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Influence of shade on panting score and behavioural responses of *Bos taurus* and *Bos indicus* feedlot cattle to heat load

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Abstract

Context. Feedlot cattle can be negatively impacted by hot conditions, such that they have reduced performance and wellbeing. This study was conducted at the research feedlot located at The University of Queensland during a southern hemisphere summer (October to April).

Aims. The objective of this study was to evaluate the influence of shade on the behaviour and panting score of *Bos taurus* and *Bos indicus* feedlot cattle during summer.

Methods. Thirty-six steers (12 Angus, 12 Charolais and 12 Brahman) with an initial non-fasted liveweight of 318.5 ± 6.7 kg were used in a 154-day feedlot study consisting of two treatments: unshaded and shaded (3 m^2/animal). Observational data were obtained for each steer at 2 h intervals between 0600 and 1800 hours daily from Day 1 to Day 154. Additional night time observational data were collected at 2-h intervals between 2000 and 0400 hours on 12 occasions. Data collected included activity (feeding, drinking, or ruminating), posture (standing or lying) and panting score. Panting scores were used to calculate a mean panting score for each breed × treatment group. Observational data were converted to a count for each breed × treatment group for each observation time point and were analysed using a binomial generalised linear model.

Key results. Maximum shade utilisation was the greatest at 1200 hours for Angus (85.5%), Charolais (32.7%) and Brahman (33.3%) steers. All breed × treatment groups exhibited a notable increase in mean panting score as heat load increased. Average increase in mean panting score was 0.36, where shaded Brahman exhibited the smallest increase (0.13) and unshaded Angus had the greatest increase (0.71). When heat load conditions were very hot (heat load index (HLI) ≥ 86) the mean panting score of all breed × treatment groups differed ($P < 0.05$).

Conclusions. Overall these results emphasise the importance of providing shade to feedlot cattle, irrespective of genotype.

Implications. These results further highlight the importance of providing shade to feedlot cattle. These results challenge the general perception that *Bos indicus* feedlot cattle do not require access to heat load alleviation strategies.

Additional keywords: heat load index, posture, respiratory dynamics, rumination, shade utilisation, thermal comfort.

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Introduction

Bos taurus cattle are particularly susceptible to hot climatic conditions, often exhibiting reduced performance and wellbeing (Hahn 1999; Mader 2003). Measurements of body temperature are considered to be the most reliable indicator of thermal stress (Gaughan *et al.* 2010*a*; Mader *et al.* 2010; Lees *et al.* 2018); however, evaluating body temperature within commercial feedlots may not always be feasible. Alternatively, respiration rate has been identified as a reliable early indicator of increasing heat load (Brown-Brandl *et al.* 2005; Gaughan *et al.* 2008*b*). Respiration rate can be subject to rapid changes where high respiration rates (rapid shallow breathing) may suddenly fall as cattle take deep breaths in order to stabilise blood pH (Baumgard and Rhoads 2007). Respiration rate can be visually assessed, although this can be difficult to evaluate under field conditions where observations can occur 30–40 m away from the cattle (Gaughan *et al.* 2010*b*), nor does respiration rate provide a descriptive indication of overall respiratory dynamics.

Panting score provides a visual assessment of respiratory dynamics in cattle and evaluates the breathing and panting condition that the animal is displaying (Young and Hall 1993) and has been described as a good indicator of heat load in feedlot cattle (Mader *et al.* 2006; Gaughan and Mader 2014). Furthermore, under field conditions the assessment of panting score has been identified as a viable alternative to using body temperature to evaluate the heat load status of feedlot cattle

(Brown-Brandl *et al.* 2006*b*; Mader *et al.* 2006; Gaughan *et al.* 2008*b*; Gaughan and Mader 2014). In addition to changes in respiratory dynamics, cattle will initiate purposeful behavioural changes in response to increasing thermal loads. Cattle utilise adaptive behaviours to reduce heat load, these behaviours consist of: (1) increased duration in shaded areas or increased shade seeking (Blackshaw and Blackshaw 1994; Sullivan *et al.* 2011), including shade provided from other animals (Mitlöhner *et al.* 2002; Castaneda *et al.* 2004); (2) alignment of the body to reduce whole body exposure to direct sunlight (Nienaber *et al.* 2003); (3) alterations in posture, including increasing the proportion of time standing (Brown-Brandl *et al.* 2006*a*; Gaughan *et al.* 2008*a*); and (4) body splashing at water troughs (Young and Hall 1993). These behavioural adaptations are the animal's first response to increasing thermal loads. Therefore, during periods of heat load animal observations can provide a valuable insight into the severity of heat load that the animal is experiencing. The objective of this study was to investigate the influence of shade on the panting score and behavioural responses of *Bos taurus* and *Bos indicus* feedlot cattle when exposed to high heat load.

Materials and methods

This study was conducted with the approval of The University of Queensland (UQ) animal ethics committee (SAFS/335/11/MLA), in accordance with the guidelines described by the Australian National Health and Medical Research Council (1997) and Queensland Department of Agriculture and Fisheries (2009). The study was undertaken at UQ research feedlot located at the Queensland Animal Science Precinct (QASP), UQ Gatton Campus, in South-east Queensland, Australia (27.54°S, 152.34°E; 100 m above mean sea level). The study was conducted over 154 days during a southern hemisphere summer between 31 October and 2 April. During the summer the location is characterised as a hot, humid sub-tropical climate. Long-term averages (96 years) indicate that the mean ambient temperature (T_A; °C) during this period range between 28.2°C (October) and 31.6°C (January) (Bureau of Meteorology 2019).

Animals

Thirty-six steers (12 Angus, 12 Charolais and 12 Brahman) with an initial non-fasted liveweight of 318.5 ± 6.7 kg were used in a 154-day feedlot study consisting of two treatments: unshaded and shaded (3 m^2/animal). Six steers from each breed were allocated to each treatment group. *Bos taurus* cattle were sourced ~80 km south-west of UQ, whilst *Bos indicus* were sourced ~380 km north-west of UQ. The region where the *Bos taurus* cattle were sourced from is classified as tick free, has a mild climate, and improved pastures. Whereas the *Bos indicus* were sourced from within the cattle tick (*Rhipicephalus* (*Boophilus*) *microplus*) zone, and unimproved pastures. The *Bos taurus* cattle were purchased from the area to the south-west to reduce negative effects, i.e. low post weaning growth, associated with tick burdens, heat and poor nutrition that can arise in areas to the north-west.

Feedlot design and infrastructure

A full description of the feedlot pens has been reported previously (Lees *et al.* 2018). Briefly, six feedlot pens (162 m^2; 27 m × 6 m) at the UQ research feedlot were used. The feedlot pens were situated in a north–south alignment, with a 2% slope from the feed bunks towards the rear of the pens. Feed bunks provided a linear area of 0.7 m^2/animal and the linear water trough area was 0.17 m^2/animal. Stocking density was 27 m^2/animal. Three shaded pens and three unshaded pens were used. The unshaded and shaded treatment pens were separated by a single unused unshaded pen, to ensure that the shade footprint from the shaded pens did not encroach on unshaded pens. Shade was provided by shade-cloth (black, 90% solar block, Darling Downs Tarpaulins, Toowoomba, Qld, Australia) attached to a 4-m high steel frame, providing a shade footprint of 3.0 m^2/animal at midday.

Animal observations

Observational data was obtained for each animal at 2-h intervals between 0600 and 1800 hours daily, between Day 1 and Day 154. Night-time observations were conducted at 2-h intervals between 2000 and 0400 hours on Days 13, 27, 35, 41, 54, 69, 75, 83, 97, 125, 139 and 153. During night-time observations, night vision binoculars (NVA 5 × 42 LT Digital Binocular, Night Vision Australia Pty Ltd, Sydney, NSW) were used to assist in the determination of individual cattle behaviours. Night-time observations were scheduled to occur at 14-day intervals; however, additional night-time observations were conducted on the forecasted hottest night during periods of high heat load.

Periods of high heat load were defined as (i) 3 or more consecutive days where maximum accumulated heat load (AHL) for unshaded Angus (threshold = 86, AHL_{86}) were ≥ 30 for 3 consecutive days and/or (ii) AHL_{86} did not completely abate ($AHL_{86} \neq 0$) at night and/or (iii) maximum heat load index (HLI) were ≥ 90 as described by Gaughan *et al.* (2008*b*). All behavioural observations were conducted from the feed bunk. This was done to minimise alterations in cattle behaviour.

For steers in the shaded pens, location within pen was described as under shade or in sun, where shade utilisation was defined as ≥ 60% of the body covered by shade (Kendall *et al.* 2006). Feeding was defined as the animal standing with their head in the feed bunk and actively eating (Mitlöhner *et al.* 2001*a*). Drinking was defined as the animal standing with their head in the water trough and actively drinking. Rumination was defined as the steer actively ruminating. When assessing the posture of the steers, standing was defined as the animals standing in an inactive upright position, whereas lying was defined as sternal recumbency as described by Mitlöhner *et al.* (2001*a*). Panting scores were visually determined based on the open and closed mouth panting of cattle using a 0 to 4.5 scale (Table 1) adapted from Brown-Brandl *et al.* (2006*a*), Mader *et al.* (2006) and Gaughan *et al.* (2008*b*). Observed panting scores were used to calculate a mean panting score for each breed × treatment combination, for each observation, using the equation described by Gaughan *et al.* (2008b);

$$\text{Mean panting score (MPS)} = \frac{\sum_{i=0}^{4.5} N_i \times i}{\sum N_i}$$

where N_i is the number of cattle observed at PS*i*.

Mean panting scores were used to categorise the severity of heat load status via four stress categories: (1) no stress, mean

Table 1. Assessment of panting score (PS), description of breathing/panting condition and associated respiration rate (RR; breaths per minute)
Adapted from Brown-Brandl *et al*. (2006*a*), Mader *et al*. (2006) and Gaughan *et al*. (2008*b*)

PS	Breathing condition	RR
0	No panting	≤60
1	Slight panting, mouth closed, no drool, easy to see chest movement	60–90
2	Fast panting, drool present, no open mouth	90–120
2.5	As for 2, but occasional open mouth panting, tongue not extended	90–120
3	Open mouth and excessive drooling, neck extended, head held up	120–150
3.5	As for 3, but with tongue out slightly and occasionally fully extended for short periods	120–150
4	Open mouth with tongue fully extended for prolonged periods with excessive drooling. Neck extended and head up	≥160
4.5	As for 4, but head held down. Cattle 'breath' from flank. Drooling may cease	Variable RR may decrease

panting score = 0 ≤ 0.40; (2) mild stress, mean panting score = 0.41 ≤ 0.80; (3) high stress, mean panting score 0.81 ≤ 1.20; and (4) severe stress, mean panting score ≥ 1.21 described by Gaughan *et al*. (2008*b*).

Nutritional management

The nutritional management, including diet ingredients and compositions for the starter and finisher rations are presented below in Table 2. Briefly, the feed bunks were read at 0700 and 1200 hours each day using a modified 'clean bunk at midday' feed intake management program (Lawrence 1998). Cattle were backgrounded from Day –14 until Day 8. Cattle were then fed a starter diet until Day 37, and then transitioned onto a finisher ration between Days 38 and 73. The cattle remained on the finisher ration from Day 73 to the end of the study. Cattle were fed once daily at ~1430 hours. The feeding schedule was modified during periods of high heat load, where feed offered was reduced to 95% of the previous 5 day mean feed intake and feeding delayed until 1530 hours.

Weather data

Weather data were collected at 10-min intervals using an automated weather station (Davis Pro V2, Davis Weather Station, Hayward, CA, USA) located at the front of the feedlot (western side). Weather data collected included T_A; relative humidity (RH; %); wind speed (WS; m/s) and direction; solar radiation (SR; W/m^2); and 24 h daily rainfall (measured at 0900 hours each day). The weather station was not equipped to record black globe temperature (BGT, °C), thus BGT was calculated by using the following equation (Hahn *et al.* 2009);

$$BGT = 1.33 \times T_{db} - 2.65 \times T_{db}^{0.5} + 3.21 \times \log_{10}(SR + 1) + 3.5,$$

where T_{db} is air temperature (°C) and SR is solar radiation (W/m^2).

Table 2. Composition of the starter and finisher rations offered throughout the study
DM, dry matter; NE_g, net energy for gain; CP, crude protein, RDP, rumen degraded protein; UDP, undegraded dietary protein; NDF, neutral detergent fibre; ADF, acid detergent fibre

Item	Starter[A]	Finisher[A]
Ingredient (kg as fed)		
Barley	165	250
Sorghum	399	339
Wheat	82.5	–
Millrun	100	100
Peanut hulls	160	–
Cottonseed meal	17.5	–
Molasses	20	20
Limestone	11	14.45
Sodium bicarbonate	8	8
Potassium chloride	3.42	–
Urea	7	6.95
Sulfur (dusting)	0.47	0.23
Moneco 200[B]	0.10	0.10
Sodium bentonite	25	25
Mineral–vitamin supplement[C]	1	1
Chickpea shell	–	200
Sunflower meal	–	35
Nutrient composition (as fed)		
DM (%)	89.30	89.20
NE_g (Mcal/kg)	1.44	1.66
Crude fat (%)	2.25	2.29
CP (%)	11.90	12.01
RDP (%)	8.49	8.39
UDP (%)	3.62	3.58
Crude fibre (%)	14.73	10.05
NDF (%)	23.74	24.16
ADF (%)	14.62	13.31
Mcal (ME, MJ/kg)	2.68 (11.20)	2.93 (12.27)

[A]Values are indicative of ingredient composition within the diet used (kg/ tonne).
[B]Contained 200 g/kg monensin sodium (International Animal Health, Huntingwood, NSW, Australia) and provided 20 mg/kg of monensin sodium to the final diet.
[C]Contained (on a DM basis): 8000 µIU/g of vitamin A; 2000 µIU/g of vitamin D; 16 000 mg/kg of vitamin E; 12 000 mg/kg of copper; 400 mg/kg of selenium; 200 mg/kg of cobalt; 1000 mg/kg of iodine; 10 000 mg/kg iron; 50 000 mg/kg of zinc; 30 000 mg/kg of manganese; and 15 000 mg/kg antioxidant.

From these data the HLI was calculated, using the equation described by Gaughan *et al*. (2008b) where the HLI equation takes the following forms:

(1) a nonlinear regression which applies when BGT is greater than 25°C

$$HLI_{BGT>25} = 8.62 + (0.38 \times RH) + (1.55 \times BGT) - (0.5 \times WS) + (e^{2.4-WS}),$$

(2) a linear model which applies when BGT falls below 25°C;

$$HLI_{BGT<25} = 10.66 + (0.28 \times RH) + (1.3 \times BGT) - WS,$$

where RH is relative humidity (%); BGT is black globe temperature (°C); WS is wind speed (m/s); and e is the base of the natural logarithm (approximate value of e = 2.71828).

Additionally, the HLI was utilised to identify four heat load stress categories: (1) cool (thermoneutral), HLI $\leq$ 70.0; (2) moderate, HLI 70.1 $\leq$ 77.0; (3) hot, HLI 77.1 $\leq$ 86.0; and (4) very hot, HLI $\geq$ 86.1 as described by Gaughan *et al*. (2008*b*).

Statistical analyses

Count within each breed × treatment were determined from the observational data for time point, i.e. number of unshaded Angus steers standing at 0600 hours. Shade utilisation was calculated by determining the count of steers standing or lying within the shade footprint provided by the shade structure. Counts per breed were then converted to a proportion, for breed × treatment combination. These data were then analysed using an analysis of variance, generalised linear model (GLM) with a binomial structure (R Core Team 2016). For feeding, drinking, ruminating, posture and mean panting score, the model analysed the effect of breed, treatment, hour (time of day; hours), day of study (day), HLI, breed × treatment, treatment × HLI, breed × day, hour × day, breed × hour, breed × HLI, breed × treatment × hour, breed × treatment × HLI and breed × hour × day. As shade utilisation could only be determined in the shaded pens, the model for shade utilisation analysed the effect of breed, hour, day, HLI, breed × day, hour × day, breed × hour, breed × HLI and breed × hour × day on shade utilisation.

Results

Weather

The weather conditions during the study period were similar to the long-term weather averages for the location, with some intermittent hot days above 35°C (n = 18). During the study there were 127 days with a maximum HLI $\geq$ 86. Of these 127 days, 91 days had a HLI $\geq$ 90, 37 days had a HLI $\geq$ 95 and 4 days had a HLI $\geq$ 100.

Animal responses

Interactions for feeding, drinking, rumination, posture, shade utilisation and mean panting score are presented in Table 3.

Feeding

Breed × treatment had a limited effect on the proportion of cattle observed feeding (P = 0.25; Fig. 1). Unsurprisingly, hour had a large impact on feeding behaviours (P < 0.0001), where the highest proportion of animals feeding for all breed × treatment combinations was observed at 1600 and 1800 hours, post feed delivery (Fig. 1). Breed (P < 0.0001) also influenced observed feeding behaviour. At 1600 and 1800 hours the proportion of Charolais (42.7 ± 3.3% vs 40.2 ± 2.6%) steers feeding were greater than the Angus steers (33.9 ± 3.2% vs 35.2 ± 2.6%) and Brahman steers (28.1 ± 3.0% vs 25.2 ± 2.3%). Feeding behaviour was influenced by time of day. Cattle were typically observed feeding between 1600 and 0400 hours and $\leq$5% of each breed × treatment group were observed at each observation between 0600 and 1400 hours. HLI also influenced feeding behaviours. Unsurprisingly as heat load category increased to hot (HLI 77.1 $\leq$ 86) and very hot (HLI $\geq$ 86.1) feeding bouts decreased for all breed × treatment groups (P < 0.0001).

Rumination

The proportion of cattle observed ruminating was highly variable throughout the study (Fig. 2). Day (P < 0.0001) and hour (P < 0.0001) influenced the proportion of cattle observed ruminating (Fig. 2). Shaded Charolais steers exhibited the maximum proportion of cattle observed ruminating at 0400 hours (20 ± 4.2%). Generally the proportion of steers ruminating were not influenced by HLI (P = 0.97); however, there was a breed × treatment × HLI effect (P = 0.01). When heat load was classified as very hot (HLI $\geq$ 86) the proportion of shaded Angus (7.0 ± 0.7%) and Charolais (8.7 ± 0.8%) steers observed ruminating were greater (P < 0.05) than their unshaded counterparts (Angus, 4.4 ± 0.6%; Charolais 6.1 ± 0.7). However, unshaded Brahman steers (7.2 ± 0.9%) were more likely (P < 0.05) to be ruminating when compared with shaded Brahman (4.3 ± 0.6%) when heat load was classified as very hot.

Table 3. Interactions (*P*-values) for feeding, drinking, rumination, posture (standing and laying), shade utilisation and mean panting score
HLI, heat load index

Item	Response						
	Feeding	Drinking	Rumination	Standing	Laying	Shade utilisation	Mean panting score
Breed	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001
Treatment	P = 0.04	P < 0.0001	P = 0.23	P < 0.0001	P < 0.0001		P < 0.0001
Hour	P < 0.0001	P < 0.0001	P < 0.0001	P = 0.002	P < 0.0001	P < 0.0001	P = 0.06
Day	P < 0.0001	P = 0.0005	P < 0.0001	P < 0.0001	P < 0.0001	P = 0.49	P < 0.0001
HLI	P < 0.0001	P = 0.06	P = 0.97	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001
Breed × treatment	P = 0.25	P = 0.03	P < 0.0001	P < 0.0001	P = 0.007		P = 0.003
Breed × hour	P = 0.10	P < 0.0001	P = 0.12	P = 0.21	P < 0.0001	P < 0.0001	P < 0.0001
Breed × HLI	P = 0.002	P < 0.0001	P = 0.30	P < 0.0001	P = 0.84	P < 0.0001	P < 0.0001
Breed × day	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001
Treatment × HLI	P = 0.48	P = 0.11	P = 0.02	P < 0.0001	P < 0.0001		P = 0.33
Hour × day	P < 0.0001	P = 0.27	P < 0.0001	P < 0.0001	P < 0.0001	P < 0.0001	P = 0.02
Breed × treatment × hour	P = 0.99	P = 0.63	P = 0.80	P = 0.40	P = 0.96		P = 0.21
Breed × treatment × HLI	P = 0.62	P = 0.53	P = 0.01	P = 0.08	P = 0.60		P = 0.37
Breed × hour × day	P = 0.40	P = 0.45	P = 0.48	P = 0.18	P = 0.007	P = 0.83	P = 0.30

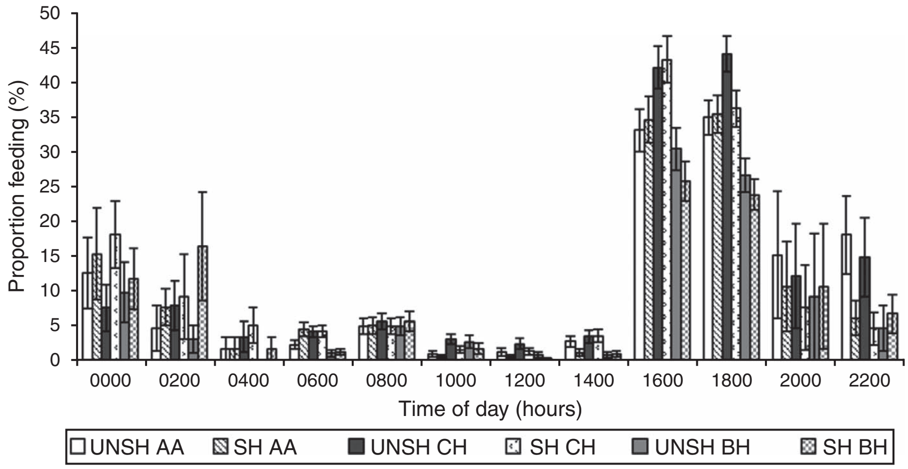

Fig. 1. Proportion of unshaded (UNSH) and shaded (SH) Angus (AA), Charolais (CH) and Brahman (SH) steers feeding across time of day (hours) during the study.

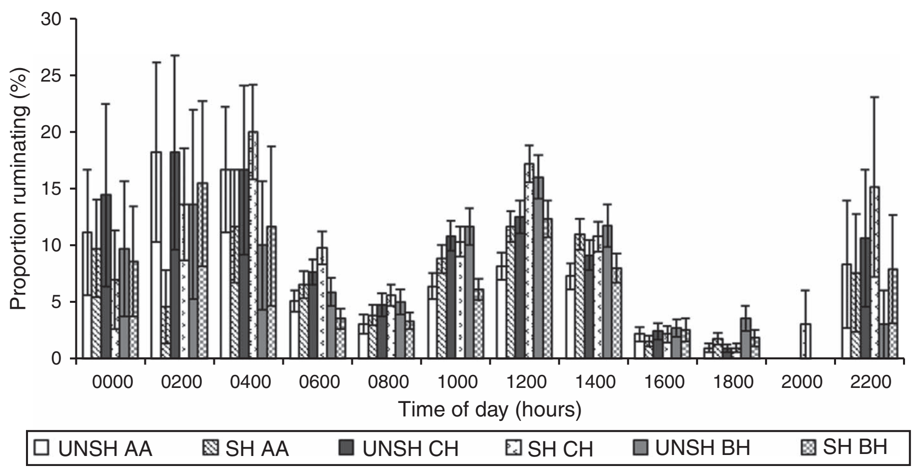

Fig. 2. Proportion of unshaded (UNSH) and shaded (SH) Angus (AA), Charolais (CH) and Brahman (SH) steers ruminating time of day (hours) during the study.

Drinking

Breed ($P < 0.0001$), treatment ($P < 0.0001$), hour ($P < 0.0001$), day ($P = 0.0005$), breed × treatment ($P = 0.03$), breed × hour ($P < 0.0001$), breed × HLI ($P < 0.0001$), treatment × hour ($P = 0.02$), and breed × day ($P < 0.0001$) influenced observed drinking behaviour in these cattle (Fig. 3). However limited conclusions can be drawn from these results as the greatest proportion of cattle observed drinking was 8.9 ± 1.2%, in shaded Angus steers at 1800 hours.

Posture

Standing and lying postures were highly variable throughout the study (day, $P < 0.0001$; hour × day, $P < 0.0001$; Fig. 4). However all breed × treatment groups were more likely to be observed standing during day time hours ($P = 0.002$; Fig. 4), and lying during night time hours ($P < 0.0001$). HLI had a significant influence on posture in these cattle ($P < 0.0001$). There was a 13.4 and 12% increase in the proportion of unshaded and shaded Angus steers observed standing when the HLI stress category increased from cool (HLI ≤ 77) to very hot (HLI ≥ 86; $P < 0.0001$). However, a greater disparity was observed between unshaded and shaded Charolais steers. The difference in the proportion of Charolais cattle observed standing between heat load categories cool and very hot was 12.9 and 4.8% respectively ($P < 0.0001$). There were limited changes in the proportion of shaded Brahman steers standing irrespective of HLI; however, there was a 5.3% increase in the proportion of unshaded Brahman steers standing when HLI stress category was classified as cool and very hot.

Shade utilisation

Shade utilisation was influenced by breed, where Angus steers exhibited the greatest shade utilisation between 0800 and 1600 hours ($P < 0.0001$). However, all breeds increased shade utilisation between 0800 and 1800 hours ($P < 0.0001$; Fig. 5*a*). Maximum shade utilisation was 85.5 ± 1.9%, 32.7

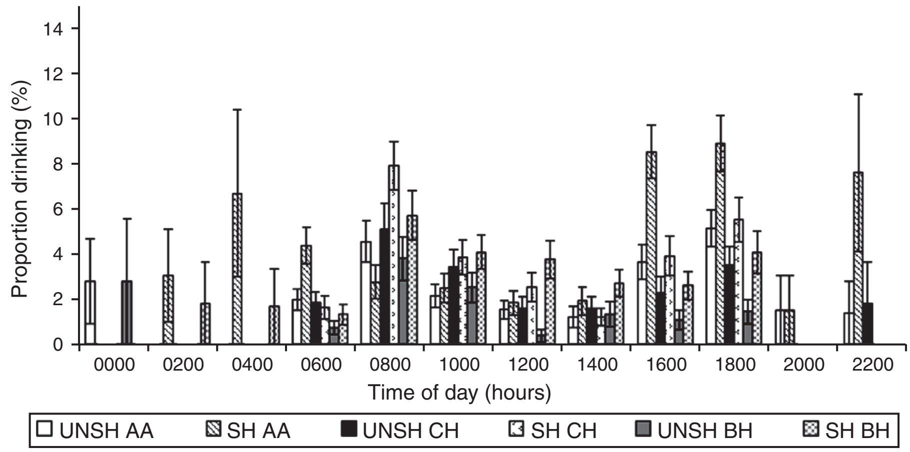

Fig. 3. Proportion of unshaded (UNSH) and shaded (SH) Angus (AA), Charolais (CH) and Brahman (SH) steers drinking across time of day (hours) during the study.

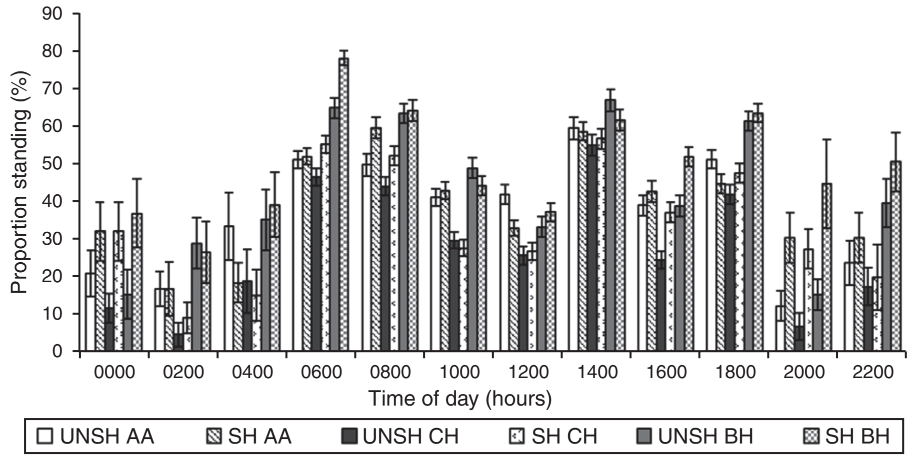

Fig. 4. Proportion of unshaded (UNSH) and shaded (SH) Angus (AA), Charolais (CH) and Brahman (SH) steers standing during the study across time of day (hours) during the study.

± 2.5% and 33.3 ± 3.3% for Angus, Charolais and Brahman steers, respectively, at 1200 hours. Brahman steers exhibited a 27.1% increase in shade utilisation between 0800 and 1200 hours.

As heat load increased there was an increase in shade utilisation (P < 0.0001) in all breeds (P < 0.0001). Angus steers had the greatest increase in shade utilisation as HLI stress category increased from cool (3.1 ± 0.9%) to very hot (64.4 ± 2.3%; Fig. 5*b*). Although the Charolais and Brahman steers exhibited a 28.1 and 15.5% increase in shade utilisation between HLI stress categories cool and very hot respectively (Fig. 5*b*).

Mean panting score

Mean panting score increased between 0600 to 1400 hours and then declined between 2000 and 0400 hours (P = 0.06; Fig. 6*a*). However, there were substantial differences in the mean panting score between breeds (P < 0.0001), treatments (P < 0.0001) and breed × treatment (P = 0.003), particularly between 0600 and 1800 hours (Fig. 6*a*). Unsurprisingly, unshaded Angus steers had the greatest increase in mean panting score, where mean panting score increased from 0.80 ± 0.03 at 0600 hours to 1.41 ± 0.05 at 1400 hours (P < 0.0001). Although there were no differences between the mean panting score of shaded and unshaded Angus steers at 0600 hours (0.83 ± 0.03) or 0800 hours (0.78 ± 0.04; P > 0.05), there were distinct differences between 1000 and 1600 hours (P < 0.05; Fig. 6*a*). A similar trend was observed for Charolais steers (Fig. 6*a*). Expectedly Brahman steers had the lowest mean panting score (0.05 ± 0.05) at 0400 hours for both shaded and unshaded cattle (Fig. 6*a*). Interestingly unshaded and shaded Brahman steers had numerically lower (P > 0.05) mean panting score at 0800 hours (unshaded, 0.13 ± 0.03; shaded, 0.08 ± 0.03) than at 0600 hours (unshaded, 0.18 ± 0.03; shaded, 0.17 ± 0.03).

Mean panting score showed a distinct increase as heat load category increased from cool (HLI ≤ 77) to very hot (HLI ≥ 86; P < 0.0001), in all breeds (P < 0.0001; Fig. 6b). When heat load category was classified as very hot (HLI ≥ 86) the mean panting score of all breed × treatment groups differed

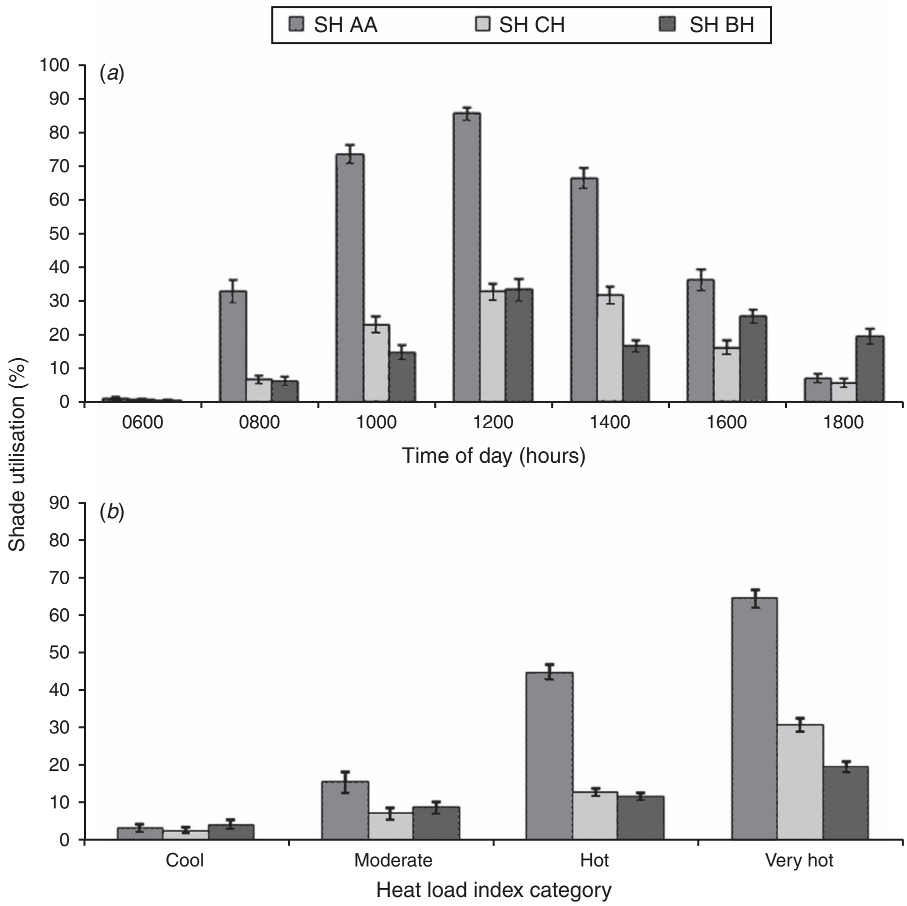

Fig. 5. Proportion of shaded (SH) Angus (AA), Charolais (CH) and Brahman (SH) steers utilising shade (*a*) during day time hours (time of day, hours); and (*b*) within heat load stress categories: cool (HLI $\leq$ 70), moderate (HLI 70.1 $\leq$ 77), hot (HLI 77.1 $\leq$ 86) and very hot (HLI $\geq$ 86).

(P < 0.05), whereby shaded cattle had lower mean panting scores compared with their unshaded counterparts (Fig. 6*b*). The maximum mean panting score determined was 3.5 in unshaded Angus at 1200 hours on Day 74, where HLI $\geq$ 97. Where heat load conditions were classified as very hot (HLI $\geq$ 86), mean panting score of shaded (0.15 $\pm$ 0.02) and unshaded (0.26 $\pm$ 0.03) Brahman steers differed (P < 0.05; Fig. 6*b*).

Discussion

Feeding and rumination

Periods of high heat load conditions have been well documented to have a negative impact on dry matter intake (DMI) (Beede and Collier 1986; Ray 1989; Hahn *et al.* 1992; Hahn 1999; Brown-Brandl *et al.* 2005). As feed intake was not measured individually within the present study, it was not possible to separate out breed and/or breed × treatment differences in DMI. Additionally, DMI and feeding behaviours are not considered as reliable measures of thermal stress as these behaviours are intermittent (Brown-Brandl *et al.* 2005). Feeding behaviour as a non-reliable measure of heat load appears to be reflected within the current study, particularly as feed was offered once daily at 1430 hours. However, Hicks *et al.* (1989) suggested that feeding patterns in cattle may be highly repeatable, therefore the trends in observed feeding behaviours were investigated. Unsurprisingly the greatest proportion of cattle observed feeding occurred at 1600 and 1800 hours, which was post feed delivery. Observations during the night (2000 to 0200 hours) suggest that all breed × treatment groups were consuming portions of feed at regular intervals. This is consistent with Ray and Roubicek (1971) and Brown-Brandl *et al.* (2005), who concluded that cattle appear to shift their feeding times to the cooler hours. Reductions in DMI reported during periods of high heat load are associated with a decrease in metabolic heat production, via ruminal fermentation, thus aiding in maintaining the overall heat balance of the animal (Beede and Collier 1986; Hahn 1999). The consumption of small frequent meals, as observed within the present study, may be an adaptation of ruminants to regulate body heat content by regulating metabolic heat production.

Rumination is a necessary component of digestion in ruminants. However, Young and Hall (1993) suggested that a reduction, or a complete termination, of rumination can be used to evaluate the degree of heat load cattle are experiencing. The proportion of cattle observed ruminating within the current study was largely influenced by time of day rather than heat load,

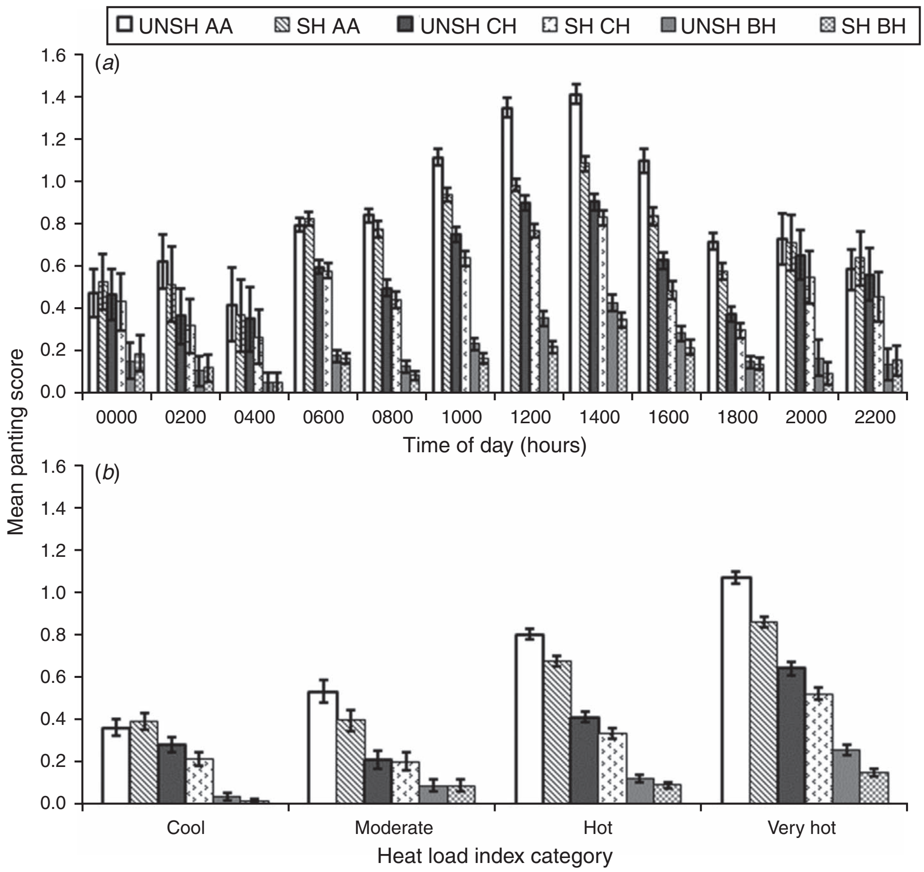

Fig. 6. Mean panting score of unshaded (UNSH) and shaded (SH) Angus (AA), Charolais (CH) and Brahman (SH) steers utilising shade (a) during day time hours (time of day, hours), and (*b*) within heat load stress categories: cool (HLI ≤ 70), moderate (HLI 70.1 ≤ 77), hot (HLI 77.1 ≤ 86) and very hot (HLI ≥ 86).

although it is important to consider that these results are likely to be confounded by feed intake, i.e. once daily feed offering at 1430 hours. Beede and Collier (1986) suggested voluntary reductions in DMI are associated with reduced gut motility and rumination. Therefore, the observation of rumination within the present study, and other studies, are potentially directly related to the amount of feed consumed rather than exposure to heat load *per se*. Afternoon feeding was deliberately implemented within this study, as shifting the time of feeding has previously been identified as a heat load mitigation strategy (Brosh *et al.* 1998). Furthermore the amount of feed offered within this study was regulated to reduce excessive feed intake during periods of high heat load (HLI > 86), thus it becomes difficult to define the response of feeding behaviours and rumination to hot climatic conditions within the current study.

Drinking

There are numerous factors that influence daily water intake in cattle including ambient conditions, diet type and genotype (Arias and Mader 2011). Genotype appeared to be an important factor in this study, where the proportion of shaded Angus steers observed drinking appeared to be more regular, during both day and night observations. McDowell and Weldy (1967) indicated that daily water intake appeared to be primarily driven by DMI, where the level of intake (kg/day) and type of ration, i.e. concentrates versus roughage diets, influences the amount of water consumed. Results from this study indicate that observed drinking events were highly variable and occurred throughout all observation times. The increased proportion of cattle drinking at 1800 hours may have been associated with feed intake post-delivery. Furthermore, within the present study the cattle may have been reluctant to drink during the hottest hours of the day as water troughs were located within an unshaded region of the pens, potentially increasing water temperature.

Posture

Feedlot and dairy cattle have been reported to increase the proportion of time spent standing during periods of high heat load (Shultz 1984; Igono *et al.* 1987; Frazzi *et al.* 2000; Brown-Brandl *et al.* 2006*a*; Gaughan *et al.* 2008*a*). Although postural changes were highly variable throughout the study, all breed × treatment groups were more likely to be observed standing during day time hours and lying during night time hours. By standing during the hot hours of the day, cattle are attempting to expose a greater proportion of their body surface to potential air movement in an attempt to increase the proportion of heat dissipation through (i) evaporative exchanges via the coat surface; and (ii) convective mechanisms via air movement around the body, while decreasing conductive heat accumulation from the pen surface (Gebremedhin 1985; Hahn 1985; Robertshaw 1985; Mader *et al.* 2002; Mader and Davis 2004). Thus, the increased proportion of cattle observed standing during day time hours are reflective of adaptive behaviours utilised by cattle to reduce heat accumulation during hot climatic conditions.

Shade utilisation

Shade utilisation for all breeds increased as heat load increased. As expected the proportion of Angus steers utilising shade was greater ($P < 0.05$) than Charolais and Brahman steers between 0800 and 1600 hours. Shade utilisation showed a marked increase between heat load categories increased from moderate (HLI, $70.1 \leq 77$) and hot (HLI, $77.1 \leq 86$), irrespective of breed, although the greatest magnitude increase was observed in the Angus steers (61.3%). We noted that the proportion of Brahman steers utilising shade increased when heat load category increased from cool to very hot, suggesting that Brahman cattle will use shade to reduce heat load, where shade is available.

It has been well established that the provision of shade is advantageous for feedlot cattle, particularly for *Bos taurus* breeds (Blackshaw and Blackshaw 1994; Entwistle *et al.* 2000; Mitlöhner *et al.* 2002; Gaughan *et al.* 2004; Brown-Brandl *et al.* 2005; Eigenberg *et al.* 2005). However, there have been limited studies highlighting the importance of providing shade to *Bos indicus* cattle. Given that the Brahman steers showed a 15.4% increase in shade utilisation when heat load category increased from cool to very hot, this suggests that *Bos indicus* cattle will utilise shade to reduce heat load when conditions are classified as very hot. The influence that shade utilisation has on thermoregulation in Brahman cattle remains unclear and warrants further investigations. However, it is clear that Brahman cattle are highly motivated to seek shade during hot conditions. Obviously, shade utilisation could only be determined for cattle within shaded pens. However, shade-seeking behaviours were observed in steers housed in unshaded pens. These cattle were observed seeking shade from other animals and from structures around the pen, i.e. fence lines, feed bunks and water troughs. These observations are consistent with those of Mitlöhner *et al*. (2001*b*), Castaneda *et al*. (2004) and Gaughan and Mader (2014). Although these observations reiterate that it is impossible to completely remove access from shade in feedlot pens, they also highlight the importance of shade provision for feedlot cattle, although there is some conjecture regarding the amount of shade (m^2/animal) required to offset the impact of heat load (Clarke and Kelly 1996; Mitlöhner *et al.* 2002; Sullivan *et al.* 2011).

Mean panting score

Mean panting score in all breed × treatment groups increased throughout the day and as heat load increased. Unshaded Angus, Charolais and Brahman steers exhibited a 29, 39 and 12% increase in mean panting score throughout the day. Whereas the shaded Angus, Charolais and Brahman steers had mean panting score increases of 34, 32 and 14% respectively. Although the magnitude of increase in mean panting score was greater in shaded Angus and Brahman steers, the maximum mean panting score was lower than their unshaded counterparts. The greater magnitude increase in mean panting score of shaded cattle may indicate an increased efficiency in utilising energy for homeostatic mechanisms, i.e. panting. Considering this, the shaded cattle may have diverted a greater proportion of energy towards maintaining homeostasis supported by a reduced accumulated heat load status, as opposed to their unshaded counterparts. This is not an illogical assumption, as Gaughan *et al*. (2008*b*) indicated that the heat accumulation threshold increases by 5 units by providing shade between 2.0 and 3.0 m^2/animal, thus the HLI threshold for heat accumulation would be 91 (HLI = 86 + 5). This is supported in part by the findings of Lees *et al*. (2018), highlighting that shade provision was able to reduce the magnitude of increase in rumen temperature in Angus and Charolais steers. The results presented here provide further evidence that shade utilisation is an important thermoregulatory mechanism for feedlot cattle. An increase in mean panting score in conjunction with heat load, irrespective of shade availability and breed, has been reported previously (Gaughan *et al.* 2010*b*).

Traditionally it has been accepted that *Bos indicus* cattle carry genetic adaptations that support thermotolerance and, consequently, are less susceptible to the negative effects of hot climatic events (Hansen 2004). Brahman steers within this study, irrespective of shade availability, exhibited increases in mean panting score, indicating that these cattle were utilising evaporative heat loss via respiration and panting to support thermoregulation (McLean 1963). Although mean panting score for the Brahman steers was predominantly categorised as no stress ($0 \leq 0.40$), the difference between the mean panting score of unshaded (0.26 ± 0.03) and shaded (0.15 ± 0.03) steers in conjunction with shade utilisation ($19.4 \pm 1.5\%$) when heat load was very hot (HLI ≥ 86.1) suggest that these cattle are were responding behaviourally and physiologically to hot climatic conditions. These results suggest that shade is an important management tool for feedlot cattle, irrespective of genotype. *Bos indicus* breeds are well recognised for their thermotolerance; however, the changes in mean panting score and shade utilisation of the Brahman steers within this study challenge the perception that these breeds do not require access to heat load mitigation strategies. Although the heat load category was classified as very hot (HLI = 86), these conditions are reflective of the thermal comfort of the reference animal, an unshaded Angus steer less than 100 days on feed as described by Gaughan *et al*. (2008*b*). Using the threshold adjustments described by Gaughan *et al.* (2008*b*), for a healthy unshaded Brahman steer that are less than 100 days on feed, the HLI threshold for heat accumulation would be 96 (HLI = 86 + 10). However, the authors acknowledged that there were not sufficient data where HLI $\geq$ 96 to provide a definitive HLI threshold for 100% *Bos indicus* cattle (Gaughan *et al.* 2008*b*). Given the increase in shade utilisation and mean panting score of Brahman steers within this study, further studies investigating thermoregulatory responses of 100% *Bos indicus* genotypes and their heat load thresholds are warranted. These results suggest that Brahman cattle are susceptible to hot climatic conditions and may exhibit reduced performance and compromised wellbeing.

Conclusion

The heat load experienced during the study was sufficient to incite purposeful behavioural responses and changes in respiratory dynamics in studied cattle. As the heat load stress category increased from cool (HLI $\leq$ 77) to very hot (HLI $\geq$ 86) there was an increase in shade utilisation and mean panting score, suggesting that heat load category has the potential to be used as a predictor of thermal comfort. Unsurprisingly, Angus steers showed the greatest increase in shade utilisation and mean panting score; however, Brahman steers also exhibited a notable increase in mean panting score and shade utilisation as heat load category increased. These results suggest that *Bos indicus* are adjusting behaviourally and physiologically to heat load conditions, albeit not to the same extent as Angus, and these cattle will use shade to support thermoregulation during hot conditions. Furthermore these results challenge the general perception that *Bos indicus* feedlot cattle do not require access to heat load alleviation strategies. Overall these results emphasise the importance of providing shade to feedlot cattle, irrespective of genotype.

Conflicts of interest

The authors declare no conflicts of interest.

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References

Arias RA, Mader TL (2011) Environmental factors affecting daily water intake on cattle finished in feedlots. *Journal of Animal Science* **89**(1), 245–251. doi:10.2527/jas.2010-3014

Baumgard LH, Rhoads RP (2007) The effects of hyperthermia on nutrient partitioning. In 'Proceedings of the Cornell nutrition conference'. pp. 93–104. (Cornell University: Ithaca, NY)

Beede DK, Collier RJ (1986) Potential nutritional strategies for intensively managed cattle during thermal stress. *Journal of Animal Science* **62**(2), 543–554. doi:10.2527/jas1986.622543x

Blackshaw J, Blackshaw A (1994) Heat stress in cattle and the effect of shade on production and behaviour: a review. *Australian Journal of Experimental Agriculture* **34**(2), 285–295. doi:10.1071/EA9940285

Brosh A, Aharoni Y, Degen AA, Wright D, Young BA (1998) Effects of solar radiation, dietary energy, and time of feeding on thermoregulatory responses and energy balance in cattle in a hot environment. *Journal of Animal Science* **76**(10), 2671–2677. doi:10.2527/1998.76102671x

Brown-Brandl TM, Eigenberg RA, Nienaber JA, Hahn GL (2005) Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 1: Analyses of indicators. *Biosystems Engineering* **90**(4), 451–462. doi:10.1016/j.biosystemseng.2004.12.006

Brown-Brandl TM, Eigenberg RA, Nienaber JA (2006*a*) Heat stress risk factors of feedlot heifers. *Livestock Science* **105**(1–3), 57–68. doi:10.1016/j.livsci.2006.04.025

Brown-Brandl TM, Nienaber JA, Eigenberg RA, Mader TL, Morrow JL, Dailey JW (2006*b*) Comparison of heat tolerance of feedlot heifers of different breeds. *Livestock Science* **105**(1–3), 19–26. doi:10.1016/j.livsci.2006.04.012

Bureau of Meteorology (2019) Climate statistics for Australian locations. Summary statistics for The University of Queensland. Available at http://www.bom.gov.au/climate/averages/tables/cw_040082.shtml [Verified 11 April 2019]

Castaneda CA, Gaughan JB, Sakaguchi Y (2004) Relationships between climatic conditions and the behaviour of feedlot cattle. *Animal Production in Australia* **25**, 33–36.

Clarke M, Kelly A (1996) Some effects of shade on Hereford steers in a feedlot. In 'Proceedings of the Australian Society of Animal Production 21st biennial conference', 8–12 July 1996, The University of Queensland, Qld, Australia. pp.235–238. (Australian Society of Animal Production: Armidale, NSW)

Department of Agriculture and Fisheries (2009) *Animal Care and Protection Act 2001*. Queensland Government, Brisbane, Qld, Australia.

Eigenberg RA, Brown-Brandl TM, Nienaber JA, Hahn GL (2005) Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 2: Predictive relationships. *Biosystems Engineering* **91**(1), 111–118. doi:10.1016/j.biosystemseng.2005.02.001

Entwistle K, Rose M, McKiernan B (2000) 'Mortalities in feedlot cattle at Prime City feedlot, Tabbita, NSW, February 2000.' (NSW Agriculture: Sydney, NSW)

Frazzi E, Calamari L, Calegari F, Stefanini L (2000) Behavior of dairy cows in response to different barn cooling systems. *Transactions of the ASAE. American Society of Agricultural Engineers* **43**(2), 387–394. doi:10.13031/2013.2716

Gaughan JB, Mader TL (2014) Body temperature and respiratory dynamics in un-shaded beef cattle. *International Journal of Biometeorology* **58**, 1443–1450. doi:10.1007/s00484-013-0746-8

Gaughan JB, Tait LA, Eigenberg R, Bryden WL (2004) Effect of shade on respiration rate and rectal temperature of Angus heifers. *Animal Production in Australia* **1**(1), 69–72.

Gaughan JB, Mader TL, Holt SM (2008*a*) Cooling and feeding strategies to reduce heat load of grain-fed beef cattle in intensive housing. *Livestock Science* **113**(2–3), 226–233. doi:10.1016/j.livsci.2007.03.014

Gaughan JB, Mader TL, Holt SM, Lisle A (2008*b*) A new heat load index for feedlot cattle. *Journal of Animal Science* **86**(1), 226–234. doi:10.2527/jas.2007-0305

Gaughan JB, Bonner S, Loxton I, Mader TL, Lisle A, Lawrence R (2010*a*) Effect of shade on body temperature and performance of feedlot steers. *Journal of Animal Science* **88**(12), 4056–4067. doi:10.2527/jas.2010-2987

Gaughan JB, Mader TL, Holt SM, Sullivan ML, Hahn GL (2010*b*) Assessing the heat tolerance of 17 beef cattle genotypes. *International Journal of Biometeorology* **54**(6), 617–627. doi:10.1007/s00484-009-0233-4

Gebremedhin KG (1985) Heat exchange between livestock and the environment In 'Stress physiology in livestock. No. I'. (Ed. MK Yousef) pp. 15–34. (CRC Press Inc.: Boca Raton, FL)

Hahn GL (1985) Management and housing of farm animals in hot environments In 'Stress physiology in livestock. No. II'. (Ed. MK Yousef) pp. 151–174. (CRC Press Inc.: Boca Raton, FL)

Hahn GL (1999) Dynamic responses of cattle to thermal heat loads. *Journal of Animal Science* **77**, 10–20. doi:10.2527/1997.77suppl_210x

Hahn GL, Chen YR, Nienaber JA, Eigenberg RA, Parkhurst AM (1992) Characterizing animal stress through fractal analysis of thermoregulatory responses. *Journal of Thermal Biology* **17**(2), 115–120. doi:10.1016/0306-4565(92)90008-4

Hahn GL, Gaughan JB, Mader TL, Eigenberg RA (2009) Thermal indicies and their applications for livestock environments In 'Livestock energetics and thermal environmental management'. (Ed. JA DeShazer) pp. 113–130. (American Society of Agricultural and Biological Engineers: St. Joseph, MI, USA)

Hansen PJ (2004) Physiological and cellular adaptations of zebu cattle to thermal stress. *Animal Reproduction Science* **82–83**, 349–360. doi:10.1016/j.anireprosci.2004.04.011

Hicks R, Owens F, Gill D (1989) Behavioral patterns of feedlot steers. Oklahoma State University Animal Science Research Report, MP-127, Oklahoma State University, Stillwater, OK, USA.

Igono MO, Johnson HD, Steevens BJ, Krause GF, Shanklin MD (1987) Physiological, productive, and economic benefits of shade, spray, and fan system versus shade for Holstein cows during summer heat. *Journal of Dairy Science* **70**(5), 1069–1079. doi:10.3168/jds.S0022-0302(87)80113-3

Kendall PE, Nielsen PP, Webster JR, Verkerk GA, Littlejohn RP, Matthews LR (2006) The effects of providing shade to lactating dairy cows in a temperate climate. *Livestock Science* **103**(1–2), 148–157. doi:10.1016/j.livsci.2006.02.004

Lawrence RJ (1998) A comparison of feedlot bunk management strategies and their influence on cattle performance and health. *Proceedings of Australian Society of Animal Production* **22**, 177–180.

Lees AM (2016) Biological responses of feedlot cattle to heat load. PhD thesis, School of Agriculture and Food Sciences, The University of Queensland, Gatton, Qld, Australia.

Lees AM, Lees JC, Lisle AT, Sullivan ML, Gaughan JB (2018) Effect of heat stress on rumen temperature of three breeds of cattle. *International Journal of Biometeorology* **62**(2), 207–215. doi:10.1007/s00484-017-1442-x

Mader TL (2003) Environmental stress in confined beef cattle. *Journal of Animal Science* **81**(14), E110–E119. doi:10.2527/2003.8114_suppl_2E110x

Mader TL, Davis MS (2004) Effect of management strategies on reducing heat stress of feedlot cattle: Feed and water intake. *Journal of Animal Science* **82**(10), 3077–3087. doi:10.2527/2004.82103077x

Mader TL, Holt SM, Hahn GL, Davis MS, Spiers DE (2002) Feeding strategies for managing heat load in feedlot cattle. *Journal of Animal Science* **80**(9), 2373–2382. doi:10.1093/ansci/80.9.2373

Mader TL, Davis MS, Brown-Brandl TM (2006) Environmental factors influencing heat stress in feedlot cattle *Journal of Animal Science* **84**, 712–719. doi:10.2527/2006.843712x

Mader TL, Gaughan JB, Johnson LJ, Hahn GL (2010) Tympanic temperature in confined beef cattle exposed to excessive heat load. *International Journal of Biometeorology* **54**(6), 629–635. doi:10.1007/s00484-009-0229-0

McDowell RE, Weldy JR (1967) Water exchange of cattle under heat stress. In 'Proceedings of the 3rd international biometeorological congress', London. pp. 414–424. (Symposium Publications Division, Pergamon Press: Oxford, NY)

McLean JA (1963) The partition of insensible losses of body weight and heat from cattle under various climatic conditions. *Journal of Physiology* **167**(3), 427–447. doi:10.1113/jphysiol.1963.sp007160

Mitlöhner FM, Morrow-Tesch JL, Wilson SC, Dailey JW, McGlone JJ (2001*a*) Behavioral sampling techniques for feedlot cattle. *Journal of Animal Science* **79**(5), 1189–1193. doi:10.2527/2001.7951189x

Mitlöhner FM, Morrow JL, Dailey JW, Wilson SC, Galyean ML, Miller MF, McGlone JJ (2001*b*) Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. *Journal of Animal Science* **79**(9), 2327–2335. doi:10.2527/2001.7992327x

Mitlöhner FM, Galyean ML, McGlone JJ (2002) Shade effects on performance, carcass traits, physiology, and behavior of heat-stressed feedlot heifers. *Journal of Animal Science* **80**(8), 2043–2050. doi:10.1093/ansci/80.8.2043

National Health and Medical Research Council (1997) 'Australian code for the care and use of animals for scientific purposes.' (National Health and Medical Research Council: Canberra, ACT)

Nienaber JA, Hahn GL, Brown-Brandl TM, Eigenberg RA (2003) Heat stress climatic conditions and the physiological responses of cattle. In 'Proceedings of the fifth international dairy housing conference', Fort Worth, TX, USA. pp. 255–262. (American Society of Agricultural Engineers: St Joseph, MI)

Ray DE (1989) Interrelationships among water quality, climate and diet on feedlot performance of steer calves. *Journal of Animal Science* **67**(2), 357–363. doi:10.2527/jas1989.672357x

Ray DE, Roubicek CB (1971) Behavior of feedlot cattle during two seasons. *Journal of Animal Science* **33**(1), 72–76. doi:10.2527/jas1971.33172x

R Core Team (2016) 'R: A language and environment for statistical computing.' (R Foundation for Statistical Computing: Vienna, Austria) Available at http://www.R-project.org/ [Verified 24 June 2019]

Robertshaw D (1985) Heat loss of cattle. In 'Stress physiology in livestock. No. I'. (Ed. MK Yousef) pp. 55–66. (CRC Press Inc.: Boca Raton, FL)

Shultz TA (1984) Weather and shade effects on cow Corral activities. *Journal of Dairy Science* **67**(4), 868–873. doi:10.3168/jds.S0022-0302(84)81379-X

Sullivan ML, Cawdell-Smith AJ, Mader TL, Gaughan JB (2011) Effect of shade area on performance and welfare of short-fed feedlot cattle. *Journal of Animal Science* **89**(9), 2911–2925. doi:10.2527/jas.2010-3152

Young BA, Hall AB (1993) Heat load in cattle in the Australian Environment In 'Australian beef'. (Ed. R Coombes) pp. 143–148. (Morescope Publishing: Melbourne)

Handling Editor: Alan Tilbrook