor α for the additional space between the circles (Figure E.5).

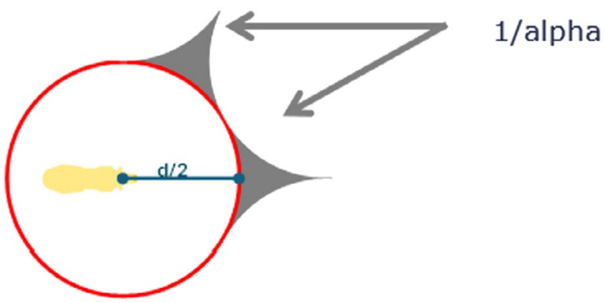

FIGURE E.5 Illustration of the spatial arrangement for an animal, occupying a minimum required circular area of diameter d_{min}. The configuration accounts for additional spacing between individuals, represented by the correction factor α and highlights the need for 10% extra space due to geometric packing constraints.

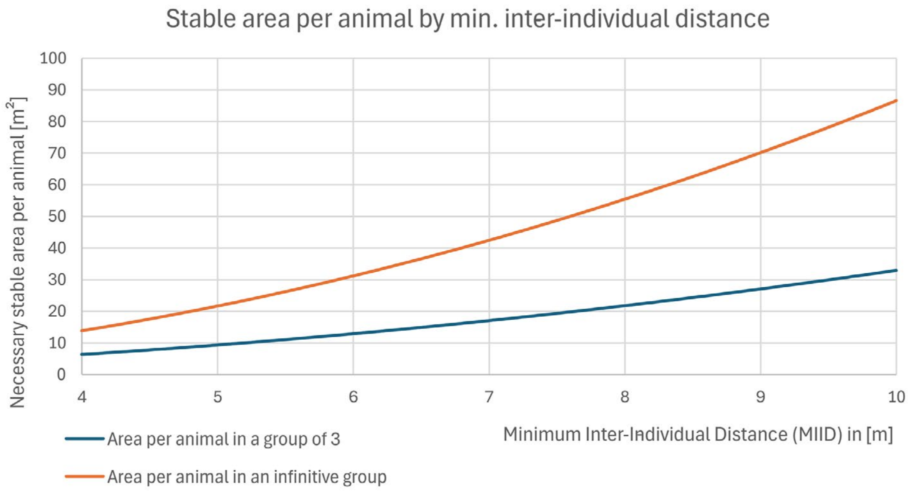

FIGURE E.6 Estimation of the relationship between minimum inter-individual distance and necessary m^2/animal assuming a rectangular pen and a group of three animals.

For limited group sizes above three animals, the necessary space depends on the group size and shape of the pen (ratio λ).

The distribution of cattle in a pen was also estimated for group sizes of 8, 14 and 20 cattle, using model calculations based on the same assumptions and pen length ratios between 1 and 1.5. Group sizes of 8, 14 and 20 animals were ultimately chosen because they reflect group sizes commonly practiced.

Model for 14 animals

For 14 animals, the necessary space is estimated as:

Number of animals:	$N = 14$
Short side:	$a = 3 \times 0.866 \times d_{min} + w$ with $0.866 = \sqrt{3/4}$
Long side:	$\lambda \times a = 3 \times d_{min} + w$
Area of the pen:	$A = \lambda \times a^2$
Area per animals:	$Z(N) = A/N$
Side ratio:	$\lambda = (\lambda \times a)/a$

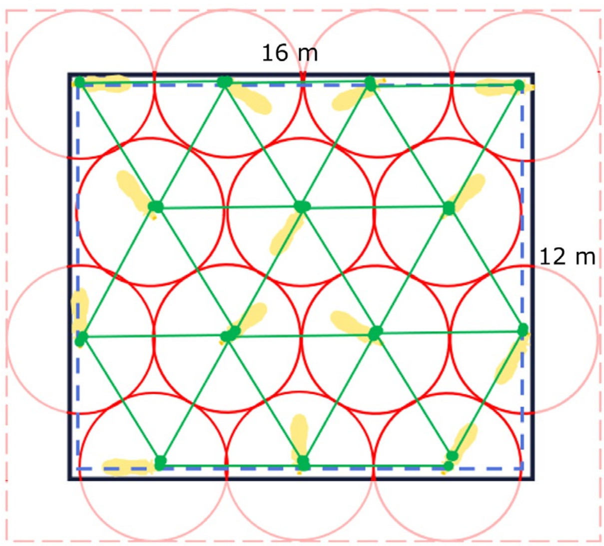

FIGURE E.7 Distribution of 14 animals in a pen following the model assumptions, i.e. an even distribution of cattle having all the same distance between heads to their neighbours and a head-to-head minimum inter-individual distance.

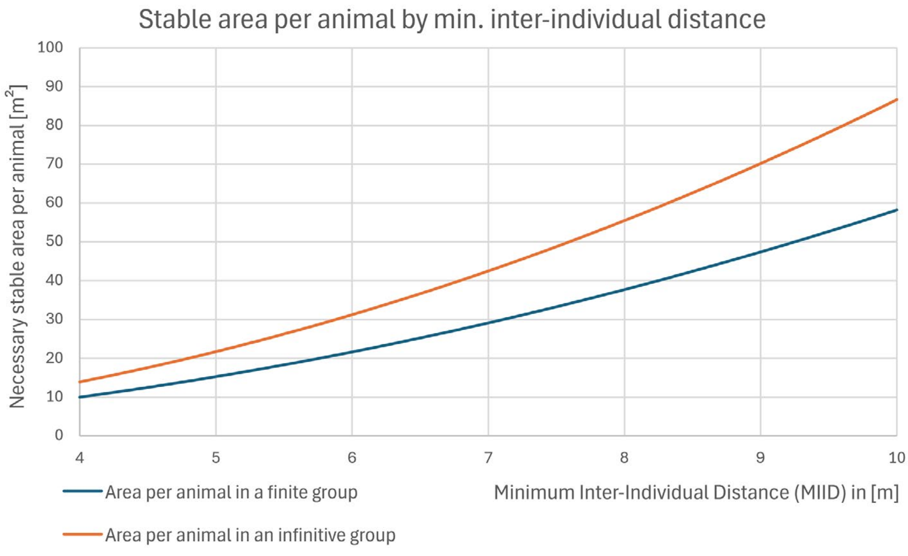

FIGURE E.8 Estimation of the relationship between minimum inter-individual distance and necessary m^2/animal assuming a rectangular pen and a group of 14 animals.

The ratio of length of the stable is for MIID from 4 to 10m is 1.15.

Model for 20 animals

For 20 animals, the necessary space is estimated as:

Number of animals:	$N = 20$
Short side:	$a = 4 \times 0.866 \times d_{min} + w$ with $0.866 = \sqrt{3/4}$
Long side:	$\lambda \times a = 3.5 \times d_{min} + w$
Area of the pen:	$A = \lambda \times a^2$
Area per animals:	$Z(N) = A/N$
Side ratio:	$\lambda = (\lambda \times a)/a$

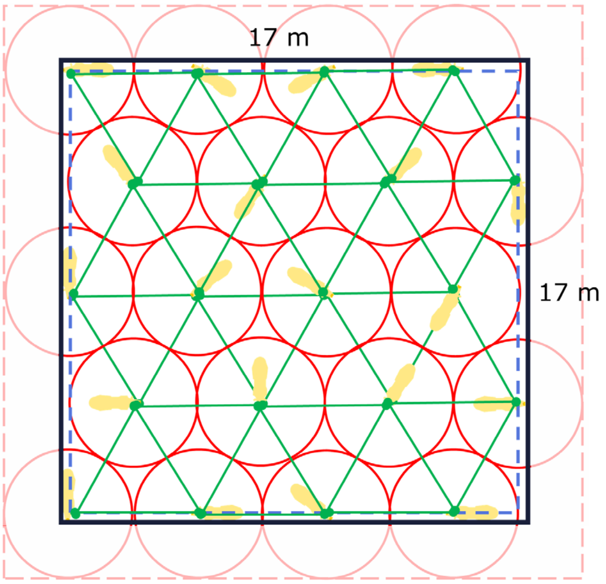

FIGURE E.9 Distribution of 20 animals in a pen following the model assumptions, i.e. an even distribution of cattle having all the same distance between heads to their neighbours and a head-to-head minimum inter-individual distance.

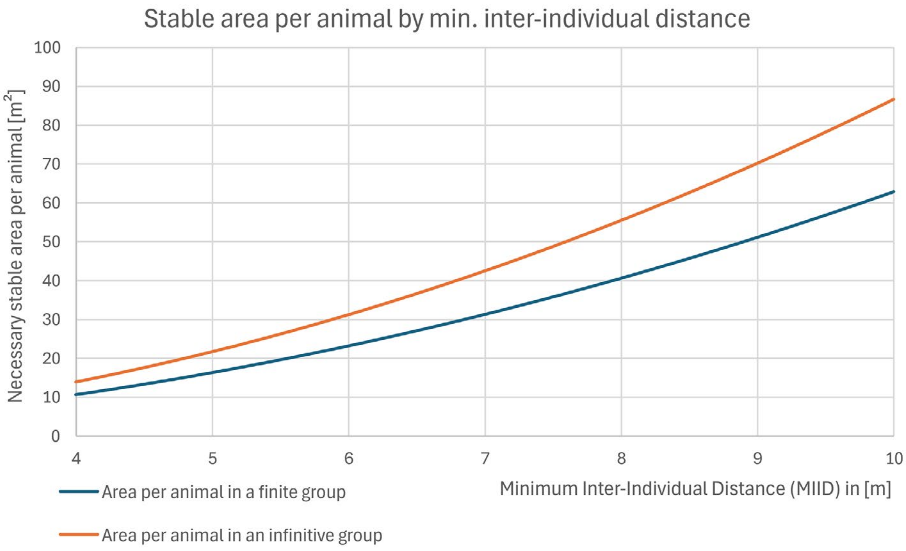

FIGURE E.10 Estimation of the relationship between minimum inter-individual distance and necessary m^2/animal assuming a rectangular pen and a group of 20 animals.

The ratio of length of the pen is for MIID from 4 to 10 m is 1.01.

Summary

The necessary lying area per cattle increases quadratically with the minimum inter-individual space.

Because the animals can use the boundaries of the pen to keep the desired minimum inter-individual distance, this effect disappears with larger groups. Thus, based on the model assumptions, larger groups need larger area per animal. The latter is limited by the space requirements per cattle of 'infinite groups'.

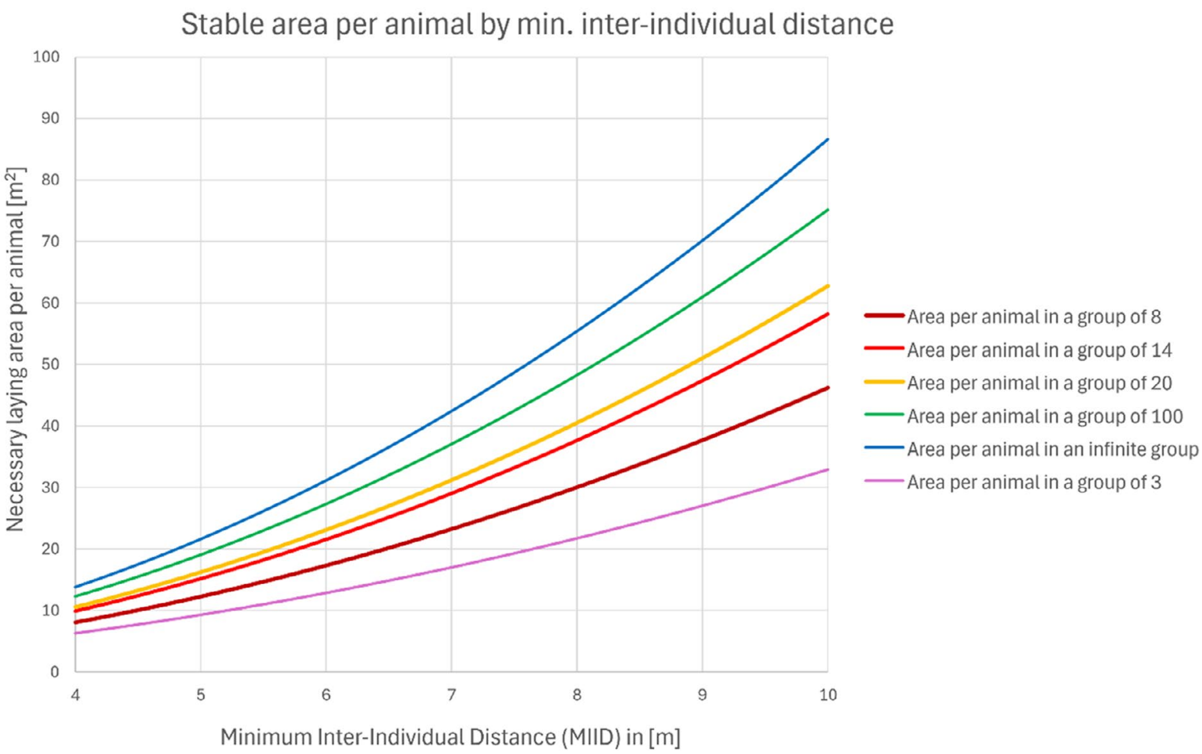

FIGURE E.11 Estimation of the relationship between minimum inter-individual distance and necessary m^2/animal assuming a rectangular pen and differently sized groups of animals.