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Investigating the impact of pre-slaughter management factors on meat quality outcomes in cattle raised for beef: A scoping review

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Introduction: The pre-slaughter management period is a critical juncture in the beef supply chain, having implications not only for animal welfare and product quality, but also for profitability. During this period, cattle are exposed to many stressors in a short time, many of which have been shown to impact meat quality. Understanding how cattle management during this terminal step in the production chain affects meat quality and economic outcomes is crucial.

Methods: The objective of this study was to investigate, synthesize, and report on research evaluating the impact of management factors during the pre-slaughter period on beef meat quality. A systematic approach was used to search for peer-reviewed and primary studies published in English in CAB Abstracts, PubMed, and Web of Science. A total of 3,217 non-duplicate records were screened for eligibility; articles were deemed eligible for inclusion if they included beef cattle in the pre-slaughter period and reported at least one meat quality outcome. After three screening rounds, 85 articles met all inclusion criteria. Data pertinent to the scoping review's aims were extracted, including study location, population characteristics, pre-slaughter factors reported, and outcomes of interest.

Results: Europe (35, 41%) and South America (21, 25%) represented approximately two-thirds of the studies. Bulls (37, 43.5%) and steers (34, 40.0%) were the most reported sex classes, with the most frequent breed types reported as predominantly British or Continental and Bos indicus breeds (24, 28.2%; 24, 28.2%, respectively). Transportation (n=46), lairage (n=36), and handling (n=35) practices were the most reported pre-slaughter factors. Overall, 59 studies reported pH as an outcome of interest – almost double that of the next highest outcome, bruising (n=35). Muscle pH was most assessed with predictors at the abattoir (n=37); conversely, the effects of transportation were most evaluated on bruising (n=23).

Discussion: A trend across all the categories was that there were relatively few studies evaluating the impact of pre-transport factors on meat quality. Charting the relevant literature is a critical step towards understanding the relationship between pre-slaughter management and end-product quality; doing so will help industry stakeholders in the beef production chain optimize management practices that improve meat quality and enhance profitability.

KEYWORDS

beef cattle, bruising, lairage, meat quality, pH, pre-slaughter management, scoping review, transport

1 Introduction

Animal well-being in the beef production chain is particularly relevant as producers, consumers, and retailers of animal-derived proteins increasingly regard food animal welfare as a chief concern (Clark et al., 2016; Wigham et al., 2018; Edwards-Callaway and Calvo-Lorenzo, 2020); this concept is reflected in many programmatic animal welfare documents and guidelines set forth by food companies (Nestle, 2014; JBS, 2019; Cargill, 2022) as well as global (OIE, 2016; GRSB, 2022) and national entities (Brazil, Macitelli et al., 2018; NAMI, 2021; Australian Animal Welfare Standards and Guidelines, 2022). Although a beef animal's welfare is impacted throughout its entire lifetime in the production chain, its welfare is particularly important during the pre-slaughter management period – this includes the time between transport from the ranch or feedlot of origin to the abattoir through the stunning or slaughter process. During the pre-slaughter period, cattle are exposed to a wide range of novel stimuli (e.g., mixing with other animals, interaction with animal handlers, new environments); consequently, cattle may become stressed or fatigued, potentially resulting in compromised welfare and subsequent adverse meat quality outcomes (Wigham et al., 2018).

A large body of work on the effect of different pre-slaughter management factors on various meat quality outcomes exists (Ferguson and Warner, 2008; Schwartzkopf-Genswein et al., 2012; Losada-Espinosa et al., 2018); still, challenges persist for examining the impacts of pre-slaughter stressors on meat quality. These challenges are not only due to the highly variable transport, handling, and lairage practices worldwide, but also because there are many intrinsic and extrinsic factors that influence meat quality outcomes. Pre-slaughter factors reported to impact meat quality outcomes include weather (Scanga et al., 1998), transport duration (Jones and Tong, 1989; Gallo et al., 2003), animal handling practices (Warriss, 1990; Frimpong et al., 2014), and lairage duration (Loredo-Osti et al., 2019; del Campo Gigena et al., 2021; Steel et al., 2021); furthermore, how these factors interact with each other to influence product quality is complex, and thus, the nature of these relationships have not been fully elucidated.

Carcass bruising and dark cutting beef, otherwise known as dark, firm, and dry (DFD) beef, are two quality defects of particular note due to their industry prevalence and implications for economic loss; in the United States, the 2016 National Beef Quality Audit (NBQA) reported 38.9% of fed steers and heifers, 42.9% of bulls, and 64.1% of cows were bruised (Eastwood et al., 2017). In Mexico, Miranda-de la Lama and others (2012) reported a 92% bruise prevalence among a population of over 8,000 beef carcasses; additionally, South American studies have reported similarly high numbers (60%, Huertas et al., 2015; 89.1%, da Silva Frasão et al., 2014), highlighting that carcass bruising is not an issue unique to North America. Yet, industry reports have estimated that carcass bruising costs the U.S. beef industry $35 million each year (Lee et al., 2017) – this significant monetary loss warrants further investigation into how and when bruising occurs along the supply chain.

Additionally, findings from 2016 NBQA identified that 1.9% of carcasses exhibited dark cutting (Boykin et al., 2017) – a costly quality defect that can result in decreased consumer eating satisfaction (Wulf et al., 2002; Węglarz, 2011; Grayson et al., 2016; Loudon et al., 2019) and a shortened shelf-life (Newton and Gill, 1981). Congruent with the findings of the 2016 NBQA, Steel et al. (2021) reported a dark cutting frequency of 2.8% in Australian beef carcasses; in contrast, Loredo-Osti et al. (2019) and Pérez-Linares et al. (2015) in Mexico and Arik and Karaca (2017) in Turkey reported substantially higher numbers (13.45%, 39%, and 24.78%, respectively). The variation in the frequency of dark cutters across the scientific literature suggests that the dark cutting condition is multifaceted, and various animal characteristics, production systems, and management factors may impact an animal's physiological reactions to stress, postmortem metabolism, and subsequently, meat quality. Furthermore, the variation in dark cutter frequency may also be explained by thresholds for classifying dark cutting across the literature, which also vary considerably (pH of 5.8 to 6.2, Jeremiah et al., 1991; 5.9 or greater, Ferguson et al., 2001; 6.0 or greater, Apple et al., 2006). Even still, the characteristic dark color associated with dark cutting beef is unfavorable to consumers and continues to have significant economic implications (Ponnampalam et al., 2017), accounting for a nearly 170-million-dollar loss to the United States beef industry annually (Underwood et al., 2007).

Although the pre-slaughter period is a necessary step in the food production chain and there has been a focus on minimizing animal fear and distress during this time by improving animal handling and management practices (Grandin, 2019; Edwards-Callaway and Calvo-Lorenzo, 2020; Grandin, 2020), cattle are subject to many inherent stressors during transport from farm to slaughter that have consequences for meat quality. To the authors' knowledge, a systematic review of the literature charting the impact of different pre-slaughter management practices on meat quality outcomes of beef cattle has not been published. This scoping review was conducted to investigate, synthesize, and report on the size and scope of the research evaluating management's impact during the pre-slaughter period on product quality. The research question was "How do pre-slaughter factors affect meat quality outcomes in cattle raised for beef?" For the global beef industry to continue to progress and evolve, understanding how cattle management during this important juncture in the food supply chain affects meat quality and economic outcomes is critical. Doing so will help inform industry stakeholders of best practices that will improve meat quality, enhance profitability, and ultimately, promote the sustainability of beef production globally.

This scoping review had two primary objectives: (1) to catalog pre-slaughter management factors that impact meat quality outcomes, and (2) to identify indicators used to evaluate the impact of pre-slaughter management factors on meat quality outcomes. The secondary objective was to gain an understanding of the relationship between the pre-slaughter phase and end-product quality.

2 Methods

Following the methodologies for performing scoping reviews first described by Arksey and O'Malley (2005) and further refined by Levac et al. (2010), as well as the reporting guidelines from the PRISMA checklist and flow diagram (Page et al., 2021), this scoping review was conducted to investigate, synthesize, and report on the size and scope of the research evaluating the impact of management factors during the pre-slaughter period on meat quality outcomes of beef cattle.

2.1 Eligibility criteria

All peer-reviewed and primary studies written in English were eligible for initial inclusion in this scoping review; no year exclusion was applied other than the default year ranges set forth by each database. The population of interest was cattle raised for beef as their primary purpose in the food supply chain during the pre-slaughter period, such as heifers and steers finished in feedlots. Cattle that became beef at some point in their lifetime, such as culled dairy cattle, were outside the scope of this particular review and therefore excluded, as meat quality is usually not a driving factor in these production systems. However, due to the highly variable nature of different beef-fattening systems globally, studies were included in the analysis when they evaluated dairy breeds and it was clear that the animals were raised for beef as their primary purpose, for example, surplus male dairy calves raised for bull beef in Spain and the United Kingdom (Rutherford et al., 2021).

For the purposes of this scoping review, the pre-slaughter period was defined as the 96 hours prior to loadout from the farm or ranch of origin through stunning or slaughter at the processing plant, which included transport and lairage, among a variety of other pre-slaughter practices and factors. Pre-slaughter factors of interest included slaughter practices, abattoir factors, feed or water management, environmental factors, handling practices, lairage practices, and transportation. Although not pre-slaughter factors, animal characteristics (e.g., breed type, sex class, animal, source, etc.), were quantified in this review due to the high proportion of studies not only reporting these population characteristics, but also acknowledging that they have some effect on cattle in the pre-slaughter period.

Articles were deemed eligible for inclusion if they met the population parameters outlined above (i.e., cattle raised for beef in the pre-slaughter period) and reported at least one meat quality outcome or carcass characteristic, or both; a key feature of a majority of the articles included in the final search was the reporting of meat quality outcomes in addition to other carcass characteristics, such as carcass weight, quality or yield grades, dressing percentage, fat thickness, and loin muscle (LM) area. The authors recognize that most of the aforementioned carcass traits will not be impacted by pre-slaughter factors, instead they are heavily influenced by animal characteristics and on-farm management practices; still, many papers reported these outcomes, so they were also quantified in this review. Meat quality outcomes of interest for this review included a wide range of outcomes. Although not an exhaustive list, the most common meat quality outcomes assessed were pH, bruising, and color. To be included in the final analysis, articles had to meet three specific criteria: (1) the population of interest (beef cattle), (2) the appropriate context (pre-slaughter period), and (3) the outcomes of interest (meat quality traits).

2.2 Search process

Three databases were used to search for all relevant articles, which included CAB Abstracts, PubMed, and Web of Science

Core Collection. Filters were used in each database to further refine the search results, which included filters for peer-reviewed, English studies. The search string refinement was an iterative process that included discussion among all of the co-authors about the population, pre-slaughter factors, and outcomes of interest; this process guided the development of a comprehensive search that would capture all articles eligible for inclusion in the analysis. The final search string was developed with the guidance of a librarian knowledgeable in conducting scoping reviews. Details about the search strings for each database can be found in Table 1.

2.3 Selection process

Citations from all three databases were downloaded to Zotero (Zotero, Fairfax, VA), an open-source citation management software, for further appraisal by another reviewer – duplicate citations were also screened for and removed at this time. This initial appraisal involved screening titles for the three inclusion criteria. Concomitantly, articles at this stage were removed based on exclusion criteria in titles; exclusion keywords included dairy, veal, poultry, broiler, swine, pig, sheep, lamb, goat, fruit, or review. In a subsequent round of screening, two reviewers independently screened abstracts; if there was a disagreement between the two reviewers, a consensus about whether to include or exclude the article was reached through discussion. In the rare occurrence that agreement could not be met after discussion among the two parties, a third party was consulted to make the final decision as to whether or not the article met all inclusion criteria. Lastly, the full text of each article that was kept after two screening rounds was retrieved and managed in Zotero. In the third and final round of screening, each full text of this final subset of articles was screened again for inclusion criteria by an independent reviewer. Although the search process was extensive and included relevant databases, the articles represented in the final search may not represent all relevant literature; for example, if a paper did not include relevant terms in the keywords, title, or abstract it may not have been captured in the selection process.

2.4 Data extraction process

After three rounds of screening, a final subset of articles was retrieved and managed in Zotero. One reviewer independently extracted data from each article pertinent to this scoping review's aims. A data extraction form was used to keep track of information about a multitude of parameters, including details relevant to the study location, population, pre-slaughter management factors (and at what time point they occurred, i.e., pre-transport, during transport, or at the abattoir), and meat quality outcomes or carcass characteristics.

3 Results

3.1 Study selection

A total of 3,747 records were obtained from three databases (CAB Abstracts, 989; PubMed, 1,713; Web of Science, 1,045) in August 2022. From those 3,747 records, 3,217 non-duplicate records were screened for inclusion in this scoping review. Citations underwent three rounds of screening in which reviewers applied inclusion and exclusion criteria to each article to determine their eligibility for inclusion in the final synthesis. After title and abstract screening, 98 full-text articles were assessed for eligibility, 13 of which were excluded for various reasons, which included wrong population, pre-slaughter management factor not assessed, non-target outcome, or non-English publication. After three rounds of screening, a total of 85 articles met the inclusion criteria and were included in the final review (*n*=85). Summary statistics were calculated in Microsoft Excel (Microsoft Corporation,

TABLE 1 Database and search string information for a scoping review on the impact of pre-slaughter management factors on meat quality outcomes in cattle raised for beef.

Database	Interface	Dates Included[1]	Search Terms (used in all databases)
CAB Abstracts	CABI	1973-2022	All fields = (fed OR native OR cattle OR heifer OR steer OR beef OR “beef cattle” OR “fed cattle” OR “fed beef” OR “grain-fed beef” OR “grain-fed cattle”) AND (“preslaughter management” OR pre slaughter OR preslaughter OR pre-slaughter OR slaughter OR antemortem OR harvest OR pre harvest OR preharvest OR pre-harvest OR abattoir) AND (transport* OR handling OR mitigation OR management OR weather OR lairage OR pens OR “holding pens”) AND (“meat quality” OR quality OR “dark cut*” OR pH OR “carcass trait*” OR “carcass characteristic*” OR performance OR bruis* OR carcass*) NOT (dairy OR veal OR poultry OR broiler* OR swine OR pig* OR sheep OR lamb* OR goat* OR fruit)
PubMed	NCBI	1950-2022	
Web of Science Core Collection	Web of Science	1945-2022	

[1]A year exclusion was not applied for any of the three databases. The date ranges depicted above represent each database's respective preset year range.

Redmond, WA) for all variables of interest. Unless otherwise indicated, the following results are reported as (*n*, percentage). More detailed information regarding the citation identification, screening, and inclusion processes is included in Figure 1.

3.2 Study characteristics

3.2.1 Article characteristics

Of the 85 articles included in the final synthesis, 36 unique journals were represented. Meat Science was the most common journal, accounting for 28.2% (*n*=24) of the articles. The second most common journal was Veterinary Record (6, 7.1%), followed by Animals, Journal of Animal Science, and Livestock Science, accounting for four articles each (4.7%), or a cumulative 14.1% (*n*=12) of the papers. Overall, publication dates ranged from 1979 – 2022, with a median publication date of 2011. Nearly half of the papers were published in the last decade (i.e., 2012 – 2022; 42, 49.4%) and thirty-four percent of articles were published within the last five years (i.e., 2017 – 2022; 29, 34.1%). The most frequent publication dates were 2019 and 2020 (8, 9.4% and 7, 8.2%, respectively).

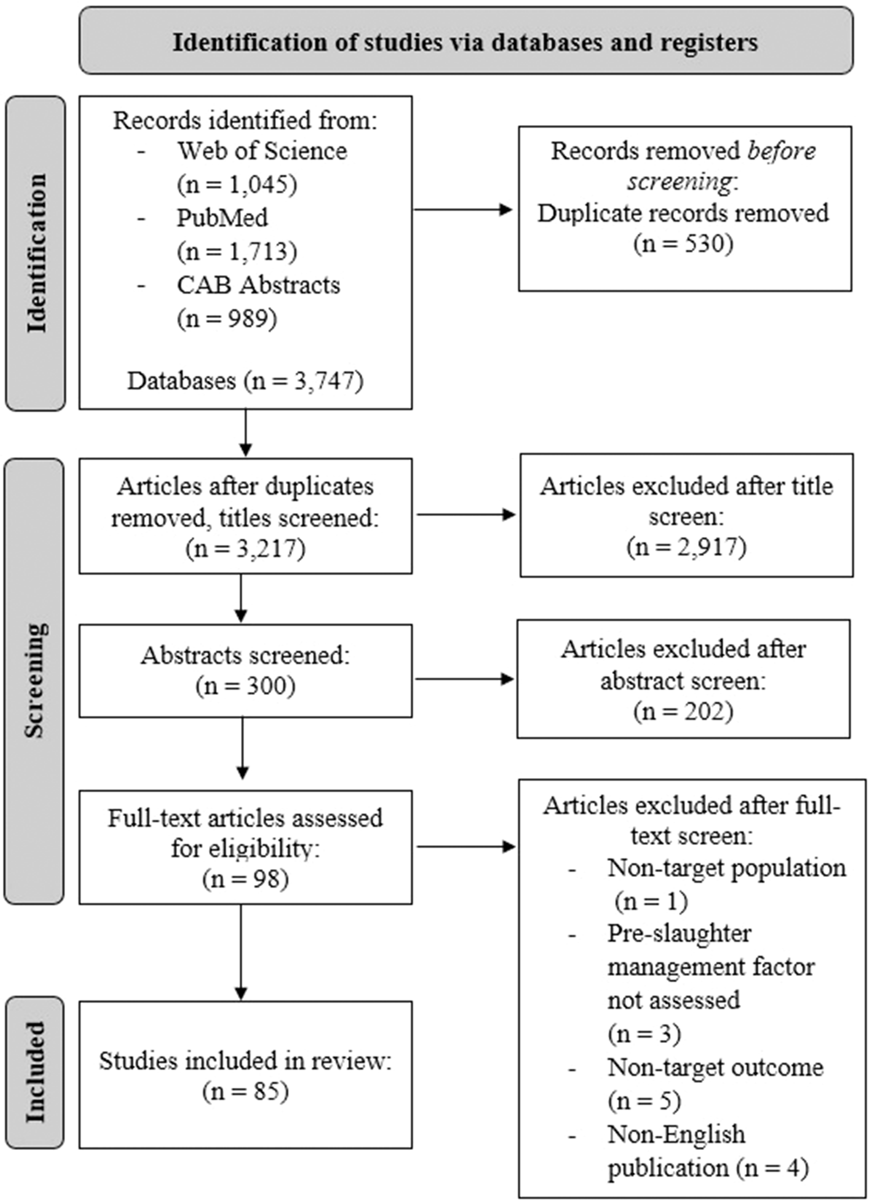


FIGURE 1
A PRISMA flow chart depicting the inclusion and exclusion of articles through three rounds of screening. The final number of articles included in the review is also represented.

3.2.2 Population characteristics

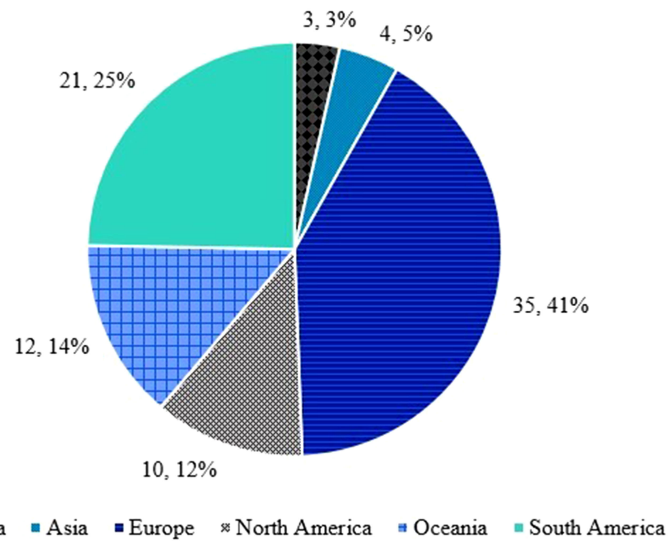
Forty-one percent (*n*=35) of studies were conducted in the European region, followed by the South American (21, 25%), Oceanic (12, 14%), and North American (10, 12%) regions. Africa and Asia represented regions with the fewest number of studies (3, 3%; 4, 5%, respectively; Figure 2). The number of animals in each study varied considerably – ranging from 16 to 2.7 million cattle; 263 was the median sample size per study. Seven (8.2%) of the 85 articles reported large sample sizes (i.e., 127,838 – 2,672,223) – these were epidemiological studies that spanned multiple years and therefore included a large number of animals. Consequently, the mean was influenced by these epidemiological studies, and thus, the mean sample size did not provide an accurate representation of the average sample size; 63.5% of the studies had sample populations of less than 500.

Regarding animal-related factors, roughly half of the studies (43, 50.5%) reported a single sex class. The remaining studies reported two or more sex classes (33, 38.8%) or none at all (9, 10.6%). Bulls, i.e., uncastrated male bovines of any age including bull calves for the purposes of this review, were the most frequent sex class reported (37, 43.5%) by any paper, followed by steers (34, 40.0%), heifers (21, 24.7%), and then cows (18, 21.2%). A small subset of articles categorized cattle as either female or male with no further specifications – these accounted for 8.2% (*n*=7) and 10.6% (*n*=9) of the papers, respectively. Fifty-six percent of the articles reported using a single breed (*n*=48), while the remaining papers reported either two or more breeds (17, 20.0%) or did not report one (20, 23.5%). Predominantly British or Continental (24, 28.2%) and Bos indicus breeds (24, 28.2%) were the most common breed types among the 85 studies, with dairy breeds (14, 16.5%) and British or Continental crosses (13, 15.3%) included in fewer studies. Approximately ten percent (9, 10.6%) of articles reported breeds native to their respective countries, e.g., native African, Chinese, Italian, and Spanish breeds, while the fewest articles reported dairy beef crosses (4, 4.7%).

3.3 Reporting characteristics

3.3.1 Pre-slaughter management factors

A key feature of many of the studies included in this review was the reporting of multiple pre-slaughter management factors, particularly at different timepoints in the final marketing phase, for example, measuring the effects of both transport and lairage duration or handling stress at loading and unloading on “x” response variable(s). Studies were grouped by the pre-slaughter management factor they evaluated, which included eight main categories: slaughter practices (*n*=5), abattoir factors (*n*=9), feed or water management (*n*=9), environmental factors (*n*=23), animal characteristics (*n*=29), handling practices (*n*=35), lairage practices (*n*=36), and transportation (*n*=46; Figure 3); a total of 55 studies (64.7%) reported pre-slaughter factors in two



[1]Geographic regions were adapted from regional groups determined by the U.S. Department of Homeland Security’s Office of Immigration Statistics.

FIGURE 2
Number of studies by geographic region[1] (*n*=85). Results are reported as (*n*, percentage).

or more of these categories. Slaughter practices included different stunning methods (e.g., electrical versus captive bolt stunning) and slaughter procedures (e.g., time between stunning and exsanguination). Abattoir factors included variables related to abattoir size and scale (Guarnido-López et al., 2022). The feed or water management category was comprised of variables relating to fasting animals prior to slaughter or providing animals with feed prior to slaughter, or both. This category also included a few studies assessing the impact of pre-slaughter administrations of a bovine appeasing substance (Cappellozza et al., 2020), glycerol (Egea et al., 2015), or other nutritional supplement on meat quality (Grumpelt et al., 2015). The next most reported pre-slaughter management category was environmental factors, which represented studies that evaluated season or weather conditions as predictors (Brown et al., 1990; Kreikemeier et al., 1998; Nanni Costa et al., 2003) or the effects of stressful conditions (e.g., noises and disturbances in the environment; Wythes et al., 1988a; Peña et al., 2014; Pighin et al., 2015; Reiche et al., 2019) on meat quality outcomes. Animal characteristics was a broad category that included animal-related factors (breed type, sex class, and horn status; Wythes et al., 1979b; Tyler et al., 1982; Fabiansson et al., 1984; Kawecki et al., 2020), as well as information relative to the animals' source, which included farm or ranch of origin (Mounier et al., 2006), marketing method (e.g., direct to abattoir versus transfer through multiple stakeholders before slaughter; Ferguson et al., 2007; Vimiso and Muchenje, 2013; Loudon et al., 2019), and production type (e.g., grass versus grain finished; del Campo Gigena et al., 2010; López-Pedrouso et al., 2020). Handling practices included factors such as prod use, handling time, or handling stress (María et al, 2004; Chacon et al., 2005; Nanni Costa et al., 2005; Nanni Costa et al., 2006). Mixing animals, whether in transport or lairage, was considered a handling practice for the purposes of this review; a total of 16 papers studied the effects of mixing during the pre-slaughter period (Bartoš et al., 1988; Lahucky et al., 1998; Lahucky et al., 1999). The lairage practices category included lairage duration (*n*=34) and pen density (*n*=4; Mach et al., 2008; Hoffman and Lühl, 2012; Romero et al., 2017; Loredo-Osti et al., 2019); just one study in this category assessed the effect of water showering in lairage during cold weather (*n*=1; Zhao et al., 2022). A notable gap in this body of work is the lack of research focused on heat mitigation during lairage. The transportation category included the most studies and included factors related to trailer motion (Kehler et al., 2022), loading density, transport distance, transport duration (Villarroel et al., 2003a; Villarroel et al., 2003b; Polkinghorne et al., 2018), transport method (e.g., truck, rail, boat, walking, etc.), and vehicle type (Silva et al., 2016; Mendonça et al., 2018; Mendonça et al., 2019; Ferreira et al., 2020). The majority of the papers in this category (37 of the 46 papers; Figure 3) evaluated transport distance or duration, or both.

3.3.2 Meat quality outcomes

Meat quality is a multifaceted term that encompasses both objective and subjective measurements; Becker (2002) categorizes meat quality outcomes into two broad categories: quality attributes and quality characteristics. Quality attributes are features of the meat that impact consumer satisfaction, such as flavor, tenderness, and juiciness, while quality characteristics are features that can be objectively measured, such as water holding capacity, quality grade, and instrumental color, (Becker, 2002). This particular scoping review includes a breadth of quality attributes and characteristics, some of which have been demonstrated to be influenced by factors in the pre-slaughter period (e.g., dark, firm, and dry beef), while others are influenced

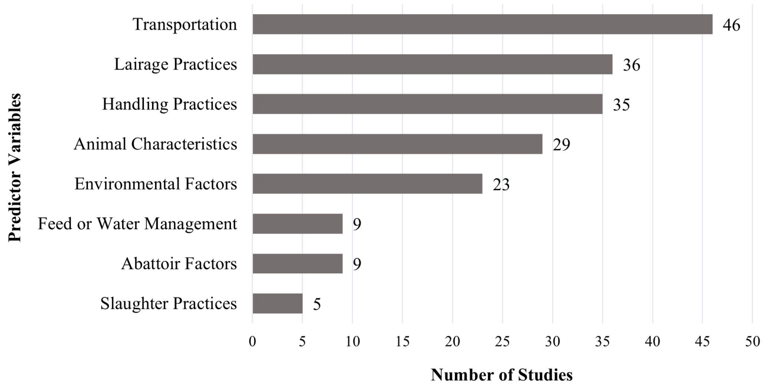


FIGURE 3
Number of studies that reported pre-slaughter management factors as predictors for meat quality outcomes (*n*=85). Pre-slaughter management factors were categorized into eight broad categories, including slaughter practices, abattoir factors, feed or water management, environmental factors, animal characteristics, handling practices, lairage practices, and transportation. Some studies may have researched more than one pre-slaughter factor.

very little by pre-slaughter stress (e.g., quality and yield grade), instead animal characteristics and feeding management plays a greater role in these outcomes. Therefore, although this review quantified many aspects of meat quality in the literature, this review's main objective was to focus on the meat quality outcomes most impacted by the pre-slaughter period.

Studies were grouped by the meat quality outcomes they evaluated, which included eight major categories: sensory traits, cooking loss, water-holding capacity (WHC), tenderness, carcass traits, color, bruising, and pH (Figure 4); the majority of the studies (51, 60.0%) reported two or more of these categories. The most frequently assessed meat quality outcome in any of the studies was pH (*n*=59; measured at approximately 24 hours post-mortem by the vast majority of the studies), followed by bruising (*n*=35), and color (*n*=30). The carcass trait category, reported in 21 studies, included a variety of carcass characteristics, such as hot carcass weight (HCW), dressing percentage, carcass fat (i.e., carcass fat score, fat thickness, and rib fat), LM area, quality grade, and yield grade. Instrumental tenderness was also evaluated in 21 studies, followed by WHC (*n*=13), cooking loss (*n*=12), and sensory traits (i.e., consumer and trained sensory panels; *n*=9; Figure 4).

Figure 5 shows the breakdown of meat quality outcomes which were assessed using predictors in each phase of pre-slaughter management – the three phases were: pre-transport (i.e., up to 96 hours prior to loading), during transport (i.e., total time in transport, including periods of rest), and at the abattoir (i.e., from unloading at the abattoir through stunning). Muscle pH was most commonly assessed with predictors at the abattoir (*n*=37), followed by the transport (*n*=31) and pre-transport (*n*=11) phases. Conversely, the effects of transportation were most commonly evaluated on bruising (*n*=23) with the fewest number of studies assessing pre-transport factors on the incidence of carcass bruising (*n*=8). A consistent trend across all of the categories was that there were relatively few studies evaluating the impact of pre-transport factors on meat quality. The remaining six categories (color, carcass traits, tenderness, WHC, cooking loss, and sensory traits) regularly reported predictors in the "at the abattoir" phase more than any of the other two phases.

Due to the variable methods for measuring carcass bruising and inconsistent reporting of results, only a subset of studies that reported bruising prevalence by a percentage of the population is depicted in Table 2. Additionally, some studies, such as Miranda-de la Lama et al. (2012) and Eastwood et al. (2017), simply benchmarked bruising prevalence in a given population and did not assess the effect of a specific pre-slaughter parameter on bruising – these studies were excluded from Table 2. In this subset of papers (*n*=21), bruise prevalence ranged from 8.6 percent to 100 percent of the populations of interest with a mean prevalence of 61.3 percent. Overall, bruise prevalence was high across all of the studies and varied by region, breed type, and sex class (Table 2). Moreover, the large variation in bruising prevalence across studies may reflect differences in methodologies for measuring carcass bruising, which differed across studies.

4 Discussion

4.1 Main findings

The primary objectives of the current study were to catalog pre-slaughter management factors that impact meat quality outcomes and to identify indicators used to evaluate the impact of pre-slaughter management factors on meat quality

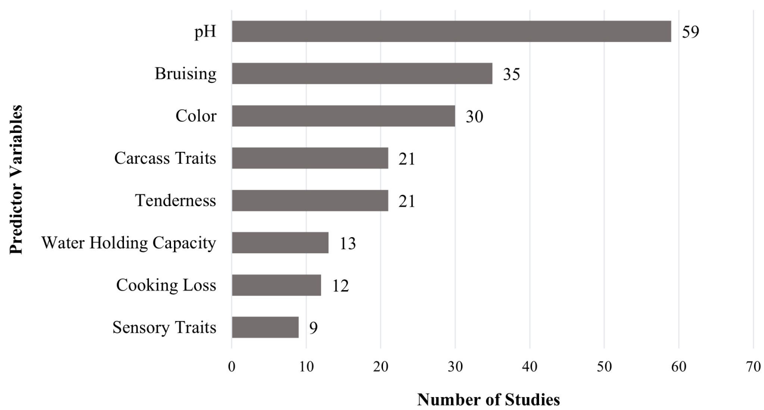


FIGURE 4
Number of studies that reported meat quality outcomes in response to pre-slaughter management factors (*n*=85). Meat quality outcomes were categorized into eight overarching categories, including sensory traits, cooking loss, water holding capacity, tenderness, carcass traits, color, bruising, and pH. Some studies may have measured more than one outcome.

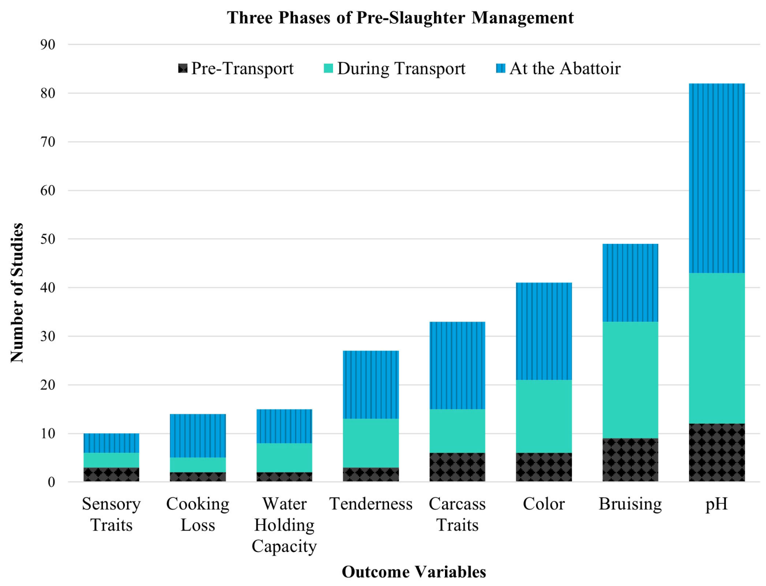


FIGURE 5
Number of studies that reported meat quality outcomes by using factors in each phase of pre-slaughter management (*n*=85). Some studies may have researched more than one pre-slaughter factor and measured more than one outcome.

outcomes. The secondary objective was to gain an understanding of the relationship between the pre-slaughter phase and end-product quality. To the authors' knowledge, this is the first global and comprehensive review of the scientific literature on the impacts of pre-slaughter management practices on meat quality outcomes for beef cattle. A total of 85 peer-reviewed journal articles were identified through a systematic search for primary studies evaluating the impact of pre-slaughter management factors on meat quality outcomes and carcass characteristics.

4.1.1 Global implications

Overall, studies assessed many different pre-slaughter management factors that encompassed all facets of this terminal step in the production chain – ranging from hours or days pre-transport (mixing groups of cattle up to 96 hours pre-transport, Wythes et al., 1979a; administering glycerol 24 hours prior to slaughter, Egea et al., 2015; fasting cattle for 48 hours prior to transport, Dodt et al., 1979) up to the time of slaughter (pre-slaughter restraint procedures, Mpamhanga and Wotton, 2015; stunning methods, Önenç and Kaya, 2004; Barrasso et al., 2022). Overall, the range of the entire pre-slaughter period varied greatly across studies, ranging from just a few hours to multiple days in length. The highly variable nature of pre-slaughter factors reported in the literature is reflective of the diversity in beef production systems globally, which include variable animal characteristics, environmental conditions, and consumer demands (Gonzalez et al., 2022). Due to these vast differences in beef production systems, studies in different geographic regions are designed to address system-specific challenges which may not be prioritized in or applicable to other areas in which cattle management differs. European and South American countries were significantly represented in this review; cumulatively, these regions comprised nearly two-thirds of the studies. This is indicative of the established beef production systems in Europe and South America – Brazil is ranked second and the European Union is ranked third in global beef production (Gonzalez et al., 2022). Additionally, South America exports the most beef globally (OECD-FAO, 2022); their responsibility to meet the expectations of high animal welfare and meat quality standards of their global trade partners is a potential reason for the extensive literature in this area. Moreover, European consumers increasingly value animal welfare; in 2016, more than half of European citizens surveyed expressed a strong concern for animal welfare (European-Commission, 2016). Historically, this increased concern and awareness of well-being of food animals has dictated demand for welfare-friendly products and influenced on-farm management practices (Veissier et al., 2008; Miranda-de la Lama et al., 2017; Alonso et al., 2020); therefore, the body of work from Europe was expected given their long-standing and robust animal welfare standards and guidelines. Contrarily, Asian and African countries were under-represented, accounting for just 8% of the studies. This under-representation may be due to the lack of substantial exports, critical harvesting capacity, and consumer demand for animal welfare. China was the world's largest beef importer in 2021 (Gonzalez et al., 2022), which potentially impacts the focus on

TABLE 2 Bruise prevalence by region, breed type, and sex class (*n*= 21).

Reference	Region	Breed Type	Sex Class(es)[1]	Bruise Prevalence, (%)[2]	*n, total*[3]
Bethancourt-Garcia et al., 2019a[4]	South America	Bos indicus	Cows, heifers, steers	17.2, 38.6	154,100
Bethancourt-Garcia et al., 2019b[4]	South America	Bos indicus	Cows, heifers, steers	20.9, 79.1	154,100
Brennecke et al., 2020	South America	Bos indicus	Heifers, steers	87, 100	270
Brito et al., 2019	South America	Bos indicus	Heifers, steers	18.4, 70.6	414
Carrasco-García et al., 2020	North America	Bos indicus	Steers	81	448
da Silva Frasão et al., 2014	South America	—	Cows	89.1	320
del Campo Gigena et al., 2021	South America	British or continental, Bos indicus	Steers	48.3	60
Ferreira et al., 2020	South America	Bos indicus	Heifers, steers	96.1, 100	701
Hoffman et al., 1998	North America	—	Cows	48.3	3,955
Huertas et al., 2018	South America	British or continental	—	90.5	8,132
Jarvis et al., 1995	Europe	British continental-cross	Bulls, heifers, steers	97	3,296
Jarvis et al., 1996	Europe	British continental-cross, Dairy	Bulls, cows, heifers, steers	99	220
Kline et al., 2020	North America	British or continental, Dairy	Bulls, cows, steers	28.1, 42.6	9,544
Liotta et al., 2007	Europe	British or continental	Bulls	35.9	28
McNally and Warriss, 1996	Europe	—	Bulls, cows, heifers, steers	59	16,600
Mendonça et al., 2018	South America	Bos indicus	Cows, steers	44, 64	4,438
Nanni Costa et al., 2005	Europe	Dairy	Bulls	72.4	105
Nanni Costa et al., 2006	Europe	British or continental	Bulls	66.9	142
Romero et al., 2013	South America	Bos indicus	Bulls, cows, heifers, steers	37.5	1,179
Strappini et al., 2010	South America	—	Cows, heifers, steers	8.6, 20.8	127,838
Vimiso and Muchenje, 2013	Africa	—	—	41.1, 63.1	315

[1]Most studies did not report individual bruising frequencies for individual sex classes; the classes indicated above simply demonstrate all of the possible sex classes that were evaluated by a study, which were often grouped into a single population.
[2]Values separated by a comma represent studies that reported a bruising prevalence for two populations, such as for different sex classes or slaughterhouses.
[3]For papers that reported bruise prevalence for two populations, this number represents the total number of carcasses assessed for bruising in a study, irrespective of population breakdown.
[4]Bethancourt-Garcia et al., 2019a and b appear to be representing the same population but this was not definitely stated in either reference.

exploring impacts on meat quality within Chinese production systems. Additionally, the harvesting capacity in many African countries is currently underdeveloped, which could contribute to the relatively lower numbers of papers found in these regions. However, the authors anticipate that as these countries' beef production systems continue to grow and evolve to meet increasing consumer demands concerning supply and animal welfare, so too will the body of work on how aspects of humane animal handling and care impact meat quality.

4.1.2 Muscle pH

Commercial transportation of livestock to slaughter has continually been identified as a factor that has implications for animal welfare and meat quality outcomes (Tarrant, 1990; Ferguson and Warner, 2008; Schwartzkopf-Genswein et al., 2012); therefore, it is not surprising that the majority of papers included in this review evaluated the effect of transport-related factors on meat quality outcomes. In total, 25 papers assessed the impact of transport distance or duration on pH; of those 25 papers, only seven observed that as cattle traveled for longer distances or durations, muscle pH increased (1 hour versus 24 hours, Tarrant et al., 1992; 92 minutes versus 265 minutes, Marenčić et al., 2012; 75-130 km versus 180-250 km, Silva et al., 2016; less than 125 km versus 300 km, Arik and Karaca, 2017; 366 km versus 1012 km, Chulayo and Muchenje, 2017; 7-10 hours versus 12-15 hours, Romero et al., 2017; 3 hours versus 12 hours, Burns et al., 2019). The remaining subset of papers (*n*=18) reported no significant findings between distance travelled and muscle pH (see for example, María et al., 2003 and Lacerda et al., 2021). The variation in transport times included in this review represents both the highly variable transport practices and regulations between different geographical locations (Twenty-Eight Hour Law, 1994; CARC, 2001; Council Regulation, 2005).

Under conditions of high metabolic demand, i.e., chronic pre-slaughter stress, initiation of the sympathetic nervous system drives the antemortem breakdown of muscle glycogen, disrupting the muscle's normal postmortem metabolism and thus reducing pH decline. This cascade of events results in a higher ultimate muscle pH producing a lean with a characteristic dark, purplish-red color; this combination of parameters results in what is referred to as dark cutting beef (DCB). The major challenge associated with evaluating and managing the dark cutting condition in cattle is that the cause of DCB is multifactorial, and factors contributing to its prevalence are found throughout the supply chain, beginning with on-farm management and ending with lairage at the abattoir. Not only are cattle subjected to novel humans, animals, and environments during this time, but they may also experience social disruption, feed and water deprivation, and weather extremes, among various other stressors (Ferguson and Warner, 2008; Edwards-Callaway and Calvo Lorenzo, 2020); thus, attributing the occurrence of dark cutting to a single pre-slaughter factor is difficult and may explain the variable results demonstrated across the scientific literature. Additionally, the inconsistent findings may be, in part, due to the range of breed types and sex classes evaluated in the literature, as previous research has reported that animal-related factors (i.e., breed type, sex class, age) may also influence the incidence of dark cutting (Scanga et al., 1998; Page et al., 2001). There are many other quality defects associated with DCB aside from its characteristic dark color, many of which were assessed in studies included in this review – these defects include reduced tenderness (Carrasco-García et al., 2020; Sierra et al., 2021), higher water holding capacity (Arik and Karaca, 2017), and poor palatability (Węglarz, 2011; Loudon et al., 2019). In commercial settings, lean color is most often assessed visually due to its association with high muscle pH (Page et al., 2001), however, more objective measures for classifying DCB have been identified, including instrumental color and pH measurements which are more often used in research settings. The authors suggest that a potential reason for the relatively greater number of studies that assessed pH and bruising were due to the ability for researchers to collect these measurements in a plant setting, compared to other instrumental measurements for tenderness and cooking loss, for example, which require samples to be taken from the plant for further laboratory analysis.

A consistent trend across all of the papers was using pre-slaughter factors at the abattoir, i.e., the time from unloading at the plant through stunning or slaughter, to evaluate meat quality outcomes. As an example, the effect of lairage duration on muscle pH was a concept that was extensively explored. The relatively high number of studies assessing the effect of lairage practices on meat pH is not surprising given the opportunity for cattle to be exposed to a multitude of novel stimuli during this time; in holding pens, cattle may be mixed with unfamiliar animals, deprived of feed for extended periods, exposed to variable weather conditions, and experience increased handling intensity. Lairage conditions and duration tend to vary by region; for example, fed cattle in North American plants are typically processed on their arrival day and spend relatively short periods in holding pens (personal communication, L.N. Edwards-Callaway), while Oceanic and South American countries tend to have more extended lairage periods to allow animals to rest after long transport (Ferguson and Warner, 2008). This concept was reflected in the studies presented in this scoping review, as conditions and duration of lairage varied substantially across regions, e.g., lairage duration ranged from hours (del Campo Gigena et al., 2021) to multiple days (Liotta et al., 2007). Overall, many papers assessed the effect of lairage duration on muscle pH, of which only three evaluated the impact of pen density on the quality outcome. The relatively few numbers of studies assessing pen density on pH was surprising as overcrowding cattle in lairage pens may impact their ability to access water, comfortably lie down, and move around freely – all of which could have an impact on muscle pH if cattle are overcrowded for extended periods of time and unable to rest and rehydrate. Some studies discovered a significant association between longer lairage times and high muscle pH (Wythes et al., 1988b; Strappini et al., 2010; Loredo-Osti et al., 2019; Steel et al., 2021) while others discovered the opposite (i.e., as lairage duration increased, pH decreased, Warriss et al., 1984; Bartoš et al., 1993; Kuzmanovic and Elabjer, 2000; Teke et al., 2014). A potential explanation for the studies that reported that longer lairage times lowered muscle pH is that cattle may have been able to restore their glycogen stores partially or completely before slaughter, therefore avoiding the dark cutting condition; however, research has demonstrated that the glycogen repletion rate in muscles of stressed cattle is slow (i.e., 1.5 μmoles/g/day; Tarrant, 1989). In order for cattle to replenish glycogen stores antemortem certain conditions need to be met, such as resting and refeeding, which has been shown to increase glycogen repletion to 6.3 μmoles/g/day (Tarrant, 1989) and subsequently, lower muscle pH (Shorthose et al., 1972; Wythes et al., 1980; Warriss et al., 1984). Even though there is conflicting research on the topic, existing evidence suggests that there could be an association between lairage time and dark cutting carcasses (i.e., the incidence of dark cutting increases with longer lairage). Still, more research is needed to fully understand this relationship. We postulate that since dark cutting is the result of chronic pre-slaughter stress, it may be possible that although animals become agitated and fatigued during this period, their stressors are not intense enough to drive the depletion of muscle glycogen and thus, contribute to the occurrence of dark cutting. Taken together, the existing body of work on lairage management on meat quality outcomes warrants future investigation into what is an optimal duration of rest, recognizing that this may be influenced by many animal and environmental factors; additionally, certain slaughter plants may not be able to accommodate ideal lairage times due to both purchasing and scheduling logistics, and facility limitations.

4.1.3 Carcass bruising

From the 15 papers that assessed the effect of transport distance or duration on carcass bruising, eight papers reported significant findings (i.e., longer transport increased bruising incidence; Jarvis et al., 1995; McNally and Warriss, 1996; Hoffman et al., 1998; Vimiso and Muchenje, 2013; Silva et al., 2016; Mendonça et al., 2018; Bethancourt-Garcia et al., 2019a; Brito et al., 2019). Similar to evaluating the effects of transport on muscle pH, ample challenges exist for assessing and managing bruising as there are multiple opportunities for bruising to occur along the supply chain (e.g., mixing cattle with different horn statuses, Shaw et al., 1976; Wythes et al., 1979b; high stocking densities, Tarrant et al., 1988; Brennecke et al., 2020; Ferreira et al., 2020; rough pre-slaughter handling conditions, Jarvis et al., 1995; McNally and Warriss, 1996; Mendonça et al., 2018).

Bruising is a quality issue that also has a significant welfare component; not only is bruised meat removed from the carcass at the slaughter plant and not used for human consumption, but also animals experience some level of fear, distress, or pain during an event that would cause an impactful bruise (Edwards-Callaway and Kline, 2020). The loss from bruising comes from the actual reduction in yield from bruise removal, the devaluing of cuts that may have been partially impacted by a bruise, the increased labor required to remove the bruises during processing, and the reduced efficiency associated with slower line speeds (McNally and Warriss, 1996; Edwards-Callaway and Kline, 2020). The economic impact of bruising is substantial and has been estimated to cost the beef industry in the millions or billions of dollars annually depending on the country (Huertas et al., 2015; Henderson, 2016; Lee et al., 2017), thus incentivizing producers and processors to focus on identifying management practices that could reduce bruise prevalence.

The prevalence of bruising across studies is highly variable, ranging from 8.6% to 100% (Table 2). Although there were several studies reporting bruise frequency of less than 25% for at least one population group (Bethancourt-Garcia et al., 2019a, b; Strappini et al., 2010; Brito et al., 2019), the majority of studies reported relatively high bruise prevalence with some reporting over 90% bruising (Jarvis et al., 1995; Jarvis et al., 1996; Huertas et al., 2018; Brennecke et al., 2020; Ferreira et al., 2020) in their study populations. Although not all bruises are the same size or severity, these bruise frequencies are substantial and cause concern both from an economic and welfare standpoint. Interestingly, the majority of studies assessing pre-slaughter management on bruising were conducted in South America, and although the impact of transportation characteristics on bruise prevalence is not consistent across studies, it is worth considering the transport conditions in South American countries. Although published statistics on average transport distance, routes, and times across countries are scarce, in South America, most beef production systems are pasture-based (Gonzalez et al., 2022), and these more remote or rural regions of cattle production could have challenges with transport infrastructure (McManus et al., 2016) that may have a downstream impact on bruising.

Bruises vary in size, shape, location, pattern, and severity which all contribute to determining what could have caused the injury (Edwards-Callaway and Kline, 2020). It is challenging to compare bruise prevalence across studies primarily due to the range of methodologies used to quantify and characterize bruising. Often studies will report the presence or absence of bruises (i.e., the frequency of bruising) in addition to the location on the carcass (Kline et al., 2020; Teiga-Teixeira et al., 2021). Many studies will use some type of carcass map in order to identify the location of the bruise (Strappini et al., 2012; Romero et al., 2013; Mendonça et al., 2019; Bethancourt-Garcia et al., 2019a; Bethancourt-Garcia et al., 2019b; Kline et al., 2020); although these maps do vary, the general concept of dividing the carcass into clear regions remains consistent across studies. In order to estimate the economic loss from bruising it is necessary to have some evaluation of size and weight of the bruise in addition to location. The NBQA has utilized a bruise scoring system based on a visual estimation of the weight of the bruise using a 10-point scale which are collapsed into broader classifications (i.e., minimal, major, critical, and extreme; Texas A & M University, 2016). Another commonly used scoring system is the Australian Carcass Bruise Score System (Anderson and Horder, 1979) which uses an estimate of bruise diameter to calculate a surface area of the bruise which is then categorized as slight, medium, or heavy; many studies in this scoping review used this methodology for quantifying carcass bruising (Wythes et al., 1979a; Wythes et al., 1979b; Wythes et al., 1985; Tarrant et al., 1988; Wythes et al., 1989; Tarrant et al., 1992; Romero et al., 2013; Vimiso and Muchenje, 2013). With any of these described systems it is important to assess interobserver reliability as many of the systems require using visual observation to make estimates of length or weight which can be challenging. Additionally, some of the systems are highly complicated, and although manageable in research settings, they would not necessarily be beneficial in a commercial setting to track bruising internally. Because bruising can only be assessed during post-mortem processing, studying factors that may impact bruising is challenging; numerous observations must be made ante-mortem and individual animal or group (i.e., lot) information must be tracked through the slaughter process, which can require substantial data collection inputs depending on the facility. Some studies have measured bruise age by visual appraisal using the method described by Gracey et al. (1999) to determine when during the pre-slaughter process bruising could have occurred (Hoffman and Lühl, 2012; Vimiso and Muchenje, 2013; Mpakama et al., 2014). Although bruise color does change with age, visual appraisal may not be the preferable method of assessment due to low reliability and accuracy (Strappini et al., 2009).

4.1.4 Beef sensory quality

Fulfilling our second primary objective, which was to identify indicators used to evaluate the impact of pre-slaughter management factors on meat quality outcomes, the authors discussed in depth the implications of the pre-slaughter period on the most commonly reported meat quality outcomes in the literature – carcass bruising and postmortem muscle pH. The remaining meat quality categories, tenderness, water-holding capacity, cooking losses, and sensory traits, did not warrant extensive discussion in this review as relatively few studies overall assessed the effects of pre-slaughter factors on these specific outcomes. However, we would be remiss not to discuss that tenderness is one of the most important drivers of beef palatability, alongside juiciness and flavor, (O'Quinn et al., 2018), which can be impacted by an abundance of pre-harvest (e.g., breed and age of animal, production system, stress prior to harvest, etc.) and post-harvest (e.g., in-plant practices, ageing method and length, packaging system, cooking method, etc.) factors (Santos et al., 2021). In the subset of papers that measured instrumental tenderness, there was conflicting results on the influence of the pre-slaughter period on tenderness; for example, some papers observed that longer transport decreased tenderness (Warner-Bratzler shear force, Guarnido-López et al., 2022; trained sensory panel, Villarroel et al., 2003a), while more studies observed no effect of transport on tenderness at all (María et al., 2003; Ferreira et al., 2006; Polkinghorne et al., 2018; Lacerda et al., 2021); there was a similar trend for the effect of the lairage period on tenderness. Due to the multifaceted influence of pre and post harvest factors on tenderness, quantifying the effect of the pre-slaughter period on this quality attribute is challenging – a common theme discussed in many of the papers assessing the impact of pre-slaughter stressors on tenderness included in this review (see for example, Ferguson et al., 2007; Gruber et al., 2010; Polkinghorne et al., 2018). Taken together, this body of work suggests that the pre-slaughter period has a relatively minor influence on beef tenderness (independent of differences in muscle pH) and that other pre-harvest variables, such as production type (e.g., grass-fed vs grain fed), breed or breed-type (e.g., Bos indicus vs Bos Taurus), supplements (e.g., beta-agonist-fed vs beta-agonist-free), and age of animal, likely contribute more significantly to measurable differences in tenderness.

4.1.5 Gaps in knowledge

As demonstrated by this review, a critical gap in research exists regarding the effect of heat mitigation during lairage on various outcomes; from the 85 studies included in this review, only one quantified the effects of water showering in lairage on beef meat quality (Zhao et al., 2022); it is important to note that this study was conducted in cold weather and does not necessarily contribute to the body of work on heat mitigation. Little industry information exists quantifying heat mitigation strategies and effectiveness throughout the beef supply chain. However, a recent survey of beef cattle processors characterized the use of different heat abatement strategies at slaughter plants in the United States; Davis and others (2022) reported that sprinklers or misters were most commonly used among beef processors. When asked if heat mitigation provides benefits during lairage, one survey respondent stated that the use of heat mitigation results in *"quality benefits such as reduced dark cutters,"* while others stated that heat abatement results in *"less stress"* and cattle that *"are more comfortable"* (Davis et al., 2022); this preliminary data from the United States suggests that processing plants both appreciate and value the benefits of heat mitigation on animal welfare and quality outcomes, which is not congruent with the available literature in this area. In a comprehensive review of the impacts of shade on cattle well-being, Edwards-Callaway and others (2021) highlighted the need to quantify the effects of shade on cattle at packing plants due to the importance of heat stress to animal welfare and economic performance outcomes. While no studies to date have been performed to assess the impact of heat mitigation during lairage on meat quality outcomes, multiple studies have assessed the use of shade in feedlot settings and found that shaded cattle experienced less heat stress and better performance outcomes (e.g., higher dry-matter intake, average daily gain, and final body weight) than unshaded cattle (Mitlöhner et al., 2002; Sullivan et al., 2011; Hagenmaier et al., 2016). More strikingly, Mitlöhner et al. (2002) found that shaded feedlot cattle experienced an approximate 50% reduction in dark cutting compared to unshaded cattle. Additionally, several studies have reported that weather significantly affects the occurrence of dark cutters (Scanga et al., 1998; Marenčić et al., 2012; Steel et al., 2021), which warrants further consideration into how implementing heat abatement strategies during lairage, while even in the short-term, may impact meat quality. The authors anticipate that the focus of heat mitigation on cattle well-being and meat quality will begin to intensify as global climate change continues to evolve and have ramifications for extreme weather events, drought, and cattle death loss associated with extreme heat stress.

4.1.6 Limitations

Three electronic databases were used to search for literature pertaining to the impact of pre-slaughter management factors on meat quality outcomes. The final search string was developed with the guidance of a librarian knowledgeable in conducting scoping reviews, thereby increasing the quality and rigor of this particular review. A limitation of this study, however, is that a single reviewer screened all of the full-text articles for inclusion criteria, potentially introducing bias into the included papers. Additionally, the population of interest for this review was restricted to cattle in the food supply chain destined to become beef as their primary purpose, which limited the scope of our search. For example, in the United States, the cull cow market represents a significant component of the beef supply chain accounting for nearly 20% of the U.S. beef supply annually (USDA-NASS, 2021), yet we did not capture this important population. The welfare of cull cattle in the final marketing phase is of particular concern since they are exchanged through multiple stakeholders and travel longer distances on their journeys to specialized processing plants (USDA, 2018; Edwards-Callaway et al., 2019). Similar challenges associated with the transport of cull cattle to slaughter have been identified in Europe (Dahl-Pedersen et al., 2018) and Canada (Stojkov et al., 2020). Due to the difference in welfare challenges and meat quality priorities, this type of animal was not included in this scoping review. Future research is needed to understand the impacts of the pre-slaughter phase on this more vulnerable population. Lastly, the exclusion of non-English studies restricted the scope of this review by potentially precluding important research that has contributed to key findings in this body of work.

4.1.7 Conclusions

Following the methodologies for performing scoping reviews first described by Arksey and O'Malley (2005) and further refined by Levac et al. (2010), as well as the reporting guidelines from the PRISMA checklist and flow diagram (Page et al., 2021), this scoping review was conducted to investigate, synthesize, and report on research evaluating the impact of management factors during the pre-slaughter period on meat quality outcomes for beef cattle. Most of the research in this space has assessed the effects of transportation, lairage, and handling practices on a suite of meat quality outcomes, primarily muscle pH, bruising, and color. However, the complexity of the pre-slaughter period poses many challenges for assessing and managing meat quality issues associated with stress before slaughter. Except for bruising (which was mainly evaluated with predictors related to transport), studies evaluated the remaining meat quality categories with predictors at the abattoir (e.g., lairage duration and density, slaughterhouse handling practices, mixing groups of cattle, etc.). A common trend across all categories was that relatively few studies evaluated the impact of pre-transport factors on product quality. The substantial variation in findings across all the studies included in the review and inconsistent reporting of those results is evidence of the challenges associated with quantifying the impact of the pre-slaughter period on meat quality. Future research should consider implementing large-scale research endeavors to better account for variations in animal characteristics and management practices so that the relationship between management during the pre-slaughter period and meat quality outcomes may be more fully elucidated; charting the relevant literature's main findings and research gaps is an important step towards this goal.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

PS, MD, and LE-C conceived and designed the study. JB advised on the methodology and provided technical advice. PS conducted the formal search and analysis and led the writing of the original draft. MD, LE-C and JB provided editing and review of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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