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BOARD INVITED REVIEW

# Impacts of shade on cattle well-being in the beef supply chain

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## Abstract

Shade is a mechanism to reduce heat load providing cattle with an environment supportive of their welfare needs. Although heat stress has been extensively reviewed, researched, and addressed in dairy production systems, it has not been investigated in the same manner in the beef cattle supply chain. Like all animals, beef cattle are susceptible to heat stress if they are unable to dissipate heat during times of elevated ambient temperatures. There are many factors that impact heat stress susceptibility in beef cattle throughout the different supply chain sectors, many of which relate to the production system, that is, availability of shade, microclimate of environment, and nutrition management. The results from studies evaluating the effects of shade on production and welfare are difficult to compare due to variation in structural design, construction materials used, height, shape, and area of shade provided. Additionally, depending on operation location, shade may or may not be beneficial during all times of the year, which can influence the decision to make shade a permanent part of management systems. Shade has been shown to lessen the physiologic response of cattle to heat stress. Shaded cattle exhibit lower respiration rates, body temperatures, and panting scores compared with unshaded cattle in weather that increases the risk of heat stress. Results from studies investigating the provision of shade indicate that cattle seek shade in hot weather. The impact of shade on behavioral patterns is inconsistent in the current body of research, with some studies indicating that shade provision impacts behavior and other studies reporting no difference between shaded and unshaded groups. Analysis of performance and carcass characteristics across feedlot studies demonstrated that shaded cattle had increased ADG, improved feed efficiency, HCW, and dressing percentage when compared with cattle without shade. Despite the documented benefits of shade, current industry statistics, although severely limited in scope, indicate low shade implementation rates in feedlots and data in other supply chain sectors do not exist. Industry guidelines and third-party on-farm certification programs articulate the critical need for protection from extreme weather but are not consistent in providing specific recommendations and requirements. Future efforts should include: updated economic analyses of cost vs. benefit of shade implementation, exploration of producer perspectives and needs relative to shade, consideration of shade impacts in the cow–calf and slaughter plant segments of the supply chain, and integration of indicators of affective (mental) state and preference in research studies to enhance the holistic assessment of cattle welfare.

**Key words:** animal welfare, beef cattle, heat stress, performance, shade, well-being

**Abbreviations**

| | |
|---|---|
| AABP | American Association of Bovine Practitioners |
| GAP | Global Animal Partnership |
| MARC | U.S. Meat Animal Research Center |
| MLA | Meat & Livestock Australia |
| NAHMS | National Animal Health Monitoring System |
| NCBA | National Cattlemen's Beef Association |
| THI | temperature humidity index |

## Introduction

What is the impact of shade implementation on cattle welfare in beef production systems? The function of shade is to reduce the thermal load on cattle in environmental conditions that are above their thermoneutral zone by reducing the solar load, thus changing the microclimate and ultimately reducing the risk and consequences of heat stress. Shade is not the only strategy that can be used to mitigate the impacts of extreme heat in cattle production systems. However, it is an environmental modification that has been explored to a relatively greater degree in research on beef cattle as compared with other modifications such as fans and sprinklers. Shade structures also have the potential to more easily be adapted into a greater variety of facility designs in the sectors of the cattle industry, as they do not rely on other resource inputs such as electricity and water to function. Shade design and implementation are an integral component of beef cattle production in other countries such as Australia, and, thus, there are many resources available to explore the effectiveness of various shade structures and materials. Additionally, heat stress and mitigation strategies, including shade, and its impacts on cattle welfare have been widely studied in dairy production systems (reviewed by Polsky and von Keyserlingk, 2017) and thus provide a body of knowledge that can be applied to other production schemes.

The increased focus on heat stress management in cattle production is being driven by numerous factors, including but not limited to an increased number of extreme weather events and climate variability, increased number of cattle in feedlots, increased demands for efficiency/growth in feedlots, changing cattle demographics, and increased societal concern with animal welfare (Brown-Brandl et al., 2003). Escalating global temperatures have brought heat stress and the need for heat abatement strategies to the forefront of cattle welfare discussions. Many reviews on heat stress or impacts of shade on the welfare of cattle begin by identifying the critical need to address the impacts of increasing global temperatures (Foust and Headlee, 2017; Polsky and von Keyserlingk, 2017; Herbut et al., 2019; Lees et al., 2019). In the United States, several heat waves in the recent past have caused extensive death loss in feedlots, costing the industry millions of dollars in lost revenue (Busby and Loy, 1997; Hahn and Mader, 1997; Brown-Brandl et al., 2006a, 2006b; Associated Press, 2017). In addition to large numbers of animals dying, the impacts of heat stress on cattle that survive can negatively influence their well-being and performance. An economic analysis published by St-Pierre et al. (2003) indicated that the consequences of heat stress result in estimated losses of US$1.69 to 2.36 billion annually to the U.S. livestock industry with an average of US$369 million of that loss attributed to the beef industry alone. A survey study of beef producers after a 1995 heat event in Iowa reported that non-shaded lots experienced substantially greater death loss than shaded lots, 4.8% vs. 0.2%, respectively (Busby and Loy, 1997). Considering the changes seen in weather, global climate, markets, and cattle characteristics that have occurred since the St-Pierre et al. (2003) economic assessment, loss estimates may be conservative given the present conditions.

There is not a cohesive belief within the cattle industry that the benefits of shade outweigh the economic investment or that there are even benefits to shade depending on the region within the United States where the cattle operation is located. One report referred to the need for shade as a "perceived need" during times of extreme heat events, but that actual research is inconclusive (Binns et al., 2003). Curtis (1983) is cited as suggesting that the lack of conclusive results regarding impacts of providing shade on animal production and welfare outcomes is in part due to the complexity of shade design combined with the diversity of animal and environment interactions. Although this variation likely impacts conclusions on the benefits of providing shade, a substantial body of research has since been added to the knowledge base on shade impacts and warrants further review. Additionally, the variation in climates across the United States adds to the diverse opinions regarding the need for shade; dependent upon weather patterns, where some areas within the United States may not require shade but others areas may benefit (animal well-being, performance, etc.) from providing shade to cattle.

Traditionally, shade studies have centered on outcomes related to performance and physiological changes indicative of stress, but animal welfare is multifaceted and includes many other components beyond health and performance that should be considered in determining the need to provide shade. Polsky and von Keyserlingk (2017) published a review on heat stress in dairy cattle utilizing Fraser et al.'s (1997) three orientations of welfare (biological functioning, affective states, and natural living) as a framework for the discussion. The review did a commendable job describing the impacts of heat stress on the overall welfare rather than just assessing factors directly related to productivity. In the context of Fraser's three orientations, the overall impacts of heat stress on cattle welfare are described by Polsky and von Keyserlingk (2017) with an illustration of a dairy cow unable to find shade in the heat. The cow's inability to use/find shade on a hot day impacts the cow's ability to express natural behavior, which causes discomfort, resulting in a negative affective (mental) state, with lack of shade also impacting biological functioning and subsequent productivity. Although this description uses a dairy cow to demonstrate heat stress impacts on welfare, the focal animal can easily be substituted with a beef cow on pasture, a steer in a feedlot, or an animal in the lairage pens at a slaughter plant. To date, heat stress impacts on the different sectors of the beef supply chain have not garnered the same attention as dairy cattle. The level of heat stress is related to both the animal and the environment; therefore, the degree and impacts of heat stress on cattle in different production systems (e.g., sectors of the beef industry) are variable. The effect of heat stress is perhaps easier to recognize in the dairy cow, as milk production losses due to heat stress are often observed after extreme ambient heat exposure (Collier et al., 1981). In feedlot cattle, growth performance losses may not be immediately obvious or may go unnoticed until slaughter. However, same-day reductions in DMI are often observed in commercial feedlots during extreme episodes of heat exposure. Daily DMI for unshaded cattle was reduced nearly 17% on days when the maximum temperature humidity index (**THI**; Thom, 1959) was classified in the emergency (≥

84) category as compared with the normal (THI < 74), alert (74 ≤ THI < 78), or danger (78 ≤ THI < 84) categories (Brown-Brandl et al., 2005). Curtis et al. (2017) demonstrated no significant correlation between daily DMI and same-day environmental measurements but reported a 3- to 5-d delay in DMI response. Welfare consequences can be serious and imminent; therefore, shade provision in beef cattle is worthy of discussion.

Despite the provision of shade being a required environmental component in many certified beef cattle care programs (GAP, 2009; American Humane, 2017; Certified Humane, 2019), the lack of shade cited as a current welfare challenge in outdoor cattle production systems (Grandin, 2016), and the negative cattle welfare and economic consequences of extreme heat events (Busby and Loy, 1997; Hahn and Mader, 1997; Entwistle et al., 2000; Brown-Brandl et al., 2006a, 2006b; Associated Press, 2017), the adoption of adding shade structures into beef cattle production systems has been rather limited and slow to progress in the United States. Although there are multiple management strategies that can help mitigate the effects of thermal stress on cattle (e.g., genetic development, nutritional management, and physical modification of the environment; Beede and Collier, 1986; Lees et al., 2019), this review will discuss the consequences of shade use on cattle welfare throughout the beef production cycle. The objective of this paper is to review shade as a strategy to alleviate the negative consequences of heat stress in cattle within the beef supply chain (i.e., cow–calf, stocker, feedlot, and slaughter plant).

## Heat Stress 101

Livestock can adapt to a broad range of environmental stressors in order to maintain homeostasis. These adaptive responses involve behavioral and physiological changes that are advantageous, but prolonged exposure can pose serious animal welfare concerns. Chronic hyperthermia, or heat stress, impacts all sectors of the beef industry by decreasing performance and reproductive efficiency and altering animal health, well-being, and behavior. Heat stress describes conditions that cause an animal's core body temperature to exceed the thermoneutral range in which the animal cannot compensate with heat dissipation. Increases in ambient temperature, humidity, solar radiation, and wind speed all contribute to environmental conditions that induce heat stress (Bernabucci et al., 2010; Belhadj Slimen et al., 2016). As body temperature increases, the animal responds with a series of physiological and behavioral changes in an effort to reduce heat load. The consequences of heat stress on physiology and behavior of cattle have been extensively studied in dairy cattle (e.g., Kadzere et al., 2002; Das et al., 2016; Polsky and von Keyserlingk, 2017; Herbut et al., 2019) and feedlot cattle (e.g., Hahn, 1999; Brown-Brandl et al., 2003, 2005, 2006a; Eigenberg et al., 2005; Mader et al., 2006; Gaughan et al., 2010; Lees et al., 2019) with limited review in the cow–calf sector. Although many mechanisms are consistent between dairy and beef cattle, this section will briefly describe the consequences of heat stress on beef cattle specifically as a framework for discussing the impacts of shade on beef cattle welfare in subsequent sections. Figure 1 provides a visual representation of cattle coping mechanisms during heat stress, indicating the direct impact these physiological and behavioral changes have on the overall cattle welfare.

Mammals have an evolved set of thermoregulatory behaviors that serve to hasten the return to homeostasis when the body temperature rises above or below the hypothalamic set point which, therefore, improves the chances of survival (Hafez, 1964). The preoptic area of the hypothalamus activates behavioral and physiological cooling mechanisms in response to an increase in body temperature (Baker, 1989; Silanikove, 2000). Cattle will dissipate heat by latent or sensible heat loss through evaporation and heat exchange with the environment, respectively. At low temperatures, heat is lost by sensible heat transfer with the environment through conduction (contact with a cooler surface), convection (air movement), and radiation (transfer without contact; Maia et al., 2005). However, at high temperatures, the body gains heat through conduction, convection, and radiation; thus, most of the heat is lost through latent heat dissipation. Initial efforts to thermoregulate with latent heat dissipation involve evaporative cooling by way of sweating and increased respiration (Blackshaw and Blackshaw, 1994; Gaughan et al., 2000). However, increased respiration and panting can disturb the balance of $CO_2$ expired vs. $CO_2$ in the blood, reducing the amount of carbonic acid formed, increasing blood pH, and ultimately altering blood acid–base balance enough to cause respiratory alkalosis, and, if not corrected, it can induce a metabolic acidosis (Sanchez et al., 1994; West, 2003). Due to water loss during these physiological processes of heat dissipation, increased water intake becomes crucial to prevent dehydration, aids in electrolyte balance, and provides small amounts of thermal heat reduction. As panting occurs, blood flow is rerouted to the respiratory muscles, nasal mucosa, and upper respiratory tract to aid in evaporative heat loss and brain cooling (Robertshaw, 2006). Throughout the body, blood is also routed toward the skin as vasodilation occurs to increase heat loss; however, it has been suggested that this is not as effective in cattle due to their size (Silanikove, 2000). Additionally, animals will attempt to reduce metabolic heat production, as it is responsible for approximately one-third of the heat load in an animal (Finch, 1986). The first step in this process appears to be reduced feed intake that decreases heat of fermentation and heat increment. Decreased DMI is attributed to appetite suppression by leptin, as leptin production activates the cooling center within the hypothalamus and causes satiety (Albright and Alliston, 1971; Silanikove, 2000). Previous studies have reported that decreased DMI begins around an ambient temperature of 30 °C with relative humidity below 80% (Hahn, 1999; Renaudeau et al., 2012). Reduced DMI has direct negative effects on subsequent performance, with potential health and well-being impacts as well.

Production is not only affected by reduced DMI but also by altered endocrine status, nutrient utilization, and maintenance requirements. In dairy cattle, reduced DMI with increased maintenance requirements causes body weight loss, especially those in high production status, such as growing calves and pregnant or lactating cows (Collier et al., 2005). When heat stressed, malnourished animals respond with nutrient partitioning and altered nutrient utilization to support the return to euthermia. This includes noticeable changes in protein, lipid, and carbohydrate metabolism mediated by endocrine changes.

The onset of heat stress stimulates the production and release of glucocorticoids and catecholamines, which mediate nutrient repartitioning. This release typically stimulates lipolysis and fat mobilization; however, multiple heat stress studies have demonstrated decreased plasma NEFA concentrations and lipolytic enzymes (Ronchi et al., 1999; Rhoads et al., 2009; Bernabucci et al., 2010; O'brien et al., 2010). It is unclear why this response is blunted under heat stress conditions, but it may be due to insensitivity from chronic stimulation or due to increases in circulating insulin concentrations. Carbohydrates are the primary energy source and blood glucose concentrations

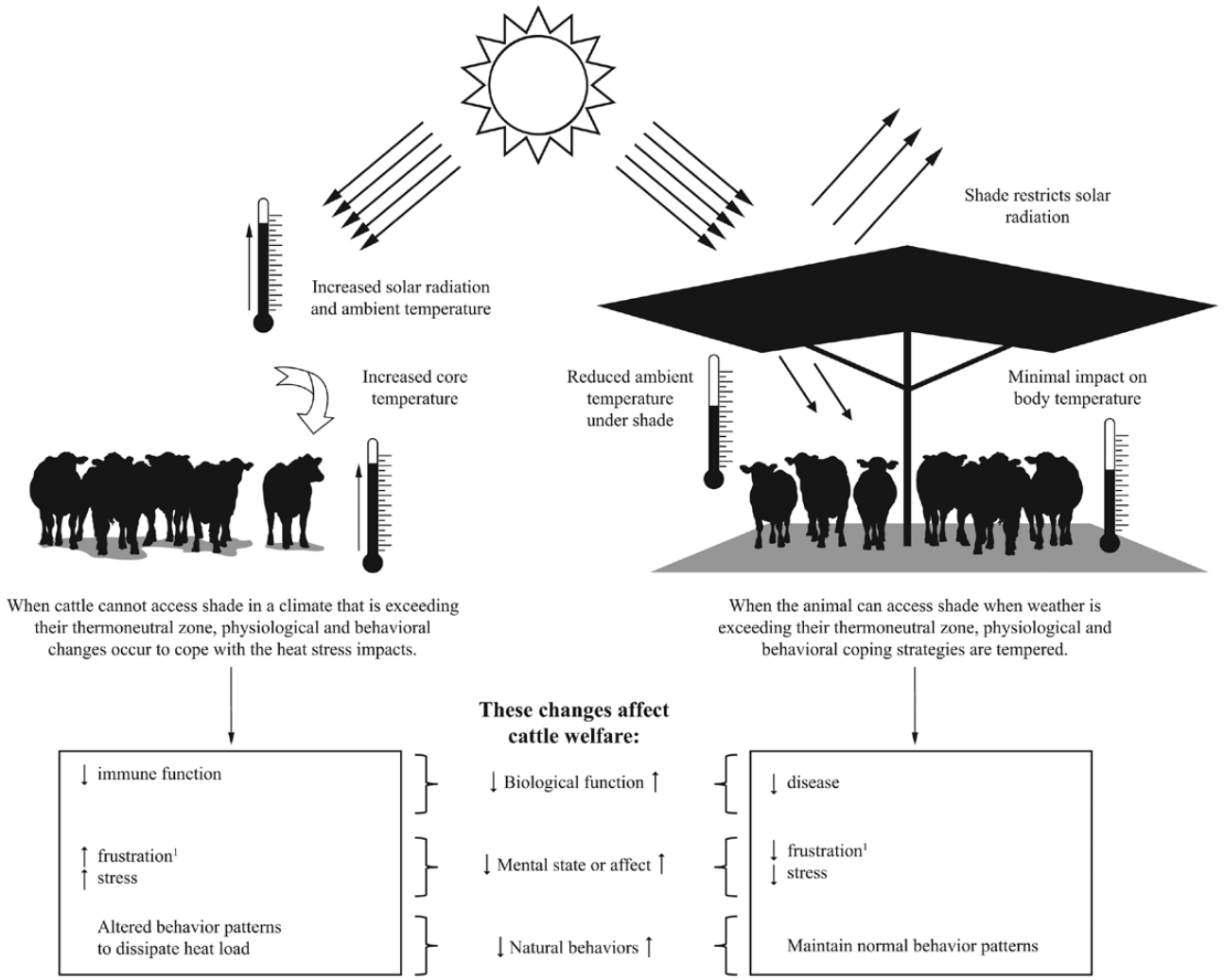


**Figure 1.** A diagram depicting the effect of the ambient environment on cattle that do not have access to shade and those that do. Physiological and behavioral changes associated with heat stress in cattle have negative consequences on cattle welfare via alterations in biological function, mental state or affect, and natural living. [1]Frustration in cattle related to shade provision is a new area of study compared with other animal welfare aspects impacted by shade or lack of shade. Polsky and von Keyserlingk (2017) suggest that dairy cows that experience heat stress are frustrated when they must choose between behaviors that help dissipate heat (stand) or rest (lie down), as cows that were deprived of lying time during thermoneutral conditions exhibited behavioral signs of frustration (Munksgaard and Simonsen, 1996).

are highly regulated by insulin, which has strong antilipolytic signaling capabilities. Heat-stressed cattle have demonstrated increased basal insulin concentrations and increased insulin sensitivity (O'brien et al., 2010). Similar to lipid metabolism, catecholamines typically suppress insulin secretion and promote the utilization of glycogen stores. However, it appears, in heat stress conditions, that glucose is the favored energy source for all tissues. Counterregulatory systems stimulate glucose mobilization and utilization concurrently by increased glycogenolysis and hepatic gluconeogenesis (Rhoads et al., 2011), thus increasing maintenance energy required to excrete nitrogen from gluconeogenic amino acids.

Heat stress has negative effects on protein synthesis and increases muscle catabolism, which contributes to altered lean tissue mass seen in carcasses from heat-stressed animals (Ronchi et al., 1999; O'brien et al., 2010). Muscle breakdown is thought to be another physiological effort to provide precursors for gluconeogenesis to support glucose metabolism (Danfær, 1994). Interestingly, insulin typically promotes protein synthesis in muscle by preventing proteolysis (Proud, 2006). It is unclear why insulin actions differ under heat stress and even more so between tissues, but it is likely due to differences in insulin sensitivity between fat and muscle.

The low efficiency and high rate of heat production from amino acid oxidation, in addition to the previously mentioned changes in fat utilization, contribute to glucose oxidation becoming a favored metabolic pathway to reduce metabolic heat production (Belhadj Slimen et al., 2016). Increased insulin production supports this adaptive response by stimulating glucose uptake and utilization. However, increases in glucose demand coupled with decreased feed intake result in hypoglycemia causing animals to enter a negative energy balance. Thus, the increases in glycogenolysis and hepatic gluconeogenesis are another adaptive response to return to euglycemia and ultimately euthermia.

Silkanikove (2000) reviewed the physiologic and behavioral changes that occur in domestic ruminants as heat stress becomes progressively worse. In the initial phases of heat stress, the animal responds with vasodilation and sweating but is able to return to euthermia without difficulty and without effects

on growth and production. While the apocrine sweat glands of cattle are not as abundant or efficient as eccrine glands found in other mammals, such as humans and horses, sweating is still considered an important physiological response to aid in thermoregulation (Gebremedhin et al., 2008; Hamzaoui et al., 2018). As the temperature continues to increase, water intake also increases and the animal begins to take more severe behavioral and physiological measures to return to a normal body temperature. Behavioral changes during heat stress center on reducing exposure to heat and increasing heat loss. Along with continued sweating, cattle will begin panting to increase water loss from the nose and mouth by vaporizing heat from the respiratory tract, to aid in evaporative cooling (Gebremedhin et al., 2008). Cattle will seek shade when available; when the shade is not available, cattle orient their body position in a way that reduces surface area exposure to solar radiation (Hafez, 1964, Silanikove, 2000). Additionally, cattle will alter rumination behavior in response to heat stress. Brscic et al. (2007) reported that cattle exposed to a THI below 72 (thermoneutral zone) spent 56 min less time ruminating compared with beef cattle exposed to a THI above 78. Other behavioral signs used to identify heat-stressed cattle include animals that are huddled together, increased standing, and use of water sources to wet the coat (Ansell, 1981; reviewed by Blackshaw and Blackshaw, 1994).

The next stage of heat stress involves the metabolic shift previously described, and these effects are seen in production measurements. Cooling mechanisms are no longer effective and core body temperature begins to increase. As the animal responds and attempts to adapt to heat stress, it does so at the expense of a well-functioning immune system, making the animal more susceptible to disease. Early studies have shown reductions in white blood cell counts after heat stress that persist even after animals have returned to a thermoneutral state (Morrow-Tesch et al., 1996). Additionally, lower feed intake and metabolic energy shifts contribute to altered ruminal pH, in conjunction with changes in respiration that contribute to altered blood pH, increasing susceptibility to respiratory alkalosis and rumen acidosis (Renaudeau et al., 2012). When these adaptive responses are still not effective, the animal enters the critical stage in which body temperature continues to rise, and if emergency action is not taken, the animal will likely experience heatstroke and die. Although not discussed in detail in this paper, it should be noted that there are other factors that can influence how cattle respond to heat stress conditions, including but not limited to health status, genetics, and cattle coat characteristics.

## Why Shade Design Matters

Heat stress in cattle occurs when an animal cannot successfully dissipate heat due to environmental conditions interfering with the animal's heat exchange mechanisms. In these stressful environmental conditions, it is necessary to implement strategies to help cattle effectively thermoregulate and mitigate the impacts of the surrounding environment. Thus, the function of shade is to provide a mechanism for reducing the thermal stress that cattle experience by providing them with a microclimate to reduce heat load.

Cattle can exchange heat with the environment via four different mechanisms: conduction, convection, radiation, and evaporation. Conduction, convection, and radiation are all dependent on the thermal gradient between the animal and its environment. The relationship between the animal and the environment is complex and is impacted by many factors, including but not limited to exposed surface area (e.g., animal lying or animal standing), temperature of the ground and the air, and properties of the ground (e.g., wet, dry, and deep soil). Evaporative cooling is also a mechanism for reducing head load and manifests in panting behavior observed in cattle experiencing heat stress. There are many environmental variables that alter the rate of heat exchange and the ability of cattle to off-load heat, such as solar radiation, air temperature, nighttime temperatures, cloud cover, wind speed, and humidity. If cattle are not provided with appropriate conditions to allow heat off-loading when temperatures have the potential to cause a heat stress event, significant welfare consequences should be expected.

Shade provision, if designed correctly, is one of the mitigation strategies that can assist in reducing heat accumulation from solar radiation, thus reducing total heat load. It should be noted that shade does provide direct relief of solar radiation, but animals in the shade are still impacted by reflected shortwave radiation, that is radiation reflected off of surrounding surfaces such as the hot ground, although significantly reduced in the shade (Binns et al., 2002). Shade comes in many shapes and sizes (e.g., artificial vs. natural, metal vs. shade cloth, and limited space vs. more space) and varies greatly by operation type, management approach, and geographic location. Not all shade structures are equal in their ability to limit heat loading from radiation. Although shade is useful for reducing thermal stress of cattle in hot conditions, if the shade structure is designed incorrectly, it may not provide the intended relief from environmental conditions and can actually worsen conditions, for example, by potentially limiting airflow and increasing moisture accumulation on the pen surface if ventilation is inadequate. There are many different physical characteristics of shade structures that, all in part, influence the ability of shade to create a favorable environment for cattle. These include: the thermal properties of the shade material, the ground cover under the shade (i.e., plant-covered ground surface is insulated against excessive heating and generally less reflective), the height of the shade structure, the size of shadow provided by the shade structure, the amount of shade provided per animal, the slope, the location, the shadow of orientation, and the level of ventilation (Owen, 1994; Petrov et al., 2001; Binns et al., 2003; Gomes da Silva and Sandro Campos Maia, 2012). Binns et al. (2002, 2003) and Petrov et al. (2001) provide comprehensive evaluations of feedlot shade design describing how certain shade features can help or hinder an animal's ability to dissipate heat load. In addition to those reports, the Meat & Livestock Australia (**MLA**), Ltd., is a valuable resource that publishes numerous reports and extensive information related to measuring and identifying heat stress, effective heat abatement strategies, and shade design (MLA, 2020).

Examining shade design is not the intention of this review but it is relevant, in brief, to mention a few important features of shade structures to highlight the diversity in design and thus the complexity in assessing the effectiveness of providing shade. Air movement underneath the shade structure is consistently identified as a critical factor for ensuring the effectiveness of shade in heat stress relief (Petrov et al., 2001; Gomes da Silva and Sandro Campos Maia, 2012; Lutrell and Keane, 2016). Shade height plays a significant role in air movement. Petrov et al. (2001) indicated that shade less than 4 m high can reduce the functional shadow produced to reduce direct solar radiation, and it can greatly reduce air movement, which, in turn, would reduce the amount of heat an animal could lose via convection. Kelly and Bond (1958) and Ittner and Kelly (1951) provide

assessments of the relative effectiveness of various shade materials. For example, shade cloth, although potentially not as effective at reducing solar radiation relative to other more solid structures, does have the advantage of allowing more air movement as compared with other materials (Kelly and Bond, 1958). The Kelly and Bond (1958) study has frequently been cited in design reviews but considering both these papers were published over 50 years ago, recent advancements and knowledge in shade design and construction materials would warrant additional assessments to determine the effectiveness of different shade types. Shadow size is also mentioned in shade design but has not been extensively explored. When discussed, the context of shadow size is often in relation to the amount of shade available to cattle. With a larger shadow size, there is more opportunity for increased numbers of cattle to benefit from space in the shade. The area of shade provided to an animal is critical, yet there are limited scientific guidelines suggesting what the optimum amount is. If space in the shade is limited, it can actually promote crowding as animals seek shade, which may actually increase thermal discomfort by limiting heat dissipation. Gomes da Silva and Sandro Campos Maia (2012) present a summary of the area of shade per animal reported as "desired figures" for shade availability from selected studies; the values range from 1.8 to 9.6 $m^2$ per animal. Gomes da Silva and Sandro Campos Maia (2012) acknowledge that 1.8 $m^2$, for example, in their experience is too little particularly for cattle lying down.

Other factors, such as initial economic investment, cost of maintenance, life span, ease of cleaning underneath, durability, supporting posts needed (or not needed) in pens, and ability to remove easily when not needed, are also important considerations for shade selection (Binns et al., 2003; Lutrell and Keane, 2016). For example, shade cloth has been reported to deteriorate more rapidly as compared with corrugated iron, but shade cloth has an advantage of increased air movement as compared with other materials (Kelly and Bond, 1958; Binns et al., 2003). Lutrell and Keane (2016) provide a side-by-side comparison of shade cloth to galvanized steel, outlining the advantages of each as an example. Although many suggestions have been made about advantages and disadvantages related to certain shade features, there is little research providing optimums for the various characteristics, for example, slope of shade, height of shade, area of shade, material of shade, and location of shade. This is an area that would benefit from further exploration to determine both operationally effective and cost-effective options for shade structures in production facilities.

Table 1 provides details about the amount of shade provided and materials used in research studies focusing on the effects of shade on beef cattle. In studies on pasture-based cattle systems, the shade type varies widely but often utilize the naturally occurring trees on the landscape. Feedlot studies, however, report impacts of shade provided by either shade cloth with varying solar radiation protection or solid structures of steel or iron. Additionally, it should be noted that not all studies in Table 1 report the height of the shade structure despite shade height being a critical feature of shade effectiveness. The minimum or average amount of shade per animal is also reported in studies; there is not a consistent standard of reporting shade availability nor a consistent amount of shade provided per animal. It can be a challenge to make conclusions about shade impact on cattle welfare with such variation in shade structures, which likely have varying degrees of efficacy. It is important to note that not all climates are equal regarding temperature (highs, lows, and averages), humidity, wind speed, and other characteristics that impact an animal's ability to offset heat load. These regional differences in weather make shade studies challenging to design and apply broadly; for example, the type of shade structure needed in an arid area with little rainfall is likely different than that needed for an area with a more temperate climate, and in some regions, perhaps shade is not needed at all.

## What Do We Know about Shade Use in the United States?

### Shade use in the beef supply chain

The National Animal Health Monitoring System (**NAHMS**) producer surveys provide valuable benchmarking information about various health and management protocols on cattle operations across the nation. The most recent beef cow–calf report provided information representing 79.6% of U.S. beef cow operations, which accounted for 87.8% of the cow inventory (NAHMS, 2009), and the most recent feedlot report included data from 2.8% of U.S. feedlots, which represented 82.1% of cattle inventory in feedlots (NAHMS, 2013). Neither of these questionnaires have included questions about general shade use on cattle operations. There was, however, a question in the feedlot survey asking specifically about resources being provided in the hospital pens at feedlots. The 2011 data reported that 65% of feedlots participating in the survey provided shade to cattle in hospital pens (NAHMS, 2013). Aside from this statistic, there is little to no aggregate industry information about how commonly used shade provisions are within the beef cattle supply chain. A survey study conducted in the High Plains region of the United States (TX, OK, NM, CO, KS, and NE) reported that 17% of participating feedlot managers ($n$ = 43) utilized shade in feeding pens and 47% provided shade in hospital pens (Simroth et al., 2017). Only 5% utilized shade in the receiving pens. A survey of consulting cattle nutritionists in the United States also reported that only 17% of the feedlots they work with provided shade structures in pens ($n$ = 24; Samuelson et al., 2016). To the authors' knowledge, there are no published data on the use of shade in lairage pens at slaughter plants. Although cattle are usually only in lairage pens for a limited amount of time, typically the pen density is much greater than seen in feedlot pens or pastures, likely creating a rather hot microclimate during warmer months. Some packing companies have started exploring the cost of implementing shade into lairage pens to improve cattle welfare during preslaughter management (L.N. Edwards-Callaway, personal communication). Although there are not many published statistics available detailing shade use across the various sectors of the beef supply chain, those that do provide some information suggest that the use of shade is not very pervasive and is likely highly dependent on geographic region.

### The standards for shade in cattle care program guidelines

Producer education materials (e.g., National Cattlemen's Beef Association [**NCBA**]), association policies and guidelines (e.g., American Association of Bovine Practitioners [**AABP**]), and/or third party product labeling programs (e.g., Certified Humane) are helpful resources to gauge current trends in management practices (e.g., pain mitigation, outdoor access, and shade provision). In the case of shade provision for beef cattle, there has not been the same extent of discussion as seen with

**Table 1.** Shade type and shade characteristics of a selection of research studies[1]

| Reference | Study location | Supply chain sector | Animal type | Shaded area/ animal[2] | Shade description | Shade height[3] |
|---|---|---|---|---|---|---|
| Aengwanich et al. (2011) | Thailand | Individual Stall | Heifers | 2.50 $m^2$ | Imperta roof, rain-tree shade | - |
| Baliscei et al. (2012) | Brazil | Pasture | Steers | - | Eucalyptus trees | 8 m[4] |
| Barajas et al. (2013) (exp. 1) | United States | Feedlot | Steers | 3.3 $m^2$ | Aluminum- & zinc-coated galvanized steel roof | 3.6 m |
| Barajas et al. (2013) (exp. 2) | United States | Feedlot | Steers | 2.4 $m^2$ | Aluminum- & zinc-coated galvanized steel roof | 3.6 m |
| Barajas et al. (2013) (exp. 3) | United States | Feedlot | Steers | 2.8 $m^2$ | Aluminum- & zinc-coated galvanized steel roof | 3.6 m |
| Blaine and Nsahlai (2011) | South Africa | Feedlot | Steers/bulls | 2.87 $m^2$ | Corrugated iron sheets every 22.5 cm | 5 m |
| Boyd et al. (2015) | United States | Feedlot | Steers | 3 $m^2$ | Two-tiered ~50% sun block high-density polyethylene snow fence | 10 m[5] |
| Brown-Brandl et al. (2013) | United States | Feedlot | Heifers | - | Timber and galvanized steel, solid structure with three sides | 8.68 m[5] |
| Brown-Brandl et al. (2005) | United States | Individual Pen | Steers | - | 0.3-mm thick polyvinyl 100% shade cloth | 3.6 m[5] |
| DiGiacomo et al. (2014) | Australia | Feedlot | Steers | ~3.2 $m^2$ | 80% solar block shade cloth | - |
| Gaughan et al. (2010) | Australia | Feedlot | Steers | 3.3 $m^2$ | 80% solar block shade cloth | 4 m |
| Geraldo et al. (2012) | Brazil | Pasture | Bulls | 10 $m^2$ | Polyethylene mesh with 80% filtration of solar radiation | - |
| Hagenmaier et al. (2016) | United States | Feedlot | Steers/Heifers | 1.5 $m^2$ | 13-ounce polyethylene fabric | - |
| Hayes et al. (2017) | United States | Feedlot | Steers/Heifers | - | Two-tiered ~50% sun block high-density polyethylene snow fence | 10 m[5] |
| Lees et al. (2018) | Australia | Feedlot | Steers | 3.0 $m^2$ | 90% solar block shade cloth | 4 m |
| Lees et al. (2020) | Australia | Feedlot | Steers | 3.0 $m^2$ | 90% solar block shade cloth | 4 m |
| Mader et al. (1999) | United States | Feedlot | Steers | 2.65 $m^2$ | White steel roofs | 3.4 m[4] |
| McIlvain and Shoop (1971) | United States | Pasture | Steers | 2.8 $m^2$ | Open-faced sheds | 4.3 m |
| Mitlöhner et al. (2002) | United States | Feedlot | Heifers | 2.12 $m^2$ | Galvanized aluminum- and zinc-coated steel roof | 4 m |
| Mitlöhner et al. (2001) (exp. 1) | United States | Feedlot | Heifers | 9 $m^2$ | 80% solar block polypropylene shade cloth | 3 m |
| Mitlöhner et al. (2001) (exp. 2) | United States | Feedlot | Heifers | 3.6 $m^2$ | 80% solar block polypropylene shade cloth | 3 m |
| Rovira (2014) | Uruguay | Pasture | Steers | 4.0 $m^2$ | 35% or 80% solar block black polypropylene cloth | 4 m |
| Rovira and Velazco (2010) | Uruguay | Pasture | Steers | 3.2; 100 $m^2$ | 80% solar block polypropylene shade cloth; trees | 2.5 m; - |
| Sullivan et al. (2011) | Australia | Feedlot | Heifers | 2.0; 3.3; 4.7 $m^2$ | 70% solar block polypropylene shade cloth | 4 m |
| Titto et al. (2011) (part 2) | Brazil | Pasture | Bulls | 8.0 $m^2$; - | 80% solar block polypropylene shade nets; Sibipiruna trees | 3.5 m; 7 to 9 m |
| Van laer et al. (2015) | Belgium | Pasture | Cows | 37.5 $m^2$ | 80% solar block polypropylene shade cloth between trees | - |

[1]Studies were included in the table based on the following criteria: the study was focused on beef cattle (i.e., any study utilizing dairy cows or bulls was not included in the table), the study had some comparison between shaded and non-shaded treatment groups, and the study was conducted at least in part in weather conditions that would result in higher heat loads for the cattle groups targeted.
[2]This represents the area provided per animal listed in the research study. Where there are multiple areas listed, there were different shaded areas provided dependent upon treatment.
[3]If a study did not provide the height of the shade provided a "-" was noted.
[4]Average height of shade.
[5]Maximum height of shade.

other "hot topics" in cattle welfare, such as pain mitigation for example. Perhaps this is due to the fact that shade is a complex issue as it can be provided in many different shapes and sizes and shade provision needs vary greatly by region.

Many U.S.-based guidance documents, in their own words, indicate the necessity of providing cattle with "opportunities for behavioral thermoregulation." Suggestions are provided but shade requirements are not mandated. Rather than specifically mentioning shade use, many of the overarching industry guidelines for cattle care discuss the need to minimize the effects of heat stress particularly during handling, loading, and transport, guiding producers to adjust handling protocols during extreme heat but not outlining specific requirements (NCBA, 2017; NCFA, 2018; AABP, 2019). The current version of the NCBA Beef Quality Assurance (BQA) National Manual, which outlines national beef industry guidelines for beef cattle care across industry sectors, does not include substantial discussion about the use of shade in production settings; however, there is a section within the manual that indicates the necessity of addressing environmental conditions (such as extreme heat) as part of proper cattle care (NCBA, 2017). The manual suggests specific guidelines to minimize the effects of heat stress, such as considering heat abatement tools like shades, but does not require them.

There are several third-party verified programs utilized in North America that have included the provision of shade within their standards of cattle care to varying degrees of specificity (GAP, 2009; Certified Humane, 2019; VBP+, 2019). Many of the programs refer to the provision of shelter for protection from extreme weather conditions, thus including the need for shade in hot weather but speaking more generally to the protection and usually qualifying the need by saying "in the case of" or "in climatic regions where" (Animal Welfare Approved, 2018; Food Alliance, 2018; VBP+, 2019). There are some verified programs that provide specific requirements for shade inclusion in cattle production settings (GAP, 2009; American Humane, 2017; Certified Humane, 2019). The Global Animal Partnership (**GAP**) Beef Cattle standards indicate that "shade must be provided that accommodates all animals in all outdoor areas" with further guidance that if shade cloth is the method of shade provision, it must filter out at least 50% of solar radiation (GAP, 2009). The GAP program differentiates requirements between program "Steps" related to the type of operation needs (i.e., ranch vs. feedlot), while the American Humane and Certified Humane programs provide identical explanations of specific shade requirements (American Humane, 2017; Certified Humane, 2019). The requirements for shade in these two programs are also specific in regard to the height of shade structures by region within the United States (12 to 14 ft or 3.7 to 4.3 m high in the southwest and 7 to 9 ft or 2.1 to 2.7 m high in the eastern United States) and space needed per animal (young cattle: 8 to13 $ft^2$ or 0.7 to 1.2 $m^2$ per animal and adult cattle: 20 to 27 $ft^2$ or 1.9 to 2.5 $m^2$ per animal). Although not directly cited, these specific recommendations are found in the Ag Guide, a guidance document for use of agricultural animals in research and teaching that also provides valuable information that can be applied to production settings (FASS, 2010). In the section specific to range and pasture systems, the Ag Guide does indicate that providing man-made or natural shade is a practical intervention to reduce the negative impacts of heat stress on cattle (FASS, 2010). In summary, the reduction of heat stress impacts is recognized as a critical component of cattle care, but how that is accomplished varies between different producer education and verification programs.

## The Effects of Shade on the Overall Cattle Welfare

There have been a substantial number of studies exploring the impacts of providing shade on various aspects of cattle well-being, usually with a primary focus on performance outcomes and typically with a focus on cattle in feedlots. As noted, cattle welfare should be assessed holistically, not only considering production outcomes. Animal performance and health indicators are generally more easily quantified and foundational to why animals are raised in production settings (i.e., to produce a product). However, ensuring optimal animal welfare requires a much more comprehensive assessment of inputs and outputs such as evaluating indicators of affective state and the ability of cattle to express the "cowness of the cow," referring to the concept that an animal, in this case a cow, should be able to behave in a way that enables it to express its true nature (Rollin, 2018). Table 2 summarizes the various outcomes measured in beef cattle shade studies across two of the three welfare components: biological functioning (e.g., carcass merit and feed efficiency) and natural living (e.g., measures of lying, standing, feeding, and ruminating behavior). Notably, outcomes relevant to the affective state of the animal are not included in Table 2; as to the authors' knowledge, no beef cattle research to date has assessed the impact of shade on affective states.

Studies on the impacts of shade often compare groups of animals that have been provided some level of shade with groups that have no access to shade and assess production, physiological, and behavioral outcomes specifically during hot weather. Every study varies slightly in how hot weather conditions are quantified, but usually a combination of dry-bulb temperature, wind speed, humidity, and other calculated variables such as heat load index is reported. The general objective of these studies is to determine the effect of shade on cattle performance, physiology, and behavior, that is, does shade provide benefits in weather known to increase the risk of heat stress in cattle. Specific to this application, outcomes such as behavior, DMI, body temperature, and respiration rate have been identified as effective indicators of how an animal is coping during heat stress conditions (Gaughan et al., 2002). It is worth noting that the benefit of shade is in its ability to reduce heat load and thus temper outcome variables known to be impacted by heat stress, such as respiration rate, panting score, and temperature. Sometimes these outcome variables are still impacted by ambient weather conditions but the magnitude of change is not as extreme as observed in those animals with no shade intervention. As discussed, some of the difficulty in sifting through the published literature to clearly outline the benefits of shade in relation to well-being is that research varies greatly in study design, type of shade utilized, statistical analyses, and outcomes measured.

Table 2 provides a summary of relevant shade research as a framework for reviewing what is currently included as welfare indicators in shade research. Studies were included in this table based on the following criteria: the study was focused on beef cattle (i.e., any study utilizing dairy cows or bulls was not included in the table), the study had some comparison between shaded and non-shaded treatment groups, and the study was conducted at least in part in weather conditions that would result in higher heat loads for the cattle groups targeted. As mentioned, the collection of outcome variables is unique to each research study, but generally, studies include measurements related to physiologic indicators of stress, live

animal performance and carcass merit, and behavior, and these are the subheadings that will be used to describe shade impacts on cattle welfare.

## The impacts of shade on physiologic indicators of stress

With the first response to heat stress being outward symptoms of altered respiration, sweating, and temperature, a focus of the literature has been shade use to reduce these responses before adaptive physiological mechanisms are enacted. Multiple studies have found shade to be effective in reducing respiration rate and panting score in the feedlot. In a recent study, Lees et al. (2020) found that shaded Angus and Charolais cattle had reduced panting scores in a time-of-day-dependent manner compared with their unshaded counterparts. In this study, and multiple others, cattle panting scores were expectedly most affected by shade in the later hours of the day when heat load was at its highest (Gaughan and Mader, 2014; Hagenmaier et al., 2016; Hayes et al., 2017; Lees et al., 2020). While any shade is better than no shade, amount and type of shade seem to play a role in the effectiveness as well (Rovira and Velazco, 2010; Sullivan et al., 2011; Rovira, 2014). When effective, as panting decreased by shade use, animals also increased feed intake indicating alleviation of heat stress to a degree in which animals resume normal behavior (Blaine and Nsahlai, 2011), to be discussed further in subsequent sections.

Direct respiration rate is also positively impacted by shade, as shaded cattle have reduced respiration rates that similarly correspond with different times of day (Brown-Brandl et al., 2005; Eigenberg et al., 2005; Gaughan and Mader, 2014; Hayes et al., 2017). Mitlöhner et al. (2001, 2002) found a combination of shade and misting to be most effective at reducing respiratory rate, yet this heat abatement strategy had no significant effect on body temperature. In studies examining the impacts of shade on cattle on pasture, shade use generally increased with increasing HLI or THI, which often varied by time of day (Rovira and Velazco, 2010; Van Iaer et al., 2015; Veissier et al., 2018). Additionally, under hot conditions (as measured by a variety of metrics), shaded cattle exhibited tempered increases in physiological outcomes, such as respiration rate, panting score, and body temperature, impacted outcomes varying by study (Rovira and Velazco, 2010; Van Iaer et al., 2015; Veissier et al., 2018). It is important to evaluate factors such as shade usage and shade type when evaluating study results. Additionally, one thing to consider when reviewing studies across different sectors is that the ground cover in the surrounding environment can alter reflected solar radiation; pasture and feedlots are clearly different in ground cover perhaps in part explaining any observed differences in effects. However, minimal studies exist that investigate heat stress abatement by shade use in sectors outside of the feedlot and is an area that warrants more research.

When initial efforts at heat reduction are not successful and when ambient temperature reaches approximately 25 °C, body temperature begins to increase, which compromises animal health (Hahn, 1999; Curtis et al., 2017). The addition of shade has been shown to reduce or maintain body temperature during peak hours of the day or during heat waves (Sprinkle et al., 2000; Gaughan et al., 2010; Melton et al., 2019). The benefits of shade differ between cattle breeds as *Bos indicus* cattle are naturally more heat tolerant than *Bos taurus* breeds (Finch, 1986; Lees et al., 2018). While shade has minimal effect on Brahman cattle, the rumen temperature and body temperature of Angus and Charolais cattle decreased in shaded vs. non-shaded animals, supporting the understanding that *B. indicus* cattle are more efficient at thermoregulation (Lees et al., 2018). This is also supported by a study in Thai Brahman cattle that showed shade had an intermediate effect on body temperature and was not consistent throughout the trial period (Aengwanich et al., 2011). A study at the U.S. Meat Animal Research Center (**MARC**) indicated that black Angus heifers had larger reductions in respiration rate when shaded compared with light-hided MARC breeds of cattle and Charolais, which only showed benefits of shade when heat stress was severe (Brown-Brandl et al., 2013). Crossbred cattle grazing pasture performed better than Angus cattle that accumulated more heat during the day and sought shade and cooling efforts earlier than Brahman × Angus and Tuli × Angus (Sprinkle et al., 2000). Thus, *B. indicus* crossed Angus cattle have more heat adaptive responses than cattle containing no *B. indicus* lineage. Together these data demonstrate that *B. taurus* cattle, especially dark-hided breeds, are most susceptible to heat stress and benefit the most from shade utilization.

## The impacts of shade on performance and carcass characteristics

Performance and carcass merit outcomes, although not the only characteristics that should be considered in the overall welfare assessment, are traditionally used to assess the impacts of various management strategies. These types of outcomes are not as relevant to the cow–calf industry and, therefore, this section will focus on feedlot operations. Additionally, these types of outcomes have a direct relationship to operation profitability and, therefore, likely play a critical role in assessing the cost vs. benefit of shade implementation in feedlot operations. Concerns regarding the cost of building and maintaining shade structures in a feedlot are often the reason given for not providing shade to feedlot cattle. To examine the impact of providing shade to feedlot cattle on live animal performance and carcass quality, a meta-analysis was performed.

### *Meta-analysis methods*

Fifteen shade vs. no shade comparisons published in nine peer-reviewed journal articles evaluating the effects of providing shade to feedlot cattle during the summer months on live animal performance and carcass characteristics were included in this analysis (Table 3). Only studies conducted with beef feedlot cattle fed typical feedlot diets were included in this review. The characteristics of interest in this analysis were: BW, DMI, ADG, G:F, HCW, dressing percentage, longissimus muscle area, subcutaneous fat depth, marbling score, and percentage Choice or greater for carcass grade. The mean and standard deviations for the aforementioned outcomes are tabulated and reported in Table 4.

Data were analyzed using PROC MIXED procedures in SAS (Statistical Analysis System, 9.4, Cary, NC) as outlined by St-Pierre (2001) for integrating quantitative findings from multiple studies. Shade treatment, coded in the data set as no shade = 0 or shade = 1, was included in all models as a fixed classification variable. Comparison number (1 to 15; Table 3) was used as a random class variable in all models evaluated. For all analyses, treatment mean within comparison number was used as the experimental unit. The inverse of the SEM squared was used to weight the analysis. The SEM for one of the variables evaluated in each of four studies was not known; These included calculated HCW and dressing percentage as

**Table 2.** Summary of reported well-being outcomes in a selection of shade studies specific to beef cattle[1]

| | Well-being outcomes | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Physiology | | | | | Performance | | | | Carcass characteristics | | | | | |
| Reference | Panting | Respiration rate | Temperature[2] | Open mouth breathing | Immune Function | Final BW | DMI | ADG or gain | Feed efficiency (G:F or F:G) | HCW | Dressing % | LM area | Fat thickness | KPH fat | Quality grade |
| Aengwanich et al. (2011) | - | X | X | - | X | - | - | - | - | - | - | - | - | - | - |
| Baliscei et al. (2012) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Barajas et al. (2013) (exp. 1) | - | - | - | - | - | X | X | X | X | - | - | - | - | - | - |
| Barajas et al. (2013) (exp. 2) | - | - | - | - | - | X | X | X | X | - | - | - | - | - | - |
| Barajas et al. (2013) (exp. 3) | - | - | - | - | - | X | X | X | X | - | - | - | - | - | - |
| Blaine and Nsahlai (2011) | X | - | - | - | - | X | X | X | X | X | - | - | - | - | X |
| Boyd et al. (2015) | X | X | X | - | - | X | X | X | X | X | X | X | X | - | - |
| Brown-Brandl et al. (2013)[3] | - | X | X | - | - | X | - | - | - | - | - | - | - | - | - |
| Brown-Brandl et al. (2005) | - | X | X | - | - | - | X | - | - | - | - | - | - | - | - |
| DiGiacomo et al. (2014) | - | - | X | - | - | - | - | - | - | X | - | - | X | - | - |
| Gaughan et al. (2010) | X | - | X | - | - | X | X | X | X | X | X | X | X | - | - |
| Geraldo et al. (2012) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Hagenmaier et al. (2016) | - | - | - | X | - | X | X | X | X | X | X | X | X | - | X |
| Hayes et al. (2017) | X | X | - | - | - | - | X | X | X | - | - | - | - | - | - |
| Lees et al. (2018) | - | - | X | - | - | X | X | X | X | - | - | - | - | - | - |
| Lees et al. (2020) | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Mader et al. (1999) | - | - | - | - | - | X | X | X | X | X | X | - | X | X | - |
| McIlvain and Shoop (1971) | - | - | - | - | - | | - | X | - | - | - | - | - | - | - |
| Mitlöhner et al. (2002) | - | X | - | - | X | X | X | X | X | X | X | X | X | X | X |
| Mitlöhner et al. (2001) (exp. 1) | - | X | X | - | - | - | - | X | X | - | - | - | - | - | - |
| Mitlöhner et al. (2001) (exp. 2) | - | X | X | - | - | X | X | X | X | X | - | X | X | X | X |
| Rovira (2014) | - | - | X | - | - | X | - | X | - | - | - | - | - | - | - |
| Rovira and Velazco (2010) | - | X | - | - | - | - | - | X | - | - | - | - | - | - | - |
| Sullivan et al. (2011) | X | - | - | - | - | X | X | X | X | X | X | - | X | - | - |
| Titto et al. (2011) (part 2) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Van laer et al. (2015) | X | X | - | - | - | - | - | - | - | - | - | - | - | - | - |

[1]Studies were included in the table based on the following criteria: the study was focused on beef cattle (i.e., any study utilizing dairy cows or bulls was not included in the table), the study had some comparison between shaded and non-shaded treatment groups, and the study was conducted at least in part in weather conditions that would result in higher heat loads for the cattle groups targeted. An "X" indicates that the outcome was measured in the noted study and a "-" signifies that the outcome was not measured within the study.
[2]Temperature was reported as rectal, surface, and/or rumen temperature depending on the study.
[3]Panting score, lying %, and standing % were indicated as measured but no data reported.

described above for Mader et al. (1999) and Mitlöhner et al. (2001), respectively, G:F for Lees et al. (2018), and for percentage Low Choice or greater for Mitlöhner et al. (2002). In these cases, *P*-values were not available; therefore, $P = 0.50$ was assumed. Degrees of freedom were calculated as the number of pen replicates minus 1. The difference between treatment means, degrees of freedom, and the corresponding value of t for a two-tailed t-test assuming $P = 0.50$ was used to estimate the missing SEM. Statistical significance for the effect of shade on various performance parameters was declared at $P \leq 0.05$, and trends were identified at $0.05 < P \leq 0.10$. Although funnel plots (Light and Pillemer, 1984) are used typically to evaluate publication bias in the meta-analysis process, they were not constructed for the current analysis. The studies used for this analysis are inherently biased in that each of these studies was conducted during the warmest months of the year, using mostly dark-hided cattle, providing the greatest opportunity for positive results for shade.

### *Meta-analysis outcomes*

Growth performance results for cattle with access to shade compared with cattle that did not have access to shade are provided in Table 5. Data indicated that while feedlot cattle that had access to shade showed no difference in terms of initial BW,

| Well-being outcomes | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carcass characteristics | | | | | | | Behavior | | | | | | |
| Yield grade | Marbling score | Carcass pH & temperature | Meat color | Texture and firmness | Liver abscess % | Dark cutting % | Lying % | Standing % | Feeding/ grazing% | Drinking/time at water/Intake /trough% | Walking % | Ruminating% | Social behavior % |
| - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | X | X | X | - | - | X | - |
| - | - | - | - | - | - | - | - | - | - | X | - | - | - |
| - | - | - | - | - | - | - | - | - | - | X | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | X | X | X | - | - | - | - |
| X | X | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | X | X | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - | X | - | - | - | - |
| - | - | X | X | X | - | - | - | - | - | - | - | - | - |
| - | X | - | - | - | - | - | - | - | - | X | - | - | - |
| - | - | - | - | - | - | - | X | X | X | - | - | X | - |
| - | X | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | X | X | X | X | - | X | - |
| X | X | - | - | - | X | - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| X | X | - | - | - | - | X | X | X | X | X | X | - | X |
| - | - | - | - | - | - | - | X | X | X | X | X | - | - |
| X | X | - | - | - | - | - | X | X | X | X | X | - | X |
| - | - | - | - | - | - | - | X | X | X | - | - | - | - |
| - | - | - | - | - | - | - | X | X | X | X | X | - | - |
| - | - | - | - | - | - | - | X | X | X | X | - | - | - |
| - | - | - | - | - | - | - | X | X | X | X | - | X | - |
| - | - | - | - | - | - | - | - | - | - | - | - | - | - |

by the end of the studies that were evaluated, cattle that were housed in pens with shade had a significantly greater final BW. Additionally, over the durations of the studies, ADG was 0.07 ± 0.021 kg/d greater ($P < 0.01$) for cattle housed in shaded pens vs. non-shaded pens. Dry matter intakes were not different between shaded ($P = 0.31$) and non-shaded pens, 8.58 vs. 8.74 kg/d ± 0.458, respectively. Yet, gain efficiency for cattle with access to shaded pens was improved 3.4% ($P < 0.01$) vs. cattle housed in non-shaded pens.

Two studies reported information concerning water intake. Gaughan et al. (2010) reported considerable differences in water intake for the duration of the entire study (53.1 vs. 49.3 L/d ± 1.5, for the no shade vs. shade treatments, respectively). Although treatment means were not presented for the duration of the study, Sullivan et al. (2011) reported no water intake differences between shade treatments. Both studies discussed significant increases in water usage by cattle that were not provided shade as compared with shaded cattle for days that were classified as hot.

The effects of shade on carcass characteristics are provided in Table 6. The studies provide substantial insights into the value of supplying shade for cattle on feed and subsequent effects on carcass outcomes. For instance, cattle that were provided access to shade yielded carcasses with greater HCW and dressing percentages than non-shaded cattle. Hot carcass weights and dressing percentages increased ($P < 0.0001$) by 5.8 ± 0.90 kg and 0.36 ± 0.004 percentage points, respectively. No differences between treatments for 12th rib subcutaneous fat depth were observed. Interestingly, longissimus muscle area tended ($P < 0.06$) to be 1.1 ± 0.45 $cm^2$ lesser for cattle housed

**Table 3.** Sources of data used for the meta-analysis evaluating the effects of shade on feedlot cattle performance and carcass characteristics

| Citation | Comparison number | Pens per treatment | Cattle per Pen | Sex[1] | Location | Breed/coat color | Days on study | Starting month |
|---|---|---|---|---|---|---|---|---|
| Barajas et al. (2013), exp. 1 | 1 | 7 | 5 | 1 | El Centro, CA | 1/4 Blood BrahmanX | 84 | July |
| Barajas et al. (2013), exp. 2[2] | 2 | 4 | 7 | 1 | El Centro, CA | 1/4 Blood BrahmanX | 56 | August |
| | 3 | 4 | 7 | 1 | El Centro, CA | 1/4 Blood BrahmanX | 56 | August |
| Barajas et al. (2013), exp. 3[2] | 4 | 4 | 6 | 1 | El Centro, CA | 1/4 Blood BrahmanX | 56 | July |
| | 5 | 4 | 6 | 1 | El Centro, CA | 1/4 Blood BrahmanX | 56 | July |
| Boyd et al. (2015)[3] | 6 | 4 | 30 | 1 | Central NE | 78% Red and 22% Black | 208 | January |
| | 7 | 4 | 30 | 1 | Central NE | 78% Red and 22% Black | 208 | January |
| Gaughan et al. (2010) | 8 | 10 | 8 | 1 | QLD, Australia | Angus | 120 | November |
| Hagenmaier et al. (2016)[4] | 9 | 7 | 100 | 3 | KS | Predominately Black | 38 | June |
| Lees et al. (2018) | 10 | 3 | 6 | 1 | QLD, Australia | Mixed[5] | 130 | November |
| Mader et al. (1999)[6] | 11 | 12 | 7 | 1 | Northeast NE | Angus/AngusX | 79 | June |
| | 12 | 12 | 7 | 1 | Northeast NE | Angus/AngusX | 79 | June |
| Mitlöhner et al. (2001) | 13 | 8 | 5 | 2 | TX Panhandle | 3 AngusX and 2 CharX/pen | 131 | June |
| Mitlöhner et al. (2002) | 14 | 6 | 14 | 2 | TX Panhandle | 70% AngusX and 21% CharX | 121 | June |
| Sullivan et al. (2011)[7] | 15 | 2 or 4 | 9 | 2 | QLD, Australia | Angus | 120 | January |

[1]Sex; 1 = Steers, 2 = Heifers, 3 = four replicates were steers and three replicates were heifers.
[2]Study was conducted as a 2 × 2 factorial. Factors were shade vs. no shade and a comparison of morning vs. afternoon feeding. Results were reported for each treatment combination in the manuscript and, therefore, data treated as two distinct shade comparisons for the meta-analysis.
[3]Study was conducted as a 2 × 2 factorial. Factors were shade vs. no shade and zilpaterol HCl vs. no zilpaterol HCl. Results were reported for each treatment combination in the manuscript and, therefore, data treated as two distinct shade comparisons for the meta-analysis.
[4]Cattle provided shade for only the final 38 d of the feeding period. Study was conducted as a 2 × 2 factorial. Factors were shade vs. no shade and zilpaterol HCl vs. no zilpaterol HCl. Only main effects reported for each factor in the manuscript and, therefore, only one shade comparison possible for the meta-analysis.
[5]Two Angus, two Charolais, and two Brahman steers housed in each pen.
[6]Study was conducted as a 2 × 2 factorial. Factors were shade vs. no shade and windbreak vs. no windbreak. Results were reported for each treatment combination in the manuscript and, therefore, data treated as two distinct shade comparisons for the meta-analysis.
[7]Study evaluated two non-shaded control pens vs. four shaded pens for each of three shade treatments.

**Table 4.** Summary of performance and carcass data used for review[1]

| Item | Mean | SD | Minimum | Maximum | Median |
|---|---|---|---|---|---|
| Study duration[2] | 103.9 | 50.36 | 38 | 208 | 102 |
| Pen replicates per treatment[2] | 6.0 | 3.02 | 2 | 12 | 4 |
| Cattle/pen[2] | 16.0 | 23.39 | 5 | 100 | 7 |
| Initial BW[2], kg | 353 | 73.8 | 242 | 570 | 352 |
| Final BW[2], kg | 495 | 106.8 | 311 | 649 | 502 |
| DMI[2], kg/hd/d | 8.75 | 1.749 | 5.5 | 11.0 | 9.5 |
| ADG[2], kg/hd/d | 1.39 | 0.304 | 0.85 | 1.97 | 1.51 |
| G:F[3] | 0.164 | 0.0373 | 0.085 | 0.245 | 0.160 |
| HCW[4], kg | 344.3 | 50.61 | 270.4 | 425.0 | 333.3 |
| Dressing percentage[5] | 61.5 | 3.40 | 53.9 | 65.6 | 62.4 |
| Longissimus muscle area[6], cm[2] | 87.8 | 9.02 | 70.7 | 96.1 | 91.1 |
| Subcutaneous fat depth[7], 12th rib, cm | 1.35 | 0.185 | 1.05 | 1.64 | 1.32 |
| Marbling score8 | 429.3 | 33.29 | 377 | 478 | 430 |
| ≥ Low Choice[9],% | 57.8 | 15.97 | 36.2 | 72.0 | 61.4 |

[1]Simple average of all data from Mader et al. (1999), Mitlöhner et al. (2001, 2002), Gaughan et al. (2010), Sullivan et al. (2011), Barajas et al. (2013), Boyd et al. (2015), Hagenmaier et al. (2016), and Lees et al. (2018).
[2]All nine studies reported these characteristics.
[3]Mader et al. (1999) and Mitlöhner et al. (2001) reported F:G; for this review, G:F was calculated utilizing values for ADG and DMI.
[4]HCW was reported in Mitlöhner et al. (2001, 2002), Gaughan et al. (2010), Sullivan et al. (2011), Boyd et al. (2015), and Hagenmaier et al. (2016) only. HCW was calculated from reported final BW and dressing percentage in Mader et al. (1999).
[5]Dressing percentage was reported in Mader et al. (1999), Mitlöhner et al. (2002), Gaughan et al. (2010), Sullivan et al. (2011), Boyd et al. (2015), and Hagenmaier et al. (2016). Dressing percentage in Mitlöhner et al. (2001) was calculated from HCW and final BW.
[6]Longissimus muscle area was reported in Mitlöhner et al. (2001, 2002), Gaughan et al. (2010), Boyd et al. (2015), and Hagenmaier et al. (2016).
[7]Fat depth over the 12th rib was reported in Mader et al. (1999), Mitlöhner et al. (2002), Gaughan et al. (2010), Sullivan et al. (2011), Boyd et al. (2015), and Hagenmaier et al. (2016).
[8]Marbling score: 300 = Slight[0], 400 = Small[0], and 500 = Modest[0]; marbling score was reported in Mader et al. (1999), Mitlöhner et al. (2001, 2002), Gaughan et al. (2010), Boyd et al. (2015), and Hagenmaier et al. (2016).
[9]USDA quality grade as percentage of carcasses grading Low Choice or greater was reported in Mitlöhner et al. (2002) and Hagenmaier et al. (2016).

**Table 5.** Least squared means showing the effects of shade on feedlot performance of finishing cattle

| Item | No shade | Shade | SEM | *P*-value |
|---|---|---|---|---|
| N | 15 | 17 | | |
| Initial BW, kg | 353.2 | 352.9 | 19.9 | 0.61 |
| Final BW, kg | 491.7 | 500.6 | 28.9 | <0.001 |
| DMI, kg/hd/d | 8.58 | 8.74 | 0.458 | 0.31 |
| ADG, kg/hd/d | 1.41 | 1.48 | 0.070 | <0.01 |
| G:F | 0.165 | 0.171 | 0.0089 | <0.01 |

**Table 6.** Least squared means showing the effects of shade on carcass characteristics of beef cattle

| Item | No shade | Shade | SEM | *P*-value |
|---|---|---|---|---|
| HCW[1], kg | 348.6 | 354.4 | 16.26 | <0.0001 |
| Dressing percent[1] | 61.6 | 62.0 | 1.18 | <0.0001 |
| Fat depth, cm[2] | 1.34 | 1.36 | 0.076 | 0.69 |
| Longissimus muscle area, cm[2,3] | 88.1 | 87.0 | 3.95 | <0.06 |
| Marbling score[2,4] | 422 | 437 | 11.8 | <0.001 |
| ≥ Low Choice[5],% | 56.3 | 61.6 | 12.67 | <0.01 |

[1]No shade treatment means = 9 and shade treatment means = 11.
[2]No shade and shade treatment means = 8.
[3]No shade and shade treatment means = 6.
[4]Marbling score: 300 = Slight[0], 400 = Small[0], 500 = Modest[0].
[5]No shade and shade treatment means = 2.

in shaded vs. non-shaded pens, while marbling score was increased ($P < 0.001$) 15 ± 2.0 units for shaded vs. non-shaded cattle, suggesting that shading may also have a positive impact on United States Department of Agriculture (USDA) quality grade. Two studies specifically reported USDA quality grade results as they relate to shade access for feedlot cattle. In these studies, the percentage of carcasses grading Low Choice or greater averaged 56.3% for non-shaded cattle, while shaded cattle reported 61.6% of carcasses achieving at least Low Choice, a notable 5.3% improvement over those with no access to shade ($P < 0.01$).

Physiological responses by shaded cattle to dissipate heat load should be reduced as compared with non-shaded cattle, and consequently, maintenance energy requirements should also be less for shaded cattle. Greater dry matter intake might also be expected for cattle provided shade as compared with cattle with no opportunity for shade. This meta-analysis demonstrates that growth performance and efficiency are improved, even without an increase in dry matter intake, suggesting that shade reduces maintenance energy requirements by feedlot cattle during the summer months. It should be noted that all studies evaluated were conducted during times where the impact of shade, on animal performance and well-being, would be greatest (e.g., during times of extreme heat load). Results from the current meta-analysis applied to cattle under shade for approximately 104 d. The proportion of the year that providing shade would result in a similar improvement in growth and efficiency likely varies tremendously from one region to another due to latitude and climatic conditions.

## The impacts of shade on behavior

### *Lying and standing*

Lying and standing are two behaviors consistently included in shade research. Although, existing research regarding the effect of shade on behavior is somewhat conflicting. Because standing serves to increase heat loss and is increased in heat-stressed cattle (Ansell, 1981), we might expect that shaded cattle would have decreased standing time or conversely, increased lying time, compared with unshaded cattle. Indeed, Rovira (2014) observed that shaded grazing steers spent less time standing compared with unshaded grazing steers, and Sullivan et al. (2011) observed more lying time in shaded feedlot animals compared with unshaded cattle. In contrast, another study reported that shaded feedlot cattle spent more time standing compared with unshaded feedlot cattle (Blaine and Nsahlai, 2011). However, other studies found no difference in lying time (Mitlöhner et al., 2001; Blaine and Nsahlai, 2011; Rovira, 2014) or time spent standing (Sullivan et al., 2011). Additionally, cattle vary their behavior throughout the day (Kilgour, 2012) and variation by time of day has been reported for shade use. Mitlöhner et al. (2002) found that behavioral differences between shaded and unshaded feedlot heifers were time-dependent, with various differences observed between 0700 and 2200 hours. For example, shaded heifers spent more time lying at 0800, 1200, and 1500 hours, but less at 1000 hours, compared with unshaded heifers (Mitlöhner et al., 2002). The discrepancies between studies in reported results specific to behavior are potentially due to behavioral observation methodology, time of day cattle were observed, differences in ground and ambient temperatures, or differing behavior definitions.

### *Feeding, ruminating, and drinking*

There is a lack of research regarding the effect of shade provision on feeding and drinking behavior. Cattle given access to 80% shaded area were reported to spend less time grazing compared with cattle given no shade (Rovira, 2014). Similar to lying and standing behavior, one study reported an effect of time of day on feeding and drinking whereby shaded feedlot heifers spent more time feeding at 0900 and 1300 hours, but less at 1100 hours, compared with unshaded heifers (Mitlöhner et al., 2002); this same study observed that shaded cattle spent less time drinking water at 1300 hours, but more time drinking at 2000 hours, compared with unshaded heifers (Mitlöhner et al., 2002). Other studies found no difference in time spent feeding between shaded and unshaded feedlot cattle (Mitlöhner et al., 2001; Blaine and Nsahlai, 2011) or grazing steers (Rovira and Velazco, 2010, Geraldo et al., 2012) and no difference in time spent drinking between shaded and unshaded feedlot cattle (Mitlöhner et al., 2001; Gaughan et al., 2010). Related to grazing and feeding behavior, rumination has also been evaluated between shaded and unshaded cattle. Time spent ruminating was higher in bulls on pasture exposed to both tree shade and artificial shade compared with unshaded herdmates (Titto et al., 2011). Again, because cattle behavior is influenced by so many variables (e.g., time of day and biological rhythms), it would be beneficial to have some consistency in the approach used to quantify behavior so that better comparisons can be made across studies.

### *Other behaviors*

There are many other behaviors that cattle exhibit outside of those previously described, but these are not included as often in shade studies. Agonistic behavior, including fighting, threats, displays, and retreats, is of interest because this type of behavior provides information about social dynamics in particular environments. Mitlöhner et al. (2002) did find that shaded heifers exhibited less bullying behavior compared with unshaded heifers at 2100 hours and less agonistic behaviors at 1900 and 2000 hours compared with unshaded heifers. Shaded cattle had approximately four times less agonistic interactions with penmates at 0100 hours compared with unshaded heifers (Mitlöhner et al., 2002). Usually, this type of behavior is not included in shade studies, possibly because agonistic behavior is generally observed in lower frequency and is, therefore, challenging to capture with some observational methodologies. Additionally, perhaps agonistic behavior simply has not been considered as a relevant behavior to be associated with the presence or absence of shade; this may change with further consideration of shade effects on cattle affective state in these types of studies.

Overall, some studies indicate that shade provision impacts lying, standing, feeding, and drinking behaviors, albeit there are conflicting results, while others found no differences in these behaviors. Additionally, some studies found differences between shaded and unshaded cattle in either lying time or standing time but not both. The effect of shade on behavior is difficult to compare between studies as factors that vary by study, such as ambient temperature, THI, type of shade, breed, age, production stage, can also affect behavior. Despite the fact that studies do try to limit confounding factors such as those listed, we encourage careful interpretation of results that considers these factors. More research is needed to determine the effect of shade on cattle behavior. Specifically, we encourage studies to utilize comprehensive ethograms that capture cattle's entire repertoire of behaviors to determine how total time budgets shift due to shade provision, which may help explain discrepancies between studies. Furthermore, future work should examine temperature and moisture differences between shaded and unshaded pens to determine how these factors interact with behavior.

## Preference for shade and the importance to cattle welfare

The aforementioned studies suggest that the use of shade by cattle varies depending on THI, time of day, and shade type. Consequently, providing an environment in which cattle can choose when and how to utilize shade is important to enhance animal welfare, as choice allows the animal freedom to decide where and how to express certain behaviors. While animals cannot verbalize their preferences, experimental preference tests can be conducted in which the animal is provided with options and we infer their preference based on where the animal chooses to go (Fraser and Matthews, 1997). Providing cattle with their preferred environmental aspects results in the animal experiencing less frustration and potentially more positive states of welfare. We assume that animals' choices are indicative of their affect, or subjective experiences, and that they will prefer options that result in less pain, distress, or discomfort and may simultaneously choose options that result in comfort or contentment (Fraser and Matthews, 1997).

To our knowledge, no preference tests regarding shade have been performed in beef cattle. However, data from beef cattle studies not designed to directly assess preference suggest that cattle utilize shade during the hottest time of the day, and when comparing different shade treatments, cattle spend more time using shade that offers more cooling (Titto et al., 2011). For insight into cattle preferences, we can extrapolate findings from preference tests in dairy cattle as a starting point for the

beef industry. For example, when exposed to shade cloths that blocked varying amounts of solar radiation, lactating dairy cows consistently chose shade cloths that blocked greater amounts of solar radiation (Schütz et al., 2009). Beyond preference tests, which allow the animal to choose between different options, motivational studies can measure how hard an animal is willing to work to obtain a given resource (Fraser and Matthews, 1997). Dairy cattle were highly motivated to obtain shade on warm days, choosing shade over lying down even when deprived of lying for 12 h (Schütz et al., 2008); it should be noted that dairy cattle are highly motivated to lie down as well (Tucker et al., 2004). Thus, providing shade to cattle, especially on warmer days, is a key to ensuring good animal welfare.

The variation of cattle behavior within a day (Kilgour, 2012) adds to the complexity of preference and motivation, as preferences and motivation can change throughout the day. As such, providing shade in a manner that allows cattle to choose how and when to utilize the shade is imperative. For example, a pen that has both shaded and unshaded portions allows the animal to perform its repertoire of behaviors in varied environments of its choosing. Future work should investigate which aspects of shade cattle prefer and which of those qualities are most important.

## To Shade or Not to Shade?

The beef industry is estimated to account for over 20% of total losses associated with heat stress in the United States, which is estimated to total US$370 million (St-Pierre et al., 2003). Therefore, there is a need to implement low-cost, yet effective, heat-relieving strategies throughout sectors of the beef industry. Since providing shade can require relatively minimal capital investments which can be stretched over multiple years, the small financial gains associated with the reduction in heat stress and improvement in performance may offset and be greater than the cost of providing artificial shade, especially in areas that are prone to greater heat loads.

In order to calculate the economic feasibility of shade provision, producers must first understand both the input costs and beneficial gains associated with providing shade. The input costs are obviously variable depending upon the chosen materials and shade type; however, once that is determined, these costs can be easily calculated. Sullivan et al. (2011) estimated the cost of providing shade to feedlot cattle, reporting a total cost of providing 2.0 or 4.7 $m^2$ of shade area per animal to be US$59.75 and 69.74/hd, respectively. The authors also cautioned that other variables such as load-bearing requirements, removal during certain seasons, and depreciation cost of the shade structures need to be considered when calculating the relative financial returns of providing shade to cattle. Overall, Sullivan et al. (2011) concluded that providing 2 $m^2$ of shade per animal during the hot portions of the year improved ADG, gain/feed, HCW, and reduced panting scores when compared with animals provided no access to shade. However, providing greater than 2 $m^2$ of shade per animal did not improve animal performance but further decreased signs of heat stress in cattle and, therefore, improved animal welfare.

Conversely, defining and describing the performance benefits and economic advantages of providing artificial shade have significant challenges. First, more efficient animals with better genotypes tend to produce a greater amount of body heat due to increased metabolism (West, 1994; Settar and Weller, 1999; St-Pierre et al., 2003). Because of this, the effects of ambient temperature, especially heat, are ever-changing as producers continually select for higher-performing, more efficient livestock. Second, production losses as a result of heat stress are often disguised among many other sources of variation, such as differences in facility and shade design, plane of nutrition, and other management decisions. Third, the many studies, which are designed to evaluate the beneficial effects that result from providing cattle with shade, all have unique atmospheric conditions. In numerous other scientific scenarios, these unique study conditions would be beneficial to confirm the efficacy or repeatability across different environments; however, for the study of shade as it relates to heat stress, this wide range of environmental conditions has different impacts on the treatment (shade) and, therefore, lead to inconsistent results, which makes drawing overarching conclusions about the effect of shade across multiple environments challenging. For example, in the studies included in the aforementioned meta-analysis, some showed no difference in dry matter intake while others found improvements for cattle given access to shade. The magnitude of the effect is likely related to differences in the environmental conditions within that geographic region at the time the study was completed. For example, Brown-Brandl (2008) provided a figure (based on Garrett, W.N., unpublished data) that shows the regions of the United States that would experience performance benefit from shade as a function of the intensity of summer weather measured as hours per year above 29.4 °C. Perhaps the most important factor a feedlot must consider when contemplating heat abatement strategies is the heat load that the cattle will be subject to. Consideration must be given to not only the average atmospheric temperature but also temperature and relative humidity extremes.

In a typical year, heat stress may have minimal impact on performance in most instances, especially in the northern regions of the Great Plains. However, extreme heat waves that are unpredictable and seem to be increasing in occurrence, aside from having grave consequences for animal welfare, can greatly diminish performance and financial gains, even in the northern regions. In a study by Mitlöhner et al. (2002), the incidence of dark-cutting cattle was reduced from 19.1% in pens that had no access to shade to 8.3% in pens that had access to shade. This near 60% reduction in the incidence of dark cutting carcasses also resulted in an approximately 20% unit increase in cattle grading USDA Choice. By analyzing a large proprietary dataset from nine commercial feedlots over a 3-yr time period, Scanga et al. (1998) also showed that extreme temperatures can increase the incidence of dark-cutting cattle. When cattle were exposed to temperatures over 35 °C within the last 1 to 3 d before harvest, there was a significant increase in the number of dark cutting carcasses. Therefore, while these temperature extremes may not be considered “normal” for most of the areas in the United States, even a short duration at the wrong time could have major implications on quality grade and financial returns.

Death loss attributed to heat is another significant factor that should be considered when contemplating the financial benefits of providing shade. A case study by Busby and Loy (1997) evaluated the effects of a 2-d extreme heat wave (temperatures in excess of 40 °C, with a relative humidity near 50% and minimal to no wind) in west-central Iowa. During this 2-d period, 3,750 cattle died due to the extreme temperatures, which was approximately 2.32% of the cattle in the area. The direct loss was estimated to cost a total of US$2.8 million. However, the losses were not spread evenly amongst all feedlots. In feedlots that provided the cattle with shade, the death loss was only 0.2%, whereas the death loss in feedlots without shade was 4.8%.

While this is an extreme example, especially for west-central Iowa, it does show the potential importance of shade in short-term, extreme weather events. While returns may be minimal in a "normal" year, savings associated with mitigating adverse heat effects by providing shade can be drawn out over multiple years, which may provide great financial returns in years with extreme temperatures.

The cow–calf segment of the beef industry can also be impacted by heat and, in some cases, may benefit by providing either natural or artificial shade. Much of the research surrounding the impact of heat on cattle on pasture has focused on dairy cattle. While there is some cross-over, the impact of heat and shade are much higher in dairy cattle compared with beef cattle due to unique attributes of dairy cattle, including greater heat production, higher plane of nutrition, and differences in breeding seasons. In the dairy industry, one of the biggest challenges associated with heat stress is the negative consequences it has on the reproductive system. Heat can impede follicle development (Wise et al., 1988; Wolfenson et al., 1995; Wilson et al., 1998a, 1998b), oocyte maturation (Collier et al., 1982; Wolfenson et al., 2000), and embryonic development (Drost et al., 1999). High temperatures may also reduce male fertility (Ax et al., 1987). In the beef industry, however, the breeding season is often in late spring and early summer before temperatures are exceedingly hot. This advantageous timing will not only reduce heat stress-associated complications during breeding but also generate early-term pregnancies during the hotter times of the year. Biggers et al. (1987) showed that heat stress can reduce both pregnancy rates and fetal weights in beef cows, which, combined, can have obvious economic implications for cow–calf producers. The extent of these losses will be proportional to the severity of the heat stress, which can also be mitigated by natural or artificial shade.

## Future Directions

The objective of this review was to identify how shade impacts cattle well-being. Throughout, the following items were identified as future needs: benchmarking of current shade provision across the supply chain, information regarding producer perspectives of cattle shade need and/or use, a broadened view of beef cattle welfare in relation to shade provision, additions to the current body of research with specific focus areas, and a better understanding of the economics of shade implementation.

Despite multiple papers on heat stress in beef cattle (primarily in the feedlot sector) beginning with a statement articulating that cattle's thermal environment can negatively impact performance and well-being (e.g., Blackshaw and Blackshaw, 1994; Mader, 2003; West, 2003; Lees et al., 2019), the adoption rate of shade provision in the United States is low. Granted, there are little data available to quantify actual shade implementation, but the lack of inclusion of shade provision questions in industry benchmarking tools suggests that shade provision is not necessarily considered as an essential part of beef cattle management, dependent upon location. It is the authors' assumption that in areas of the United States that experience high temperatures and humidity during significant portions of the year, shade is usually integral to cattle systems. In other areas that do experience periods of similar hot, humid weather, but perhaps not for the same extent of time, many of the beef operations do not provide shade when it is likely that some shade could be beneficial to welfare. Additionally, benchmarking of current shade provision, including information about operation location and shade type used, could be helpful in establishing the current state of shade use in the cattle industry. Information regarding producer perception of the benefits of shade could also be extremely useful in identifying some of the reasons that shade is or is not provided on operations. From the authors' participation in cattle industry conversations, the three main reasons given when producers are asked about why they do not provide shade at their facilities are 1) that shade it not needed where their operation is located, 2) in their experience, shade does not improve animal performance, and 3) the benefits of the shade do not exceed the cost of the shade. This type of benchmarking information should include all segments of the beef cattle supply chain (e.g., cow–calf, stocker, feedlot, and packing plant) as perceptions and use likely vary, and currently, there is considerably more attention paid to shade use in the feedlot sector.

Throughout the current shade research summarized in Table 2, there is a clear focus on performance indicators. This is in part due to the primary sector of research being the feedlot; performance and carcass characteristics are traditionally included in studies to assess effectiveness of a management strategy. Additionally, performance indicators are used to determine if returns in profit from increased gain or improved quality would outweigh the cost of implementing something like shade structures. The focus on performance is also due to the still narrow view of what constitutes good cattle welfare. Although performance indicators do provide information on the biological functioning of an animal, a clear component of welfare, there are many other factors that should also be considered when assessing the overall cattle welfare. An animal's ability to perform natural behaviors and its emotional state, which are both influenced by its environment, should be integral to well-being assessment. There likely needs to be a shift in how shade benefits are evaluated in beef cattle; a better understanding of industry perceptions of cattle welfare paired with additions to how research studies integrate comprehensive welfare outcomes is needed.

Although there are studies reporting how shade impacts various well-being outcomes in beef cattle, the total number of published papers is limited relative to other areas of cattle welfare research, such as pain mitigation and nutritional management, and is certainly limited compared with heat stress research in dairy cattle. This could in part be due to the complexity of shade implementation across beef supply chain sectors based on all the impacting factors of design and operation location. It could also be an artifact of the previous discussion of the perceived need of shade within the industry. Lastly, the paucity of shade research is likely a result of limited funding opportunities. Regardless of the reason that shade studies are limited, this does identify a gap in cattle welfare research with many opportunities for further investigation. Future studies could focus on shade type and effectiveness; there are many different methods of providing shade, and a useful resource would be how different types of shade impact cattle welfare. Another area of needed research is identifying the impacts of having shade (or not having shade) during hotter weather on cattle affective state. Although traditionally the consideration of affective state of livestock in facility design has been rather limited, there has been a significant increase in applying methods of this type of assessment across livestock sectors. Ede et al. (2019) review research techniques for assessing affective state in dairy cattle, but the described methods can be applied across animal types. Preference tests and strength of motivation tests would add value to the welfare discussion around shade implementation

and perhaps draw attention to other aspects of cattle welfare that are occasionally marginalized.

The selection of animal well-being outcomes measured across shade studies is inconsistent and there is not a core subgroup of essential indicators included across studies. Interestingly, there is little to no inclusion of measures associated with immune function and subsequent health outcomes such as morbidity and mortality. With smaller sample sizes and relatively low frequencies of death loss across operations, shade impacts on mortality may not be able to be effectively assessed, but perhaps treatment rate and disease prevalence would be of interest in future studies. Additionally, the current review identified many differences in methodology of behavioral assessment (including data collection scheme and ethogram selection) making cross-study comparisons challenging. Lastly, regarding areas that could benefit from further research, although not specifically addressed in this review, there may be populations of cattle that are at higher risk for heat stress, and, therefore, these animals may be the priority for shade provision research. Cattle populations at risk to experience heat stress during hot weather could include cattle not adapted to hot and humid climates, long-fed cattle in feedlots, cattle close to being finished, cattle with dark and thick coats, newly received cattle due to cumulative stressors associated with arrival at new location, and sick cattle (Gaughan et al., 2002). Perhaps prioritizing research in these areas would be beneficial. It is essential to apply these research suggestions across beef industry sectors as there is limited research specifically in the cow–calf and packing plant segments.

Lastly, there is a significant need for further economic analysis of shade implementation to provide current information considering significant changes in cattle size, weather patterns, and market prices over the past couple of decades. The only published economic assessment of shade in the beef industry is from 2003 (St-Pierre et al., 2003). Although St-Pierre et al. (2003) identified economic losses of US$369 million to the beef cattle industry, the conclusion made in that paper was that the economic loss on a per animal basis from heat stress for both beef cow and finishing cattle did not justify high-cost heat abatement strategies such as shade implementation. This analysis utilized DMI and death loss due to heat stress to estimate the loss. Further analyses should include a more comprehensive evaluation of other relevant welfare and economic factors to estimate the true value or cost of shade provision. It should be noted that although economics are certainly important in decision-making, a broader consideration for welfare impacts that are potentially more challenging to financially quantify needs to be considered as well. Additionally, considering the technological advancements and experience of the dairy industry and other cattle industries across the globe (e.g., Australia), we should have many more sustainable options for shade structures that could be considered to reduce capital investment.

## Conclusions

The welfare benefits of shade in cattle operations have been documented, yet there are some inconsistencies between studies, particularly in behavior patterns in shaded and unshaded groups. Studies have shown reduced physiological responses to heat stress, performance benefits, and increased use of shade in cattle provided the opportunity to utilize shade in the weather outside of their thermoneutral zone. Common reasons for not providing shade on operations are often related to the cost of the investment paired with the assumed unclear benefits and the questionable need for shade in certain regions of the United States. Fraser's framework for animal welfare was discussed, identifying the need for a holistic approach to welfare assessment when evaluating the impacts of shade on overall cattle well-being. Current research focuses on performance indicators in part due to the fact that if economic value can be found with shade implementation, then the return on investment becomes extremely clear. It is important for stakeholders to expand their vision of animal welfare to include things such as cattle preference, mental state, and opportunity for choice in their environment when evaluating the value of shade to cattle welfare. Future research should focus on quantifying current shade provision across the supply chain, understanding producer perspectives of cattle shade need, including indicators of the affective state into studies, and assessing the economics of shade implementation.

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## Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

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