Final report

Evaluation of shade and shelter solutions in a southern Australian feedlot

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Abstract

The influence of climatic stressors on feedlot cattle production and wellbeing is critical as cattle have a narrow range of climatic conditions where optimal thermal comfort occurs. In Australia extensive research has been conducted on understanding and mitigating the impacts heat stress, however the impact of cool and/or wet conditions has been limited. The aim if this project was to understand the impact of shade and shelter solutions on animal welfare health and performance outcomes for feedlot cattle during a summer and winter production cycle. For the summer study 720 heifers were enrolled and randomly allocated to three treatment groups: 1) unshaded; 2) shade cloth (shaded); and 3) partial pen coverage with a waterproof structure for the summer study. In the winter study, a total of 480 steers were enrolled and were randomly allocated to one of two treatments: 1) unsheltered; and 2) sheltered with partial pen coverage with a waterproof structure.

Key findings of the summer study included:

- Partial pen coverage with a waterproof system provided significant productivity benefits, via an increased carcase adjusted Average Daily Gain (ADG_{adj}; 100 g/hd/d), feed efficiency (4 %) and hot standard carcase weight (HSCW; 7 kg).
- There were no differences in cattle performance between the shaded and unshaded treatments, most likely reflecting the mild and wet summer conditions.
- During very hot conditions (heat load index ≥ 86), waterproof cattle and shaded (shade cloth) treatments had lower mean panting scores when compared to unshaded cattle highlighting improved animal comfort.

Key findings for the winter study included:

- Partial pen coverage with waterproof shelter significantly improved carcase adjusted ADG (100 g/hd/d) and feed efficiency (5.3%); and tended to improve HSCW (5 kg).
- Adrenal gland weight an objective measure of chronic stress was greater in unshaded pens.

Executive summary

Climatic conditions remain a significant challenge to the feedlot industry, despite decades of research. As such there is a constant requirement to evaluate cost-effective management strategies to reduce climate-related production losses and welfare impacts on feedlot cattle. Grandin (2016) described three major animal welfare issues associated with outdoor feedlots: (1) impacts of muddy pens and keeping cattle clean; (2) heat stress, and an associated lack of shade; and (3) managing handling of large numbers of cattle. The influence of climatic stressors on feedlot cattle production and wellbeing is critical as cattle have a narrow range of climatic conditions where optimal thermal comfort occurs. In the Australian context, extensive research has focused on understanding and mitigating the impacts of hot climatic conditions, whereas the impact of cool and/or wet conditions has received limited attention. In addition, heat stress studies have predominantly occurred in the sub-tropical regions of Queensland. Thus, it is unclear whether these benefits of shade are applicable across other climatic zones within Australia, specifically within southern temperate climates. Furthermore, there is limited information available regarding the benefits of providing partial shelter in outdoor environments, particularly within the Australian context. This project aims to providing evidence of the impact of shade and shelter solutions on animal welfare health and performance outcomes for feedlot cattle during a summer and winter production cycle. For this project two studies were conducted: 1) Summer study (December to May); and 2) a Winter study (July to November).

For the summer study, a total of 720 *Bos taurus* heifers were randomly allocated to three treatment groups: 1) unshaded; 2) shade cloth (shaded 2.8 m2/head); and 3) partial pen coverage with waterproof system (4 m2/head). Six pen replicates of 40 head each were fed. Cattle were unbedded for the duration of the research trial.

Key findings of the summer study included:

- Partial pen coverage with a waterproof system provided significant productivity benefits increased carcase adjusted average daily gain (ADG; + 100 g/hd/d), feed efficiency (4%) and hot standard carcase weight (HSCW; 7 kg).
- There was no difference in performance between the shaded and unshaded treatments, most likely reflecting the mild and wet summer conditions.
- During very hot conditions (heat load index ≥ 86), waterproof cattle and shaded (shade cloth) treatments had lower mean panting scores when compared to unshaded cattle indicating improved animal comfort.

In the winter study, a total of 480 *Bos taurus* steers were randomly allocated to either 1) unshaded or 2) partial pen coverage with waterproof system (4 m2/head). Six pen replicates of 40 head each were fed. Cattle remained unbedded for the research trial. Behavioural observations were unable to be conducted due to COVID-19 restrictions, however adrenal gland weights as an indicator of chronic stress were collected from the abattoir.

- Partial pen coverage with waterproof shelter again significantly improved carcase adjusted ADG (100 g/d) and feed efficiency (5.3%); and tended to improve HSCW (5 kg).
- Adrenal gland weight an objective measure of chronic stress were greater in unsheltered pens.

Further research to quantify animal behavioural responses and utilisation of the shelter structure, is required to completely elucidate these responses.

Overall, the results from this project have shown that there are production and welfare benefits of providing shade and shelter to feedlot cattle in temperate regions. However, providing shade solutions for temperate feedlots needs further consideration as the summer conditions within this project were much cooler than anticipated. In addition, due to the COVID-19 restrictions, behavioural responses were not investigated during the winter study and is worthy of further consideration.

Finally, studies need to evaluate the shade/shelter allocation (m^2/hd) to offset the negative impact of adverse climatic conditions for feedlot cattle. Regardless, the studies conducted within this project have provided further evidence that shade and shelter provisions have a positive impact on production and welfare outcomes for feedlot cattle.

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1. Background

Cattle have a narrow range of climatic conditions that are considered to be within their thermoneutral zone. The accumulation and dissipation of heat from the body is constantly adjusting in order to maintain optimum health and productivity. However as ambient conditions increase or decrease beyond given threshold, energy is expended to maintain homeostasis. Once this energy expenditure occurs animal welfare, comfort and productivity can be compromised, regardless of hot (Hahn, 1999; Mader, 2003) or cold (Mader, 2011; Mader and Griffin, 2015) conditions. A welfare concern for feedlot cattle can be issues associated with muddy pens and keeping cattle clean (Grandin, 2016). Cattle housed in muddy pens have a tendency to reduce feeding frequencies, and muddy coats can compromises thermal insulation (Mader, 2011). The negative impacts of muddy pens can be further reduced by utilising bedding materials to absorb excess moisture from pen surfaces (Mader, 2011; Grandin, 2016). However, bedding materials can be expensive and difficult to ensure a consistent supply.

As such there has been an increasing interest in providing cattle with shelter solutions providing protection against both heat wave and cold/wet conditions. This is an important consideration as some temperate regions experience cool wet conditions during the winter months but also expose cattle to heat load conditions during the summer months. Chronic exposure to heat stress is present in many regions worldwide during the summer months and is often a major stressor for healthy feedlot cattle (Gaughan et al., 2013). Providing shade to feedlot cattle alters the microclimate within the pen, potentially providing an area for cooling (Mitlöhner et al., 2002). Although there is, still some conjecture regarding the amount of shade (m^2/animal) required to offset the impact of heat load, providing shade has been associated with improved average daily gain, carcass quality, decreased respiration rate and panting score and improved overall animal wellbeing (Mitlöhner et al., 2002; Gaughan et al., 2010a; Sullivan et al., 2011; Lees et al., 2020).

Studies conducted in Australia have observed an increase in cattle performance (Gaughan et al., 2010a) and cattle welfare regardless of variation in shade allocation (Sullivan et al., 2011) and cattle genotype, i.e. *Bos taurus* versus *Bos indicus* (Lees et al., 2020). However, these studies were conducted in sub-tropical regions of Queensland and as such it is unclear whether these benefits of shade are applicable across other climatic zones within Australia. Adverse weather events have become more prevalent and/or extreme when compared with past events and the recent IPCC (2021) report suggests that this variability will become more extreme in future years. This project aims to providing evidence of the impact of shade and shelter solutions on animal welfare health and performance outcomes for feedlot cattle that will allow for commercial feedlots to investigate the viability of shade and shelter solutions for their businesses.

2. Objectives

The project objectives were:

1. Execute research methodology to evaluate the shade and shelter solutions under large pen research conditions (> 40 head) in an unbiased fashion;
2. Evaluate the effects of shade and shelter on animal welfare, health, cattle performance and carcass characteristics during both summer and winter conditions relative to conventional production practices at that feedlot;
3. Determine the cost-benefit of the shade and shelter solutions; and
4. Make recommendations on the feasibility of the shade and shelter solutions to the Australian feedlot industry.

3. Summer Cattle

3.1 Introduction

Heat stress has been identified as a significant welfare and production issue for the feedlot industry worldwide. Cattle have a relatively narrow range of climatic conditions that are considered to be within their thermoneutral zone. Furthermore, the accumulation and dissipation of heat from the body is constantly adjusting in conjunction with ambient conditions and metabolic heat production. As ambient conditions increase beyond given threshold, which is largely species specific, an increasing proportion of energy is diverted from growth and production traits and utilised to maintain homeostasis (Baumgard and Rhoads, 2012). In conjunction with this redistribution of energy during periods of hot weather, cattle typically exhibit reduced dry matter intake (Beede and Collier, 1986; Brown-Brandl et al., 2005). Thus, during summer feedlot cattle often have decreased growth and feed conversion efficiency (Brown-Brandl et al., 2005; Eigenberg et al., 2005; Brown-Brandl et al., 2006b).

Globally, it has been well established that the provision of shade is advantageous for feedlot cattle, and other species. Providing shade to feedlot cattle alters within pen microclimates, which potentially provide an area for cooling (Mitlöhner et al., 2002). Although there is still some conjecture regarding the amount of shade (m^2/animal) required to offset the impact of heat stress on feedlot cattle, providing shade has been associated with improved average daily gain, carcass quality, decreased respiration rate and panting score and improved overall animal wellbeing (Mitlöhner et al., 2002; Gaughan et al., 2010a; Sullivan et al., 2011; Lees et al., 2020). Previous studies conducted in Australia have observed an increase in cattle performance (Gaughan et al., 2010a), and cattle welfare regardless of variations in shade allocation (Sullivan et al., 2011) and cattle genotype, i.e. *Bos taurus* versus *Bos indicus* (Lees et al., 2020). However, these studies have been conducted in sub-tropical regions of Queensland and as such it is unclear whether these benefits of shade are applicable across other climatic zones within Australia, specifically within southern temperate climates. As such, the objective of this study was to evaluate the impact shade and shelter strategies on the health, animal behaviour and welfare, animal performance and carcass characteristics of feedlot cattle during summer in a southern Australian environment.

3.2 Materials and Methods

3.2.1 General methodology

This project was conducted with the approval of the University of New England's (**UNE**) animal ethics committee (AEC 20-091, see appendix 9.1), in accordance with the guidelines described by the Australian (National Health and Medical Research Council, 2013). The project was undertaken in the New England district of New South Wales at the UNE research feedlot 'Tullimba' (30°28 S, 151°11 E, 950 m above mean sea level), commencing during a southern hemisphere summer (December) and concluding in autumn (May). The climate in the region is classified as temperate climate, as per Köppen climate classification, which typically has a summer dominant rainfall area and an annual average rainfall of 767 mm.

3.2.2 Animal management

A total of 720 *Bos taurus* heifers were used within this study. The UNE SmartFarms sourced the cattle for this experiment via a number of local stock and station agents. Cattle were sourced between February 2020 and December 2020. Upon arrival to Tullimba cattle were vaccinated for clostridial diseases (enterotoxaemia (pulpykidney disease), tetanus, blacks disease, malignant edema, and blackleg; Websters 5-in-1, Virbac Pty Ltd, Australia, Milperra NSW), then backgrounded on pastures[1] until feedlot induction. Two weeks prior to feedlot induction cattle were vaccinated for respiratory pathogens (Bovilis MH + IBR, inactivated *Mannheimia haemolytica* and Bovine Herpes Virus Type 1; Coopers Animal Health Intervet Australia, Macquarie Park, NSW).

Heifers were pregnancy tested by an accredited veterinarian on day -30 and day -15 for Cohort 1 (n = 360 hd) and Cohort 2 (n = 360 hd), respectively. There were 37 heifers from Cohort 1 and 53 heifers from Cohort 2 determined as pregnant (< 4 months in calf). These heifers in this were treated an aborfactant (2mL Estromil, 250 mcg/mL cloprostenol, Troy Animal Health, Australia, Glendenning NSW) on day -28 and day -13, respectively.

Cohort 1 and Cohort 2 were weighed on day -15 and day -17, respectively, and these weights were used to provide preliminary weight data, to be used as a basis for cattle sorting. Cattle within each cohort were randomly allocated to nine pen groups of 40 animals, ensuring that breed types were equally represented across each pen. For each cohort three pen groups were then randomly allocated to three treatments; 1) unshaded; 2) shade cloth (shaded); and 3) waterproof, see section 3.2.7 below.

The cattle were weighed (non-fasted) at induction (described below); day 50, where weighing occurred between 0800 h and 1200 h; and upon exit using a single animal weighing box (Ruddweigh 600mm Weigh Beam 2000kg weighing capacity, Ruddweigh, Guyra, NSW, Australia) with solid sides, and an automated readout system (Gallagher Weigh Scale readout W310 v2 to 2kg increments, Gallagher Australia, Epping, Vic, Australia). The scales were calibrated by placing 30 × 20 kg (total weight = 600 kg) certified test weight, prior to weighing. On day 50 cattle were weighed in consecutive pen order, commencing at the unshaded, then the shade cloth, and concluding at the waterproof pens.

3.2.3 Health management

Pens were walked daily after the 0800 h behavioural observations, described below in section 3.2.8. Cattle that were treated for acute health concerns, e.g. footrot, were walked to the hospital pen, treated and returned to their home pen for monitoring. For more chronic health aliments, cattle were pulled from their home pens and relocated to hospital pens for treatment and recovery, cattle that recovered within 4 days were returned to their home pens. Cattle that had not recovered after 4 days were removed from the study. All treatments were noted with their diagnosis and treatment. For mortality events, necropsies were conducted by veterinarian or UNE SmartFarm staff, as per the UNE SmartFarm autopsy protocol.

3.2.4 Feedlot induction

The heifers, were inducted into the feedlot as two cohorts (n = 360 hd) 28 days apart (Cohort 1, 23rd December 2020; Cohort 2, 20th January 2021). On day 0 cattle were inducted into the feedlot, for each respective cohort. At induction cattle were vaccinated for clostridial diseases (enterotoxaemia (pulpykidney disease), tetanus, blacks disease, malignant edema, and blackleg; Websters 5in1, Virbac Pty Ltd, Australia, Milperra NSW) and respiratory pathogens (Bovilis MH + IBR, inactivated *Mannheimia haemolytica* and Bovine Herpes Virus Type 1; Coopers Animal Health Intervet Australia,

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[1] Rye grass (*Lolium perenne*); spear grass (*Heteropogon contortus*); corkscrew grass (*Austrostipa scabra*); Phalaris (Phalaris aquatica); prairie grass (*Bromus stamineus*); cocksfoot (*Dactylis glomerate*); Barley grass (*Hordeum glaucum, Hordeum leporinum*); tussock (*Poa labillardierei*); Clover (*Trifolium spp.*); Medics and (*Medicago spp.*)

Macquarie Park, NSW). Cattle were also treated for internal (Exifluke ® 240, 240g/L triclabendazole, Bayer Animal Health, Australia, Pymble NSW) and external parasites (Dectomax, doramectin 0.5% w/v, Zoetis Australia, Silverwater, NSW); and received a hormonal growth promotant (Component TE-200, 20 mg oestradiol 17β + 200 mg trenbolone acetate, Elanco, West Ryde, NSW).

3.2.5 Nutritional management

The cattle were gradually adapted (Table 1) to a total mixed ration finisher diet (Table 2), with a targeted DM % between 73 % and 79 % depending on the ration type. All rations were based on tempered barley, commencing at 38.5 % (as-fed basis) for the prestart ration and gradually increasing to 83 % for the finisher ration (Table 1; Table 2). Due to persisting wet conditions zinc (ZinMet®, Austasia Animal Products Pty Ltd, Forbes New South Wales, 2871) was added to the ration for Cohort 1 at a rate of 1.2 kg/tonne (as-fed basis) from day 17 to day 21, then at 0.6 kg/tonne from day 22, and remained in the ration for the duration of the study. Zinc was added to the ration for Cohort 2 for the whole duration of the study.

Cattle were fed as a pen, once per day, at 0900 h and 0800 h respectively for Cohort 1 and Cohort 2. Pens were fed in a consecutive pen order relative to cohort. In addition, feed was offered to the unshaded, shade cloth, then the waterproof pens, in consecutive pen order at each feeding. Feed was mixed and delivered in a Rotomix TMR 4610 mixer (1 kg scale resolution) over two or three batches per cohort per day, depending on ration and pen consumption. Cattle were fed using a clean bunk management protocol modified from Lawrence (1998), ensuring cattle had feed available at all times. A daily grab sample was collected from each pen and batched into a daily per cohort sample. A 200 g sample of the daily feed was collected and analysed, in duplicate, for dry matter content by oven-drying at 80 °C for 36 h.

Table 1. Feeding protocol for adapting cattle to grain-based finisher ration

Ration Type	Grain Content, % as-fed basis	Days fed	
		Cohort 1	Cohort 2
Prestart	38.5	0 to 7	0 to 6
Start 1	45.5	8 to 12	7 to 14
Transition 1	60.0	13 to 18	15 to 17
Transition 2	68.0	19 to 22	18 to 22
Finisher	83.0	23 to exit	23 to exit

Table 2. Formulated ingredient and nutrient composition of the diets

Item	Prestart	Start 1	Transition 1	Transition 2	Finisher
Ingredient[1]					
Barley, tempered	385	455	600	680	830
Oat hay	200	130	80	50	**0**
Millrun	120	120	80	40	**0**
Water	120	120	90	60	**0**
Cottonseed, high lint	80	80	80	80	80
Wheat straw	60	60	60	45	35
Supplement	35	35	40	45	55
Formulated Nutrient Analysis[2]					
DM, %	73.82	72.98	74.49	75.87	79.48
Protein, %	13.84	14.23	14.4	14.65	14.94
Eq Prot, %	0.62	0.62	0.68	0.77	0.9
ME, MJ/kg	11.1	11.38	11.68	11.95	12.26
NEm, Mcal/kg	1.74	1.8	1.88	1.94	2.01
Neg, Mcal/kg	1.12	1.18	1.24	1.3	1.37
NDF, %	38.72	35.03	30.65	27.24	22.66
eNDF, %DM	26.65	22.44	18.28	15.09	10.64
Fat, %	4.49	4.49	4.26	4.17	3.95
Vit A, KIU/kg	1.66	1.68	1.82	2.08	2.42
Vit E, IU/kg	10.67	10.79	11.73	13.34	15.57
Calcium, %	0.61	0.59	0.61	0.66	0.74
Phosphorus, %	0.43	0.45	0.43	0.42	0.41
Monensin, ppm	15.65	15.83	17.2	19.57	22.83

[1] per 1000 kg, as-fed basis

[2] formulated nutrient composition 100 % DM basis

3.2.6 Feedlot description

A total of 18 pens (500 m^2; 40 m long × 12.5 m wide) within UNE research feedlot “Tullimba” were used. Six unshaded, six shade cloth and six waterproof shelter pens were used (described in section 3.2.7 below). There was no separation between the different treatments, i.e. the last unshaded pen was directly beside the first shade cloth pen and the last shade cloth pen was situated adjacent to the first waterproof shelter pen. Due to the alignment of the pens the different shade type did not encroach into other treatment pens. The pens were situated in a north-south alignment. Pen surface was soil over gravel and pens had a 5 % slope from the feed bunks towards the rear of the pens (east). Feed bunks were concrete and had a 3 m concrete apron located at the front of each pen (west). Stocking density was 12.5 m^2/animal. Each feed bunk provided a bunk space allocation of 31.25 cm/hd and the water trough (3 m long × 0.5 m wide) was shared between two pens.

3.2.7 Shade structures

For the shade cloth treatment shade was provided by shade cloth (black, 290/300 GSM knitted Monofilament polyethylene, 80% solar block, Architex Fabric Structures, North Richmond NSW, Australia). The waterproof treatment shade was provided by a waterproof polyethylene material (white, 340 GSM, high UV, Architex Fabric Structures, North Richmond NSW, Australia) respectively (Figure 1). The shade materials were suspended by a cabling system that was attached to an angled structure which was 4.5 m at the lowest point and 5.8 m at the highest point. For the waterproof treatment, the waterproof material was fixed to both the front and back sections of the truss structure which also extended over the feed bunk. In addition, there was a 500 mm gap in the peak between front and back sections of the truss structure to encourage air flow. The waterproof shade structure provided a shade footprint of 3.97 m^2/hd (12.7 m× 12.5 m) at midday. Initially, the shade cloth was installed on the front and back portions of the truss structure providing a shade footprint of 3.89 m^2/hd (12.45 m× 12.5 m). On January 12th and 13th 2021, repairs and maintenance were conducted on the shade cloth and waterproof shade structures. During this time, the shade cloth was retracted on the front portion of the truss to provide a shade footprint of 2.78 m^2/hd (8.9 m × 12.5 m) at midday.

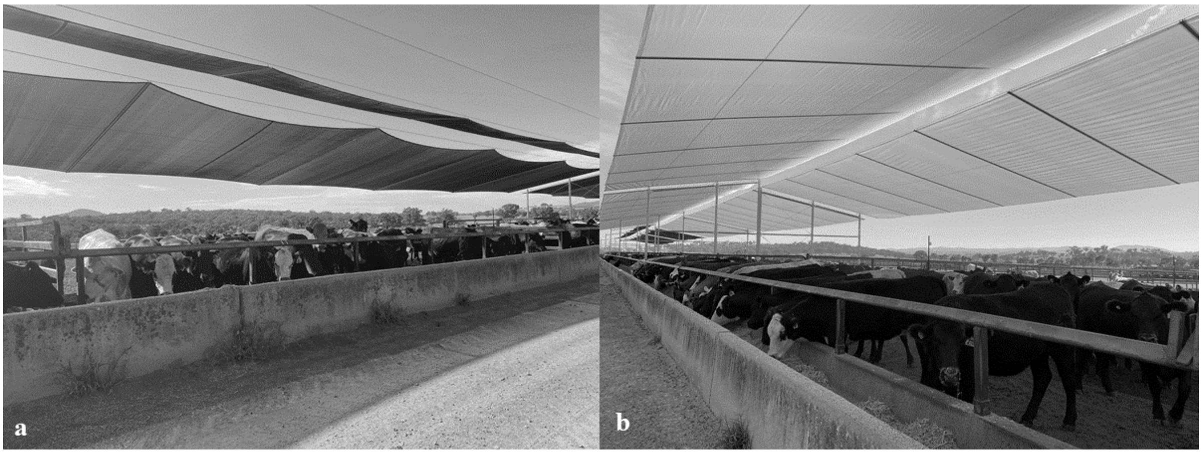

Figure 1. A representation of the a) shade cloth and b) waterproof shade structures over the Tullimba research feedlot pens

3.2.8 Behavioural observations

Behavioural observations (posture, activity, shade utilisation, panting score) were conducted four times daily (0800 h; 1100 h; 1300 h; and 1500 h AEDT). Posture was defined as either i) standing, the cows standing in an inactive upright position, or ii) laying where a cow was in a state of sternal recumbency as described by Mitlöhner et al. (2001a). Shade utilization was described *in situ* as under shade or in sun. Utilization of shade was defined as ≥ 50 % of the body covered by shade, as described by Kendall et al. (2006). Animal activity, i.e. feeding, drinking and ruminating, was determined by recording the activity that individual animals were undertaking at the time of observation (Lees et al., 2020). Feeding was defined as the animal standing at the feed pad with their head in the feed bunk actively eating (Mitlöhner et al., 2001a). Similarly, drinking was defined as the animal standing with their head in the water trough actively drinking, and rumination was classified where the cow was actively ruminating (Lees et al., 2020). Panting scores were evaluated based on the on the open and closed mouth panting of cattle using a 0 to 4.5 scale as per Table 3 below (Brown-Brandl et al., 2006a; Gaughan et al., 2008; Lees, 2016; Lees et al., 2022). 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. (2008);

$$Mean\ Panting\ Score = \frac{\sum_{i=0}^{4.5} N_i \times i}{\sum N_i}$$

Where N_i = 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 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).

Table 3. Assessment of panting score and description of breathing/panting condition[1]

Panting Score	Breathing Condition
0	No panting, normal respiratory motions
1	Slight panting with slight movement of the chest cavity. The mouth is closed and no drool is present.
1.5	Fast panting with rapid easily observed chest movements. The mouth closed remains closed with no drool.
2	Fast panting with rapid easily observed chest movements. The mouth closed remains closed with drool present.
2.5	As for 2, but occasional open mouth panting, with the tongue not extended
3	Open mouth and excessive drooling, neck extended, the tongue may (typically for short durations) or may not extend from the mouth.
3.5	As for 3, but with tongue out slightly and occasionally fully extended for short periods
4	Panting with open mouth, with the tongue fully extended from the mouth for prolonged periods often with excessive drooling. The neck is generally extended and the head held in an upright position
4.5	As for 4, but head held down. Cattle “breath” from flank and drooling may cease.

[1] Modified from Brown-Brandl et al. (2006a); Gaughan et al. (2008); Lees (2016); and Lees et al. (2022)

3.2.9 Rumen temperature

Rumen temperatures (**T_{RUM}**, °C) were obtained from 90 Angus heifers from each cohort (30 heifers from each respective treatment), for the duration of the feeding term. Rumen boluses (smaXtec, Bolus TX-1442A, smaXtec animal care GmbH, Austria) were orally administered to 10 heifers from each pen (n = 18) on day 0, during induction for each respective cohort. Rumen temperature boluses were cylindrical (3.4 cm diameter × 10.5 cm in length) and weighed approximately 205 g. Rumen temperatures were recorded at 10 min intervals for the duration of the study (Cohort 1 = 104 days; Cohort 2 = 109 days). Rumen temperature data were communicated to a base station (smaXtec Base Station, smaXtec animal care GmbH, Austria), these data were then transmitted to a data server and stored in an online database (messenger.smaxtec.com) until downloaded for analysis.

3.2.10 Climatic conditions

Weather data were collected at 10 min intervals using an automated onsite weather station (atmos41 weather station, METER Group Inc., Pullman, WA, United States). Weather data included ambient temperature (**T_A**; °C), relative humidity (**RH**; %), wind speed (**WS**; m/s) and direction, solar radiation (**SR**; W/m^2), and 24 h daily rainfall (measured at 0900 h). Black globe temperature (BGT; °C), was calculated by using the following equation adapted from (Hahn et al., 2009):

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

Where T_{db} = air temperature (°C) and SR = solar radiation (W/m^2)

From these data temperature humidity index (**THI**), heat load index (**HLI**) and accumulated heat load (**AHL**) were calculated. The THI was calculated using the following equation adapted from Thom (1959):

$$THI = 0.8 \times T_A \left\lfloor (\frac{RH}{100} \times (T_A - 14.4) \right\rfloor + 46.4$$

Where RH = Relative Humidity (%) and T_A = wet bulb or dew point temperature

Heat load index and AHL were calculated based on equations described by Gaughan et al. (2008). The HLI is calculated based on two BGT thresholds where BGT < or ≥ 25 °C, by using the following equations:

i) A nonlinear regression which applies when BGT is equal to or greater than 25 °C

$$HLI_{BGT\geq25} = 8.62 + (0.38 \times RH) + (1.55 \times BGT) - (0.5 \times WS) + [e^{2.4-WS}]$$

ii) 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 = Relative Humidity (%); BGT = Black Globe Temperature (°C); WS = wind speed (m/s); and e = the base of the natural logarithm (approximate value of e = 2.71828)

The AHL was calculated based on conditions being below or above the upper HLI thresholds, by using the following equations:

i) If $[HLI_{ACC} < HLI_{Lower\ Threshold}, (HLI_{ACC} - HLI_{Lower\ Threshold})/M]$; and

ii) If $[HLI_{ACC} > HLI_{Upper\ Threshold}, (HLI_{ACC} - HLI_{Upper\ Threshold})/M, 0]$

Where HLI_{ACC} = the actual HLI value at a point in time; $HLI_{Lower\ Threshold}$ = the HLI lower threshold where cattle will dissipate heat (e.g. 77); $HLI_{Upper\ Threshold}$ = the HLI upper threshold where cattle will gain heat (e.g. 86); and M = number of measures per hour, i.e. number of times HLI data are collected per hour; If every 10 minutes, then M = 6 (Gaughan et al., 2008).

For this project the upper threshold was defined as 86 as per the reference animal, a healthy un-shaded Angus < 100 days on feed, as described by Gaughan et al. (2008). The lower HLI threshold for the for the reference animal, was defined as HLI = 77 as determined by Gaughan et al. (2008). Additionally, for this study, HLI was divided into four stress categories: (1) cool (thermoneutral), HLI ≤ 70; (2) moderate, HLI 70.1 ≤ 77; (3) hot, HLI 77.1 ≤ 86; and (4) very hot, HLI > 86 (Gaughan et al., 2008). Further to this, AHL were divided into five stress categories: (1) low, AHL ≤ 1; (2) mild, AHL 1.1 ≤ 10; (3) moderate, AHL 10.1 ≤ 20; (4) hot, AHL 20.1 ≤ 50; and (5) extreme, AHL ≥ 50.1 (Gaughan et al., 2008).

3.2.11 Pen microclimate

Pen microclimates, specifically ambient temperature (**T_A**; °C), relative humidity (**RH**; %), were recorded at 10 min intervals (HOBO ProV2, U23-001, Onset Computer Corporation, USA). Two T_A and RH data loggers were position 2 m above the pen surface in every second pen, thus there were six T_A and RH data loggers per treatment. Data loggers were positioned 5 m from the feed bunk and 5 m from the back of the pens, this meant that data loggers placed at the front of the pens so the microclimate benefits from the shade and waterproof treatments could be evaluated. From these data within pen THI was calculated using the equation adapted from Thom (1959) described above.

3.2.12 Pad conditions

Pad samples and moisture

A total of three pad samples were collected throughout the study. An initial pad sample was obtained on day 8 for Cohort 1 and for Cohort 2. A second pad sample was collected on day 69 and day 41 for Cohort 1 and Cohort 2, respectively. This sample was collected after a rain event. A final pad sample was collected on cattle exit, which occurred on day 104 and day 109, for Cohort 1 and Cohort 2, respectively.

Pad samples were collected from three positions within the pen: 1) front, 5 m from the feed bunk; 2) middle, 2 m above of the water troughs; and 3) back, 5 m from the back of the pens. On exit an additional sample was collected from a 4th position, located at the very back of the pens adjacent to the laneway. Pad sample positions 1 and 3 were in alignment with the pen microclimate T_A and RH data loggers. Three pen surface samples were collected from each the three aforementioned positions. Core samples were collected to the pen interface, as such depth of sample was determined by pen surface conditions and position within pen. Samples were then homogenised with a hand trowel, and a subsample was obtained for each of the three positions across the individual pens. The subsamples were immediately frozen (-4 °C) until sample moisture could be determined. For pad moisture, samples were thawed to room temperature (≈ 24 °C) and then dried at 105 °C, until there was no change in the sample weight. From these data moisture content was calculated using the following formula: change in weight (wet-dried) divided by initial sample weight × 100.

On cattle exit, a final pad sample was collected and the depth from the surface to interface layer was measured (cm). Samples were ground until a homogenous sample was obtained, these samples were then analysed, in duplicate, for moisture, volatile solids (VS), carbon (C) and nitrogen (N) content. For VS, C and N, a 30 g subsample sample was obtained and immediately placed on ice, and frozen at -4 °C. These samples were freeze dried at -50 °C for a 7 day period (Alpha1-4 LDplus, Martin Christ Freeze Dryers, Osterode, Germany). Samples were then split to obtain homogenous material for VS, C and N analysis.

Volatile solids

Volatile solids were determined following standard methods (APHA 2540E, 2000), the clean crucible was placed in a 550 °C muffle furnace for 10 minutes, cooled in a desiccator, then 2 g of sample was loaded in crucible and placed in 550 °C muffle furnace. The furnace gradually came to temperature allowing the sample to 'burn off', allowing complete combustion of the sample. The sample was removed and cooled in desiccator and weighed, and the process was repeated until the change was less than 5% difference in weight.

Carbon and nitrogen

For C and N, a 0.15 to 0.20 g of ground sample was weighed to four decimal places and analysed for C and N content via combustion (TruMac determinator; LECO Corporation, St Joseph, MI, USA).

3.2.13 Exit, lairage and slaughter

On exit from the feedlot cattle were evaluated for coat cleanliness (Table 4), during weighing on d104 and d109 for Cohort 1 and Cohort 2, respectively. However, cattle were predominantly classified as a coat condition score 0, thus data not reported here.

Table 4. Coat cleanliness assessment and descriptors[1]

Score	Coat Condition
0	Cattle are clean with no visible signs of dags or muddied areas on the body
1	Cattle have dags/mud on legs, otherwise there are very limited dags or muddied areas on the body
2	Cattle have dags/mud on legs and belly areas, otherwise there are limited dags or muddied areas on the body
3	Cattle have dags/mud on legs, belly areas and the sides of the animal
4	Cattle are completely covered with dags or muddied areas over the entire body

[1]Adapted from (Grandin, 2016)

For each respective cohort, cattle were transported to a commercial abattoir in South-East Queensland (Oakey Beef Exports Pty Ltd, NH Foods, Oakey, QLD, Australia) the day prior to slaughter. Each cohort were transported to the commercial abattoir via 6 × B double trucks. This meant that some pens were split across trucks (Table 5). As such the cattle were consigned across nine National Vendor Declarations (**NVD**) to ensure they were slaughtered within their pen groups. Treatments were allocated to their trucking order in a 3 × 3 latin square design and pens were randomly allocated to trucks (Table 5). This was done to ensure that all there were no transport duration effects on carcass traits. Cattle were then slaughtered across the nine slaughter groups in a 3 × 3 latin square design (Table 5). Upon arrival at the abattoir cattle were unloaded into receival yards. During lairage all cattle were washed four times for 2 min, as per abattoir protocol. After washing cattle were housed in lairage pens with concrete flooring under a solid roof structure until slaughter on the following day.

Table 5. Transportation configuration and slaughter group allocations for Cohort 1 and Cohort 2

Truck	Trailer	Cohort 1	Slaughter Group	Cohort 2	Slaughter Group
1	A	20 hd × Waterproof (Pen 30)	5	20 hd × Unshaded (Pen 17)	5
	B	40 hd × Waterproof (Pen 28)	1	40 hd × Unshaded (Pen 19)	1
2	A	20 hd × Shade cloth (Pen 25)	6	20 hd × Waterproof (Pen 32)	6
	B	40 hd × Shade cloth (Pen 21)	2	40 hd × Waterproof (Pen 31)	2
3	A	20 hd × Unshaded (Pen 20)	4	20 hd × Shade cloth (Pen 26)	4
	B	40 hd × Unshaded (Pen 15)	3	40 hd × Shade cloth (Pen 22)	3
4	A	20 hd × Shade cloth (Pen 25)	6	20 hd × Waterproof (Pen 32)	6
	B	40 hd × Shade cloth (Pen 24)	7	40 hd × Waterproof (Pen 27)	7
5	A	20 hd × Unshaded (Pen 20)	4	20 hd × Shade cloth (Pen 25)	4
	B	40 hd × Unshaded (Pen 16)	8	40 hd × Shade cloth (Pen 23)	8
6	A	20 hd × Waterproof (Pen 30)	5	20 hd × Unshaded (Pen 17)	5
	B	40 hd × Waterproof (Pen 29)	9	40 hd × Unshaded (Pen 18)	9

3.2.14 Adrenal gland collection and carcase evaluation

Hot standard carcass weight (**HSCW**, kg) was determined once the carcasses were dressed and prior to chilling as per AUS-MEAT carcass standards (AUS-MEAT Limited, 2005). Adrenal glands were also obtained from all carcasses prior to chilling at the abattoir. Adrenal glands were chilled and returned to UNE the day after slaughter and were dissected and denuded of all external fat and weighted individually to the nearest 0.001 g.

Post-chilling, carcasses were evaluated by two independent accredited Meat Standards Australia (**MSA**) graders (Meat Standards Australia, 2007). All carcases were evaluated for hump height (mm); fat colour; meat colour; MSA marbling score; rib fat depth (mm); ossification score; ultimate pH (**pH$_u$**);

eye muscle area (**EMA**, cm^2). Hump heights were measured using a 5 mm graduated metal ruler, and is used within the MSA program as an estimation of Bos *indicus* content (Meat Standards Australia, 2007; Watson et al., 2008). Fat colours were determined against the AUS-MEAT fat colour reference standards against the intermuscular fat positioned laterally to the rib eye muscle using a 0 (white) to 9 (deep yellow) scale (AUS-MEAT Limited, 2005). Similarly, meat colour was evaluated using the AUS-MEAT colour reference standards on the bloomed rib eye muscle (*longissimus thoracis et lumborum*) using a 1 (light pink) to 7 (deep purple) scale (AUS-MEAT Limited, 2005). MSA marbling score was evaluated as described by the MSA reference standards at the quartering site of chilled carcasses and was estimated by evaluating the amount and distribution of marbling fat deposited between individual fibres, on a scale ranging from 100 to 1100 (Romans et al., 1985; AUS-MEAT Limited, 2005; Meat Standards Australia, 2007). Rib fat depth, was measured using a graduated metal ruler, at the quartering site positioned between the 12th and 13th rib (AUS-MEAT Limited, 2005). Ossification score was determined a scale between 100 and 590 in accordance with the guidelines described by the United States Department of Agriculture (Romans et al., 1985). Ossification score is an assessment of physiological age of a bovine carcass, based on the calcification of the spinous processes in the sacral, lumbar and thoracic vertebrae (AUS-MEAT Limited, 2005). Ultimate pH and loin temperature were measured in the rib eye muscle (*longissimus thoracis et lumborum)* at the time of carcase grading. Carcass temperature and pH were measured using an MSA approved temperature and pH probes (TPS MC-80 or TPS WP-80M pH Meter, TPS Pty Ltd., Springwood, Brisbane, Qld, 4127, Australia). Eye muscle area was determined for each carcase by measuring the *longissimus thoracis et lumborum* at the quartering site using a standardised grid (AUS-MEAT Limited, 2005). Carcase grading data was then used to calculate an MSA index value as described by McGilchrist et al. (2019) to estimate the predicted eating quality of each carcase.

3.2.15 Statistical analysis

All data exploration and statistical analyses were conducted in R (R Core Team, 2019). Data merging and manipulation, data visualizations and summary data were conducted using the 'dplyr' (Wickham et al., 2019b), 'ggplot2' (Wickham et al., 2019a) and 'table1' (Rich, 2018) packages respectively.

Data exclusions

Two heifers from Cohort 1 died during the study. One heifer from the unshaded treatment died on day 66, of suspected clostridial disease. In addition, one heifer from the waterproof treatment died on day 77. This death was complex, whilst histological samples were collected and evaluated the results did not provide conclusive evidence for cause of death. However, gross evidence during the necropsy highlighted that the death was a result of a multisystem immunochallenge associated with a significant heat wave event in the days prior, where the gross pathology were indicative of lethal heat stress (Burhans et al., 2022). Thus, data from these two heifers were adjusted and removed accordingly from the statistical analysis.

Within Cohort 2, two heifers were removed from the study, two heifers were euthanised due to broken legs and two heifers died throughout the study. One heifer from the waterproof treatment was removed from the study on day 75, due to lameness in the shoulder that failed to respond to treatment. One heifer from the waterproof treatment was removed from the study on day 86 due to a neck abscess that failed to effectively drain and recover. Two heifers, one from the unshaded (day 68) treatment and one from the shade cloth (day 86) treatment, sustained broken legs and were humanely euthanised. One heifer died due to suspected, although not confirmed by pathology, salmonella on day 103. In addition, one heifer from the shade cloth treatment collapsed, became non-ambulatory and was euthanised at the abattoir. Data from and additional four heifers was also excluded, one heifer calved (stillborn) on day 86 and an additional three heifers were determined as pregnant post-slaughter. One carcass was incorrectly corralled at the abattoir and as such failed to get MSA graded. Therefore, from Cohort 2 data from 11 heifers has been excluded from statistical analysis. Thus, data pertaining to these animals were adjusted and removed accordingly from the statistical analysis.

Animal performance and carcase traits

Data collected throughout the project was used to determine dry matter intake (**DMI**), average daily gain (**ADG**, kg/d), gain to feed ratio (**G:F**) and adjusted final liveweight (**Final LW$_{adj}$**, kg). Dry matter intake was measured on a per pen basis and reported as kg DMI/head.day. Average daily gains were determined for each individual from the day 0 weight to subsequent weighing days, i.e. day 0 to day 50, day 50 to exit and day 0 to exit (Cohort 1 = 104 days; Cohort 2 = 109 days) for each cohort. Gain to feed (G:F) was determined as cumulative liveweight gain per pen (kg/head.day) divided by the cumulative feed intake per pen (kg DM/head.day) the for two periods throughout the study, day 0 to day 50 and day 0 to exit (Cohort 1 = 104 days; Cohort 2 = 109 days) for each cohort. Adjusted liveweight was calculated by dividing individual HSCW by the mean dressing percentage for cattle within each respective cohort. Relative adrenal weight (g per 100 kg HSCW) was calculated from the heaviest adrenal gland weight (g) x 100 divided by HSCW (kg) as described by Wilson et al. (2002). The aforementioned data were then modelled using a linear mixed effects model from the 'lme4' package (Bates et al., 2019) and estimated marginal means were generated using the 'emmeans' package (Length, 2019). The final model for all productivity and carcase traits incorporated treatment as a fixed effect and cohort as a random effect.

Behavioural responses

Initially, pen observational count data were converted to a proportion of heifers utilising shade; standing; lying; ruminating; drinking or feeding within each pen for each observation, i.e. proportion of heifers standing at 0800 h for each pen. Panting score data were used to calculate mean panting score for each pen by observation time point, using the equation described by Gaughan et al. (2008). All behavioural data were then modelled using a repeated measures linear mixed effects model using REML within the 'nlme' package (Pinheiro et al., 2019). Estimated marginal means were then determined within the 'emmeans' package (Length, 2019). Behaviour models were run twice, the first model incorporated observation, cohort, day and treatment × observation as fixed effects and pen nested within treatment was incorporated as a random effect. The second model incorporated observation, cohort, HLI category and treatment × observation as the fixed effects and pen nested within treatment was incorporated as a random effect. Shade utilisation could only be determined in the shade cloth and waterproof pens.

Rumen temperature

Ten minute T_{RUM} were aggregated to hourly temperature by averaging over the 10 minute observations. Linear mixed effects models were estimated with T_{RUM} as the dependent variable and treatment, date, hour of day and treatment × hour interactions as fixed effects and animal ID as random effect. The dependence structure in the time series was accounted for with a first order autocorrelation.

Pen microclimate

One logger from the unshaded treatment failed to download, thus was excluded from analysis. Initially 10 min data logger data were converted to an hourly mean for T_A, RH and THI. Hourly pen microclimate data were then analysed using a first-order autoregressive repeated measures model.

The model incorporated treatment, logger position within pen, day, hour and treatment × position as fixed effects and pen was included as the random effect.

Pad conditions

Pad measures were analysed using a linear mixed effects model incorporating treatment, position within pen and treatment × position as fixed effects and pen was included as the random effect.

3.3 Results

3.3.1 Transport

Transport duration was varied between individual trucks and between the cohorts (Table 6). Mean transport duration was 7:46 ± 0:04 h and 6:32 ± 0:19 h for Cohort 1 and Cohort 2, respectively.

Table 6. Transport duration time for Cohort 1 and Cohort 2

Truck	Transport Duration, h	
	Cohort 1	Cohort 2
1	7:54	6:22
2	7:43	6:08
3	8:00	7:25
4	7:45	7:45
5	7:28	5:39
6	7:48	5:55

3.3.2 Climatic conditions

The weather conditions throughout the study were mild, with some intermittent days above 30 °C (n = 11). Mean hourly weather conditions are presented below in Table 7. During the study, there were 63 days where maximum HLI was classified as hot (HLI 77.1 to 86) and there were 30 days where HLI was classified as very hot (HLI ≥ 86.1; Figure 2). There were 3 days where maximum AHL was ≥ 10.1, these corresponded with day 15 for Cohort 1 (AHL = 10.8), day 68 to day 69 for Cohort 1 and day 45 to 46 for Cohort 2, where the maximum AHL was 14.7 and 12.3 respectively (Figure 2). Night time conditions were mild throughout the study, where the minimum HLI was ≤ 60 on all nights of the study. These data indicate that these cattle were able to dissipate any AHL throughout night time hours, thus returning to a thermal equilibrium based on the threshold for unshaded Angus (AHL_{86} = 0).

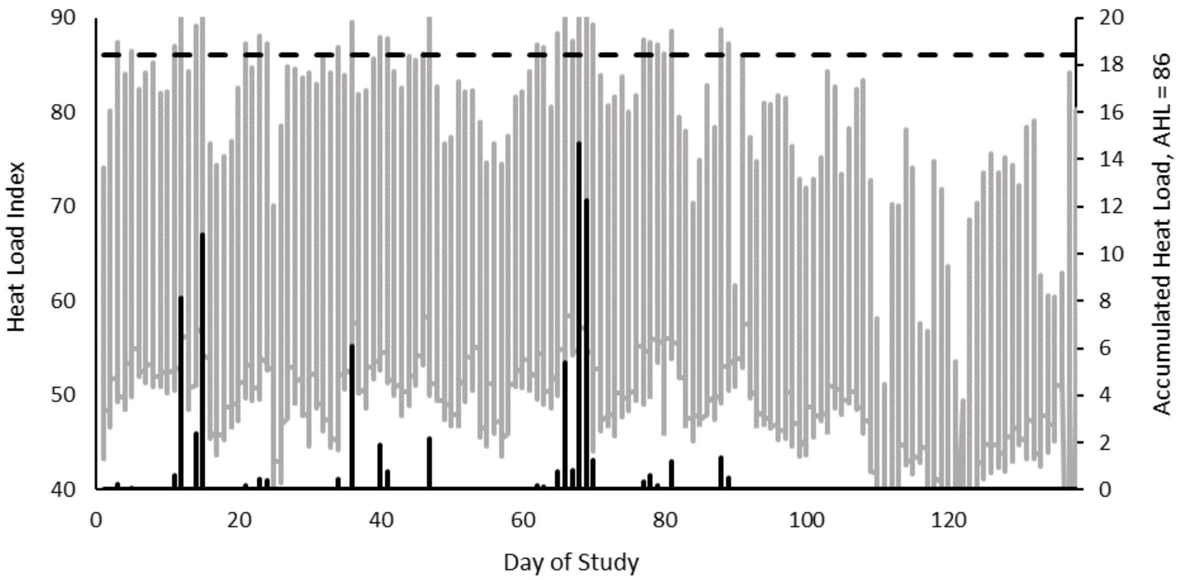

Figure 2. Heat load index (grey line) and accumulated heat load (black line) calculated based on an upper threshold of 86. The dashed line represents the heat load index threshold of 86

Table 7. Mean (± SD) hourly ambient temperature (T_A,°C), relative humidity (RH, %), wind speed (WS, m/s), solar radiation (SR, W/m2), black globe temperature (BGT, °C), heat load index (HLI), accumulated heat load index (AHL_{86}) and temperature humidity index (THI) over the study period

Hour	T_A	RH	WS	SR	BGT	HLI	AHL_{86}	THI
0000	14.6 ± 3.9	83.8 ± 8.6	1.5 ± 1.0	0.0 ± 0.0	12.9 ± 3.6	49.4 ± 5.2	0.0 ± 0.0	58.2 ± 6.3
0100	14.2 ± 3.9	85.3 ± 6.5	1.4 ± 1.0	0.0 ± 0.0	12.5 ±3.6	49.4 ± 4.7	0.0 ± 0.0	57.5 ± 6.5
0200	13.8 ± 4.0	86.3 ± 6.4	1.3 ± 0.8	0.0 ± 0.0	12.2 ± 3.7	49.3 ± 4.7	0.0 ± 0.0	56.9 ± 6.7
0300	13.4 ± 4.1	87.2 ± 6.3	1.2 ± 0.8	0.0 ± 0.0	11.8 ± 3.7	49.2 ± 4.7	0.0 ± 0.0	56.2 ± 6.9
0400	13.1 ± 4.2	87.9 ± 6.0	1.2 ± 0.8	0.0 ± 0.0	11.5 ± 3.7	49.1 ± 4.7	0.0 ± 0.0	55.7 ± 7.1
0500	12.9 ± 1.2	88.6 ± 6.1	1.1 ± 0.8	1.9 ± 7.0	11.8 ± 4.1	49.7 ± 5.0	0.0 ± 0.0	55.2 ± 7.2
0600	13.1 ± 4.5	88.9 ± 6.4	1.2 ± 0.8	45.7 ± 58.5	15.3 ± 5.6	54.3 ± 6.7	0.0 ± 0.0	55.7 ± 7.7
0700	14.5 ± 4.6	88.5 ± 7.9	1.6 ± 1.1	172.5 ± 112.9	19.7 ± 4.8	60.8 ± 7.9	0.0 ± 0.0	58.0 ± 7.9
0800	16.6 ± 4.1	84.8 ± 10.2	2.2 ± 1.4	317.2 ± 157.1	22.7 ± 4.3	67.1 ± 10.3	0.0 ± 0.3	61.4 ± 6.8
0900	18.6 ± 3.6	78.4 ± 11.3	2.6 ± 1.5	454.0 ± 193.4	25.2 ± 4.0	70.3 ± 10.2	0.1 ± 0.6	64.3 ± 5.6
1000	20.2 ± 3.5	72.1 ± 12.0	2.8 ± 1.4	557.8 ± 228.1	27.1 ± 4.1	72.6 ± 10.0	0.2 ± 0.9	66.5 ± 5.0
1100	21.4 ± 3.5	67.0 ± 12.9	2.8 ± 1.3	609.7 ± 259.4	28.5 ± 4.2	74.3 ± 8.9	0.3 ± 1.4	68.0 ± 4.9
1200	22.3 ± 3.6	63.3 ± 14.0	2.8 ± 1.2	611.0 ± 274.3	29.4 ± 4.4	74.7 ± 8.3	0.4 ± 1.7	68.9 ± 4.8
1300	22.8 ± 3.9	60.8 ± 15.4	2.9 ± 1.2	594.1 ± 265.3	30.0 ± 4.6	74.8 ± 8.1	0.4 ± 1.9	69.5 ± 4.9
1400	23.1 ± 4.0	59.7 ± 16.0	2.8 ± 1.2	502.8 ± 260.3	29.9 ± 4.9	73.8 ± 8.6	0.5 ± 2.0	69.7 ± 5.0
1500	23.0 ± 4.3	59.9 ± 17.4	2.9 ± 1.3	404.0 ± 226.6	29.4 ± 5.5	72.2 ± 9.3	0.5 ± 2.0	69.4 ± 5.3
1600	22.4 ± 4.4	61.1 ± 18.1	2.9 ± 1.3	261.8 ± 168.5	28.2 ± 5.5	70.3 ± 9.9	0.4 ± 2.0	68.7 ± 5.4
1700	21.6 ± 4.5	62.2 ± 17.4	2.6 ± 1.3	126.9 ± 112.6	26.0 ± 6.1	66.1 ± 11.5	0.4 ± 1.8	67.7 ± 5.6
1800	20.1 ± 4.6	65.6 ± 16.7	2.3 ± 1.4	39.8 ± 52.8	21.9 ± 7.0	59.8 ± 12.7	0.3 ± 1.7	65.9 ± 6.0
1900	18.6 ± 4.1	69.7 ± 14.6	2.0 ± 1.4	3.1 ± 8.1	17.7 ± 5.1	52.2 ± 8.1	0.1 ± 1.0	63.9 ± 5.7
2000	17.4 ± 3.8	74.2 ± 12.3	1.9 ± 1.3	0.4 ± 10.9	15.6 ± 3.8	49.9 ± 4.9	0.0 ± 0.0	62.3 ± 5.6
2100	16.5 ± 3.7	77.8 ± 10.6	1.8 ± 1.2	0.0 ± 0.0	14.7 ± 3.6	49.8 ± 4.8	0.0 ± 0.0	61.1 ± 5.7
2200	15.8 ± 3.7	80.5 ± 9.2	1.6 ± 1.1	0.0 ± 0.0	14.0 ± 3.6	49.8 ± 4.8	0.0 ± 0.0	60.0 ± 5.9
2300	15.1 ± 3.8	82.5 ± 8.1	1.5 ± 1.0	0.0 ± 0.0	13.4 ± 3.6	49.7 ± 4.8	0.0 ± 0.0	59.1 ± 6.1

3.3.3 Pen microclimate

Ambient temperature

Average T_A was approximately 18 °C and exhibited a typical diurnal variation, regardless of shade treatment (Figure 3). Ambient temperature in the shade cloth treatment was on average 1.23 ± 0.27 °C cooler at the front of the pen when compared with the back of the pens ($p \leq 0.0001$). However, there were no differences in the T_A obtained from the front and back of pens within unshaded and waterproof pens ($p > 0.50$). Within the shade cloth treatment, the T_A obtained from the front the pens were on average 2.71 ± 0.30 °C cooler than the back of the pens between 0900 h and 1600 h ($p \leq 0.0001$; Figure 3). Similarly, the T_A at the front of the unshaded pens was 2.61 ± 0.34 °C ($p = 0.04$), 3.02 ± 0.34 °C ($p = 0.019$), 3.05 ± 0.34 °C ($p = 0.018$) and 2.86 ± 0.34 °C ($p = 0.025$) warmer than the shade cloth pens at 1200 h, 1300 h, 1400 h and 1500 h respectively (Figure 3). In addition, there was a tendency for the front of the shade cloth pens to be 1.29 ± 0.30 °C ($p = 0.07$) cooler when compared with the back of the pens at 1700 h. There was a tendency for the shade cloth pens to have a lower T_A than the unshaded pens by 2.17 ± 0.34°C ($p = 0.09$) and 2.27 ± 0.34 °C ($p = 0.07$) at 1100 h and 1600 h, respectively. Ambient temperature was 2.44 ± 0.34 °C cooler at the front of the waterproof pens at 1500 h when compared with the unshaded pens ($p = 0.05$; Figure 3). Furthermore, under the waterproof structure T_A tended to be 2.18 ± 0.34 °C ($p = 0.09$), 2.42 ± 0.34 °C ($p = 0.06$) and 2.23 ± 0.34 °C ($p = 0.08$), when compared with T_A from the front section of the unshaded treatment at 1300 h, 1400 h and 1600 h respectively (Figure 3). Ambient temperature from the back of the pens was not different across the three treatments ($p \geq 0.90$; Figure 3).

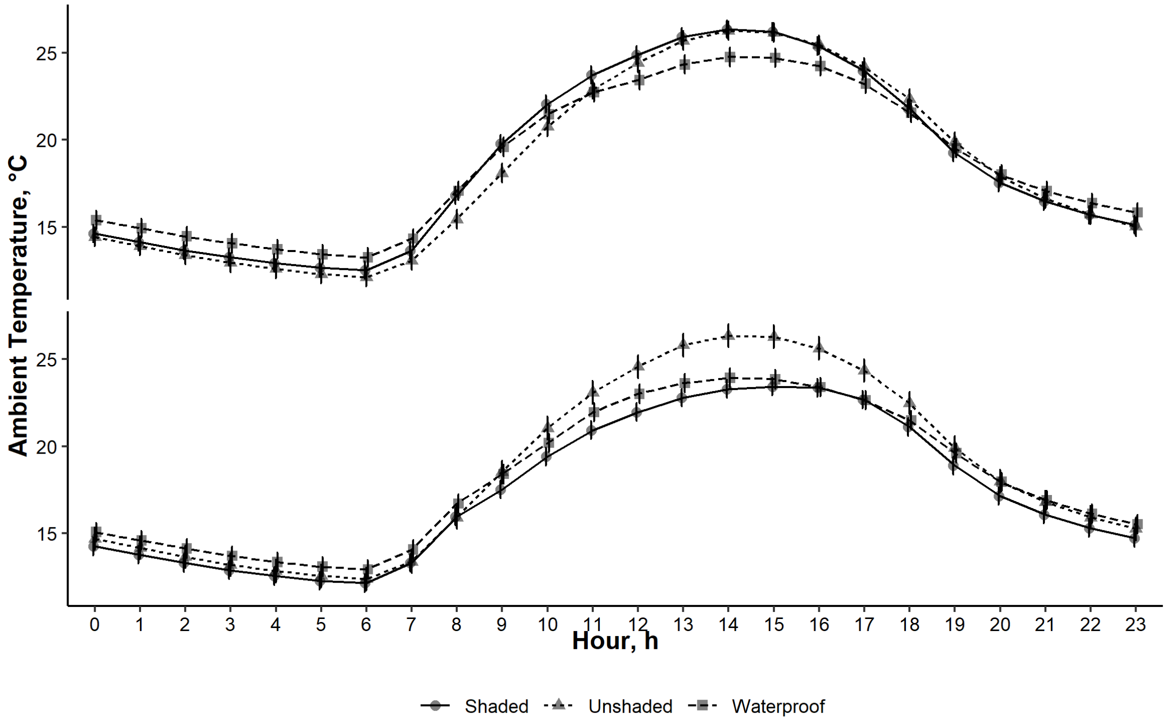

Figure 3. Average hourly ambient temperature (T_A, °C; emmean ± 95% confidence interval) at the front and back in unshaded, shade cloth (shaded) and waterproof pens

Relative Humidity

The average RH of the unshaded, shade cloth and waterproof pens were 66.8 ± 0.91 %, 70.3 ± 0.90 % and 69.0 ± 0.90 %, respectively (Figure 4). The RH within the shade cloth pens was on average 3.52 ± 0.93 % greater when compared with the unshaded pens ($p = 0.02$; Figure 4). There were no differences in the RH between the front and back positions within the unshaded and waterproof pens, however the RH at the front of the shade cloth pens was 3.94 ± 1.12 % ($p = 0.006$) greater when compared with the back of the pens.

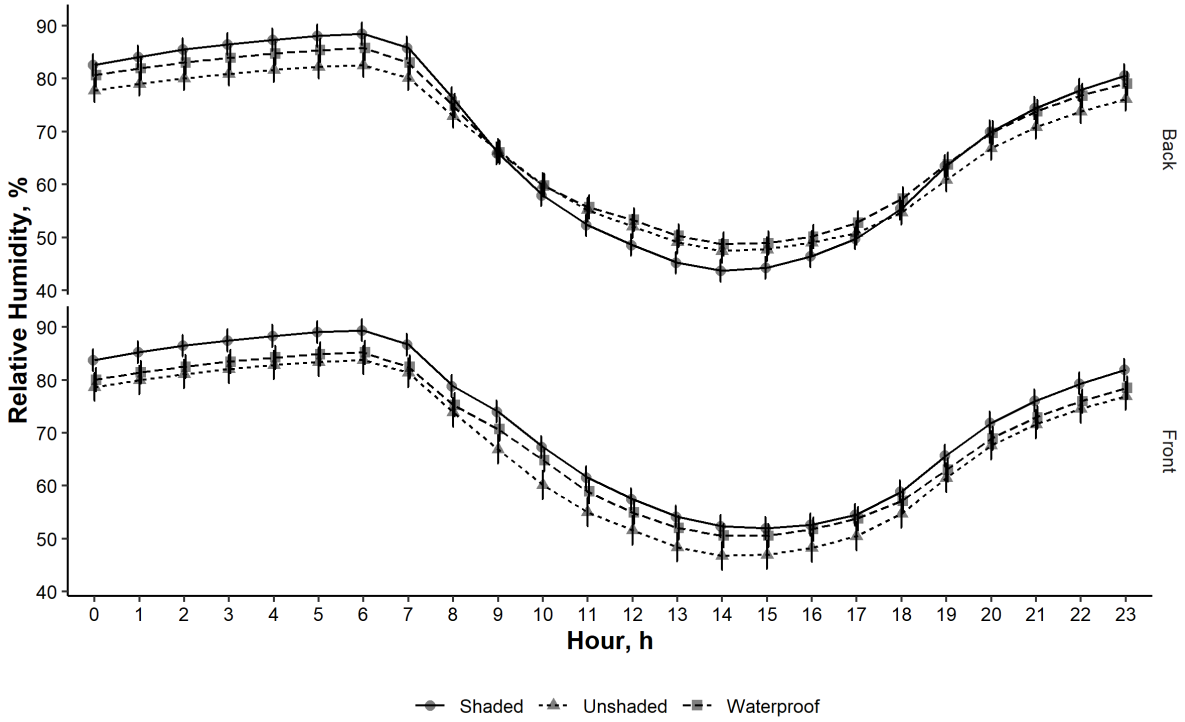

Figure 4. Average hourly relative humidity (RH, %; emmean ± 95% confidence interval) at the front and back in unshaded, shade cloth (shaded) and waterproof pens

Temperature Humidity Index

Overall mean THI within the pens was 63.18 ± 0.32, 62.48 ± 0.32 and 63.09 ± 0.32 for the unshaded, shade cloth and waterproof pens, respectively (Figure 5). The front of the shade cloth pens had a THI that was on average 1.33 ± 0.40 units lower than the back section of the pens ($p = 0.013$; Figure 5). There was a tendency for the THI to be 1.67 ± 0.47 units lower at the front of the shade cloth pens, when compared with the unshaded pens ($p = 0.079$; Figure 5). Specifically, between 0900 h and 1600 h the front of the shade cloth pens had THI values that were 3.01 ± 0.43 units lower, when compared with the back of the pens ($p \leq 0.01$; Figure 5). In addition, there was a tendency for the THI from the front of the unshaded pens to be 3.19 ± 0.51, 3.59 ± 0.51, 3.40 ± 0.51 units higher when compared with the front of the shade cloth pens at 1200 h, 1300 h and 1500 h ($p \geq 0.06$; Figure 5).

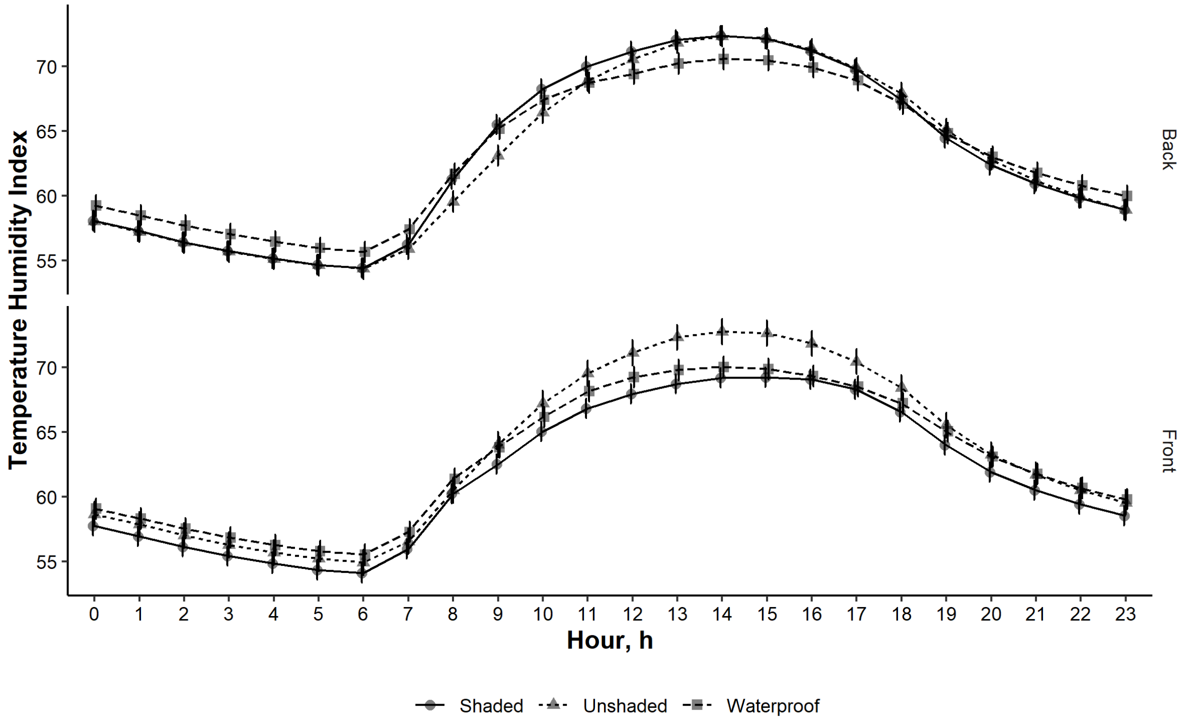

Figure 5. Average hourly temperature humidity index (THI; emmean ± 95% confidence interval) at the front and back in unshaded, shade cloth (shaded) and waterproof pens

3.3.4 Pad conditions

Pad moisture

There were no differences in pad DM across treatment × position × cohort across the three samples obtained throughout the study (Figure 6). Pad DM was influenced by sample collection date, where sample 2 was collected after a rain event and was associated 20% increase in pad moisture regardless of treatment ($p \leq 0.001$; Figure 6).

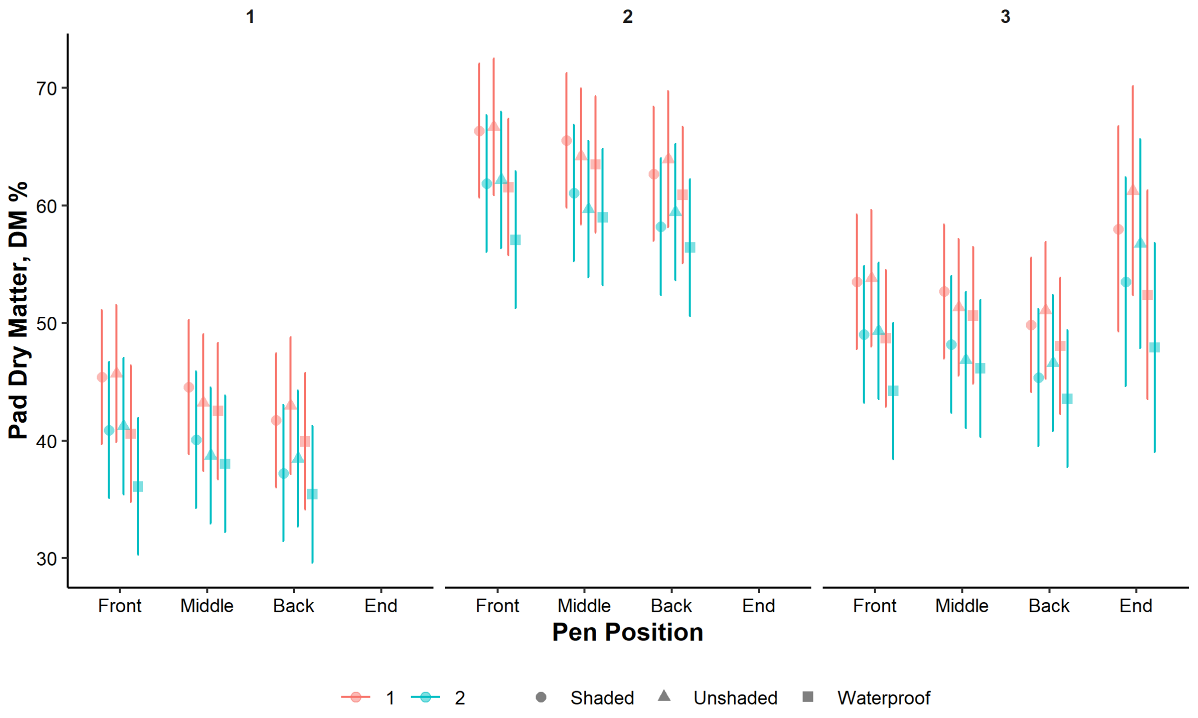

Figure 6. Pad dry matter (DM, %; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unshaded, shade cloth (shaded) and waterproof pens across the three sampling periods, where Sample 1 was collected on day 8, Sample 2 was collected on day 69 and day 41 for Cohort 1 and Cohort 2, respectively, and Sample 3 was collected on cattle exit (Cohort 1, day 104, in red; Cohort 2, day 110, in blue)

Carbon and nitrogen

Total carbon and total nitrogen within the pad were not impacted by the shade cloth or unshaded treatments nor were there treatment × cohort effects (Figure 7a; Figure 7b). However, total carbon was influenced by the waterproof treatment, where the front of the waterproof pens had total carbon that was 8.53 ± 1.20 % greater when compared with the middle, back and end of the pens in both cohorts ($p \leq 0.009$; Figure 7a). Total carbon also tended to be 7.53 ± 1.91 % lower in the middle section of the waterproof pens when compared with the middle section of the unshaded pens ($p = 0.10$; Figure 7a). Similarly, total nitrogen 0.46 ± 0.09 % and 0.62 ± 0.09 % lower at the back and middle (of the pens when compared with the front for both cohorts ($p \leq 0.003$; Figure 7b).

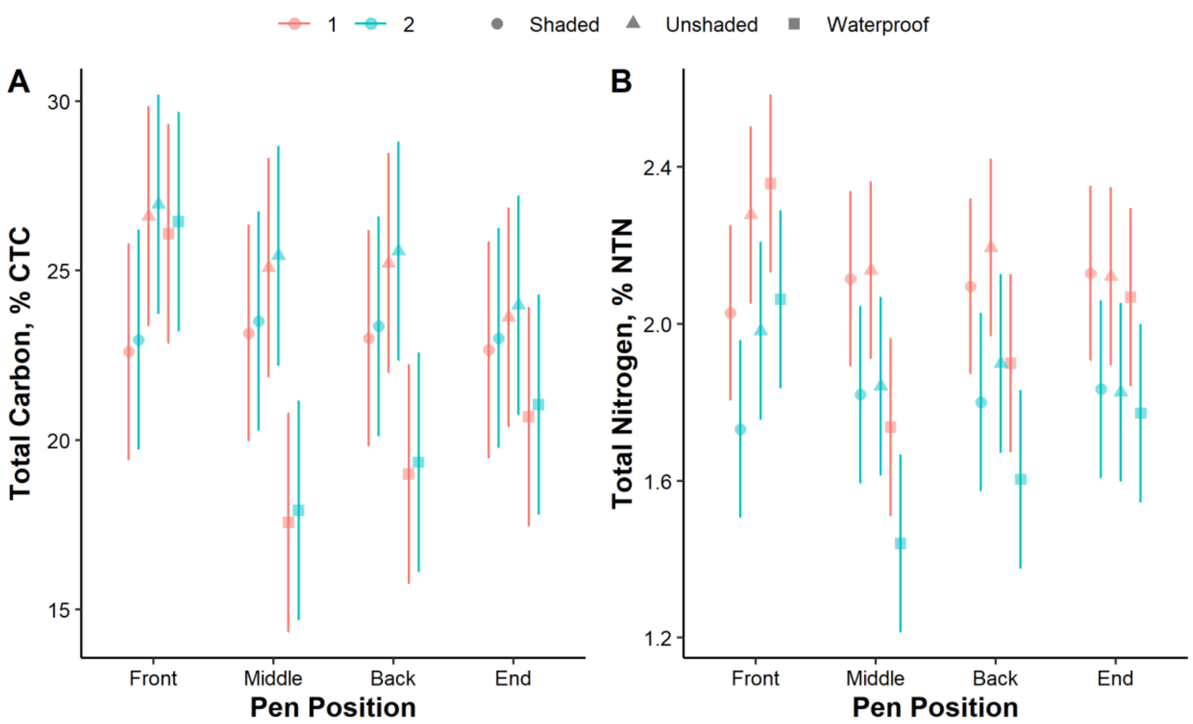

Figure 7. Pad A) total carbon (% C_{TC}; emmean ± 95% confidence interval) and B) total nitrogen (% N_{TN}; (emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unshaded, shade cloth (shaded) and waterproof pens on cattle exit (Cohort 1, day 104, in red; Cohort 2, day 110, in blue).

For the C:N ratio there was a strong cohort effect, where the C:N ratio was lower in Cohort 1 ($p < 0.0001$; Figure 8). Cohort 2 had a C:N ratio that was 1.92 ± 0.20 units higher when compared with Cohort 1, regardless of pen position and shelter provision ($p < 0.0001$; Figure 8). Within Cohort 1, the C:N ratio was 0.99 ± 0.21 units lower at the back and 1.08 ± 0.21 units lower at the end of the pens, when compared with the front of the pen ($p < 0.0001$; Figure 8). Similarly, in Cohort 2 the C:N ratio was and 1.08 ± 0.21 units lower at the end of the pens, when compared with the front of the pen ($p < 0.0001$; Figure 8). Pad C:N ratio was also on average 1.43 ± 0.31 units lower at the back and middle sections of the in the waterproof pens when compared with the unshaded pens, regardless of cohort ($p \leq 0.04$; Figure 8).

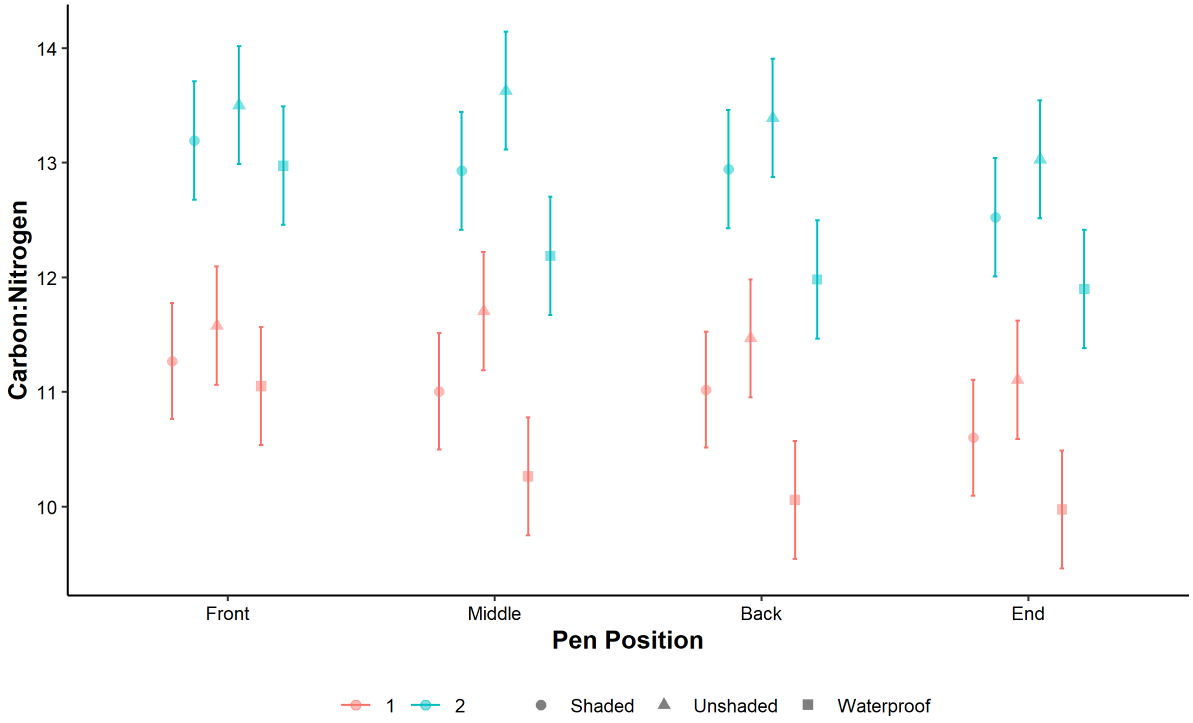

Figure 8. Pad total carbon to total nitrogen (C:N; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unshaded, shade cloth (shaded) and waterproof pens on cattle exit (Cohort 1, day 104, in red; Cohort 2, day 110, in blue).

Volatile Solids

The volatile solid content of the waterproof treatment was on average 8.99 ± 3.42 % lower when compared with the unshaded treatment (*p* = 0.05). This difference was largely attributed to the 17.98 ± 3.94 %, 15.04 ± 3.94 % and 15.56 ± 3.94 % higher volatile solids at the front, middle and back sections of the unshaded pens when compared with the middle section of the waterproof pens ($p \leq 0.05$; Figure 9). The front of the waterproof pens had a volatile solid composition that were 17.21 ± 2.26 %, 14.16 ± 2.26 % and 11.83 ± 2.26 higher when compared with the middle, back and end sections of the pens regardless of cohort ($p \leq 0.001$; Figure 9).

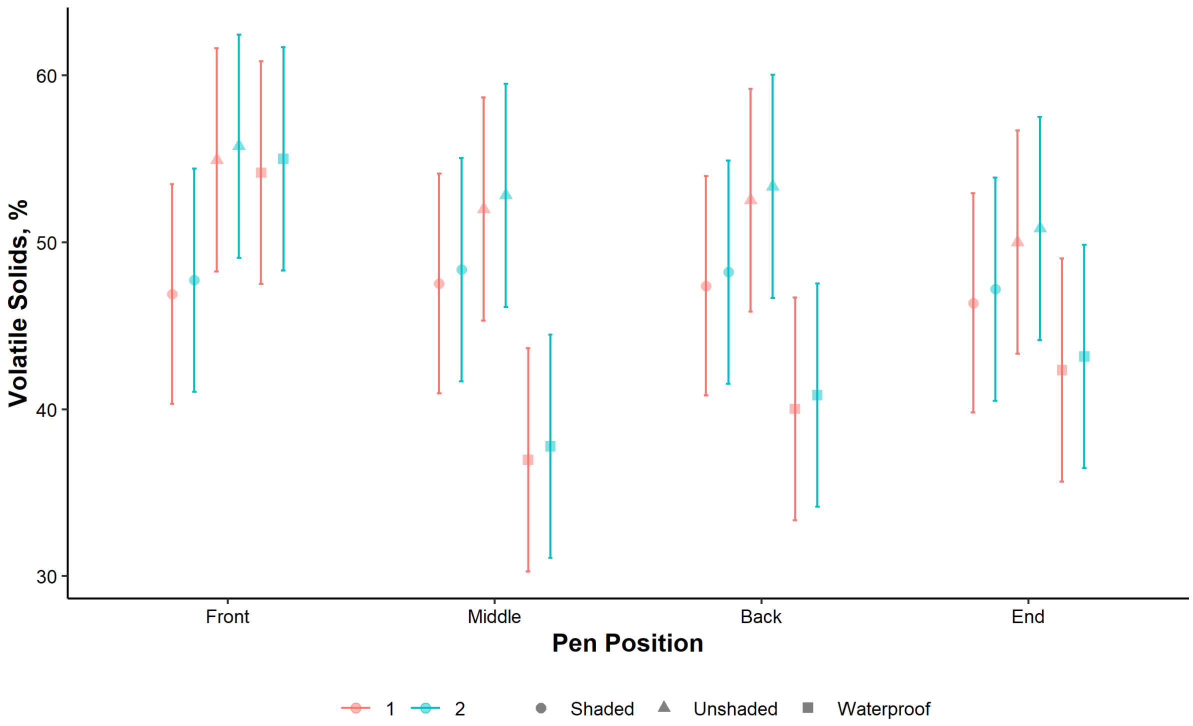

Figure 9. Pad Volatile Solids (%; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unshaded, shade cloth (shaded) and waterproof pens on cattle exit (Cohort 1, day 104, in red; Cohort 2, day 110, in blue).

Pad depth

Pad depth was not influenced by treatment, position or cohort in the left ($p > 0.14$) or right positions ($p > 0.24$; Figure 10). Pad depth in the centre of the unshaded pens tended to be and 9.47 ± 0.48 and 9.13 ± 2.48 cm deeper at the middle ($p = 0.06$) and back ($p = 0.07$) sections of the pen, when compared with the front section of the unshaded pens (Figure 10).

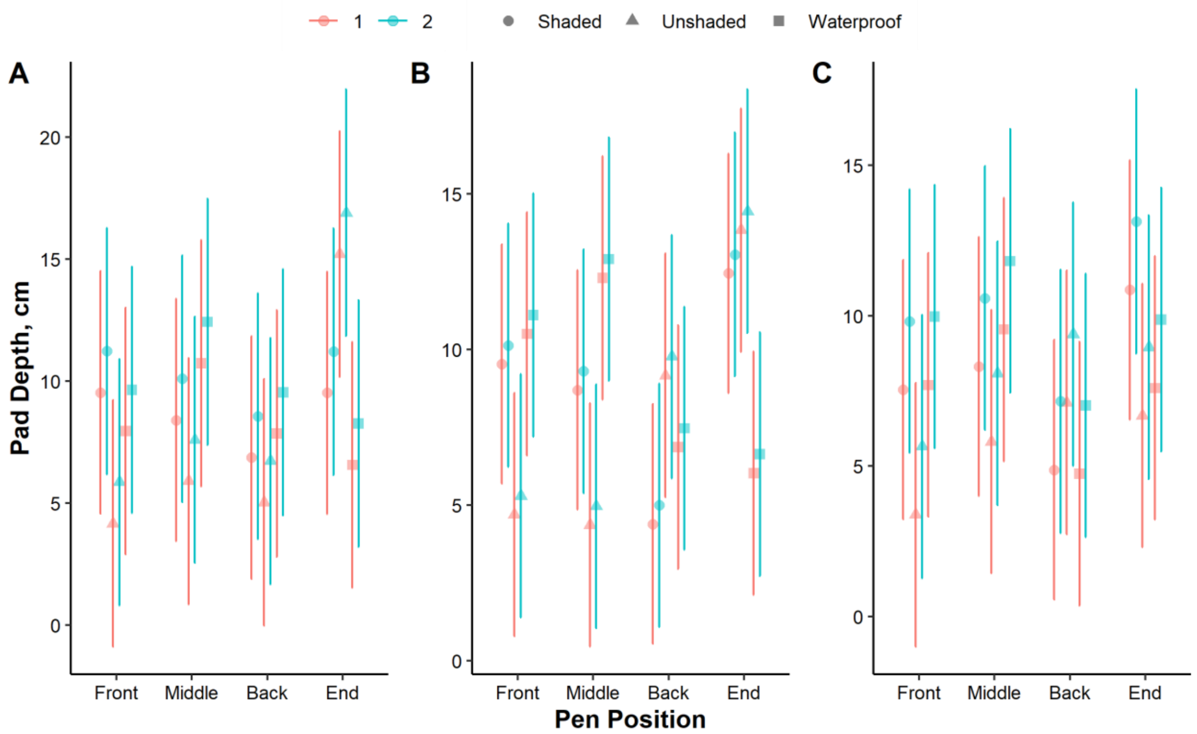

Figure 10. Pad depth (cm; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unshaded, shade cloth (shaded) and waterproof pens on the A) left, B) middle and C) right hand side of the pens on cattle exit (Cohort 1, day 104, in red; Cohort 2, day 110, in blue)

3.3.5 Shade availability

Due to the slope on the infrastructure to supply shade the shade footprint travelled throughout the day, from the front of the pens (bunk end) towards the rear of the pens. The shade footprint within the shade cloth treatment provided a shade allocation of between 2.09 m^2/hd and 2.89 m^2/hd, and the waterproof treatment 2.19 m^2/hd and 4.75 m^2/hd, depending on the time of day (Table 8). The shade footprint from the shade cloth and waterproof treatment extended beyond the feed bunks until 1000 h and 1400 h, respectively.

Table 8. Shade footprint[1] of the shade cloth (shaded) and waterproof treatments between 0900 h and 1700 h

Hour[2]	Shade cloth		Waterproof	
	m^2/hd	Dimensions, m (w × h)	m^2/hd	Dimensions, m (w × h)
0900	2.09	6.7 m × 12.5 m	2.19	7.0 m × 12.5 m
1000	2.89	9.25 m × 12.5 m	3.05	9. 75 m × 12.5 m
1100	2.91	9. 3 m × 12.5 m	3.31	10.6 m × 12.5 m
1200	2.78	8.9 m × 12.5 m	3.97	12.7 m × 12.5 m
1300	2.78	8.9 m × 12.5 m	4.41	14.1 m × 12.5 m
1400	2.89	9.25 m × 12.5 m	4.66	14.9 m × 12.5 m
1500	2.59	8.3 m × 12.5 m	4.31	13.8 m × 12.5 m
1600	2.53	8.1 m × 12.5 m	4.75	15.2 m × 12.5 m
1700	2.19	7.0 m × 12.5 m	4.56	14.6 m × 12.5 m

[1] Data were collected on AEDT

[2] Shade allocation was determined on 40 head per pen

3.3.6 Animal behaviour

Posture

Standing and lying postures were variable across the four observation periods ($p < 0.0001$; Figure 11a; Figure 11c) and heat load index categories ($p < 0.0001$; Figure 11b; Figure 11d). Standing was largely not influenced by shade treatment, however the proportion of waterproof cattle standing was 9.36 ± 1.85 % and 7.89 ± 1.85 % greater when compared with the shade cloth ($p = 0.006$) and unshaded ($P = 0.02$) cattle, respectively (Figure 11a). And there was a tendency for more shade cloth cattle (6.56 ± 1.88 %) to be standing when compared with the unshaded cattle at 1300 h ($p = 0.09$). There were no differences in the proportion of cattle lying across the treatments 0800 h or 1500 h ($p \geq 0.26$; Figure 11a). At 1100 h, the proportion of cattle lying in the waterproof treatments was approximately 10 % less when compared with the unshaded and shade cloth cattle ($p \leq 0.0008$; Figure 11c). In addition, at 1300 h there were 7.13 ± 1.74 % less cattle lying in the unshaded pens when compared with the shade cloth cattle ($p = 0.03$; Figure 11c).

The proportion of unshaded, shade cloth and waterproof cattle standing increased when the heat load index category changed from cool (HLI ≤ 70) to moderate (HLI 70.1 ≤ 77; $p \leq 0.0001$), moderate (HLI 70.1 ≤ 77) to hot (HLI 77.1 ≤ 86; p ≤ 0.0001), and cool (HLI ≤ 70) to hot (HLI 77.1 ≤ 86; $p \leq 0.0012$; Figure 11b). There were no differences in the proportion of cattle standing between shade treatments across the heat load index categories, with the exception of the waterproof treatment where 12.43 ± 0.80% more cattle were observed standing when conditions were classified as hot (HLI 77.1 ≤ 86) when compared with cool (HLI ≤ 70) conditions ($p \leq 0.0001$; Figure 11b). When conditions were classified as cool (HLI ≤ 70) there were no differences in the proportion of cattle lying in shade cloth and unshaded ($p \geq 0.9$) or unshaded and waterproof ($p = 0.20$) treatments, however the proportion of cattle lying in the waterproof was 4.63 ± 1.14 % less when compared with the shade cloth cattle ($p = 0.04$; Figure 11d). This trend persisted across moderate conditions (HLI 70.1 ≤ 77) and hot (HLI 77.1 ≤ 86; Figure 11d).

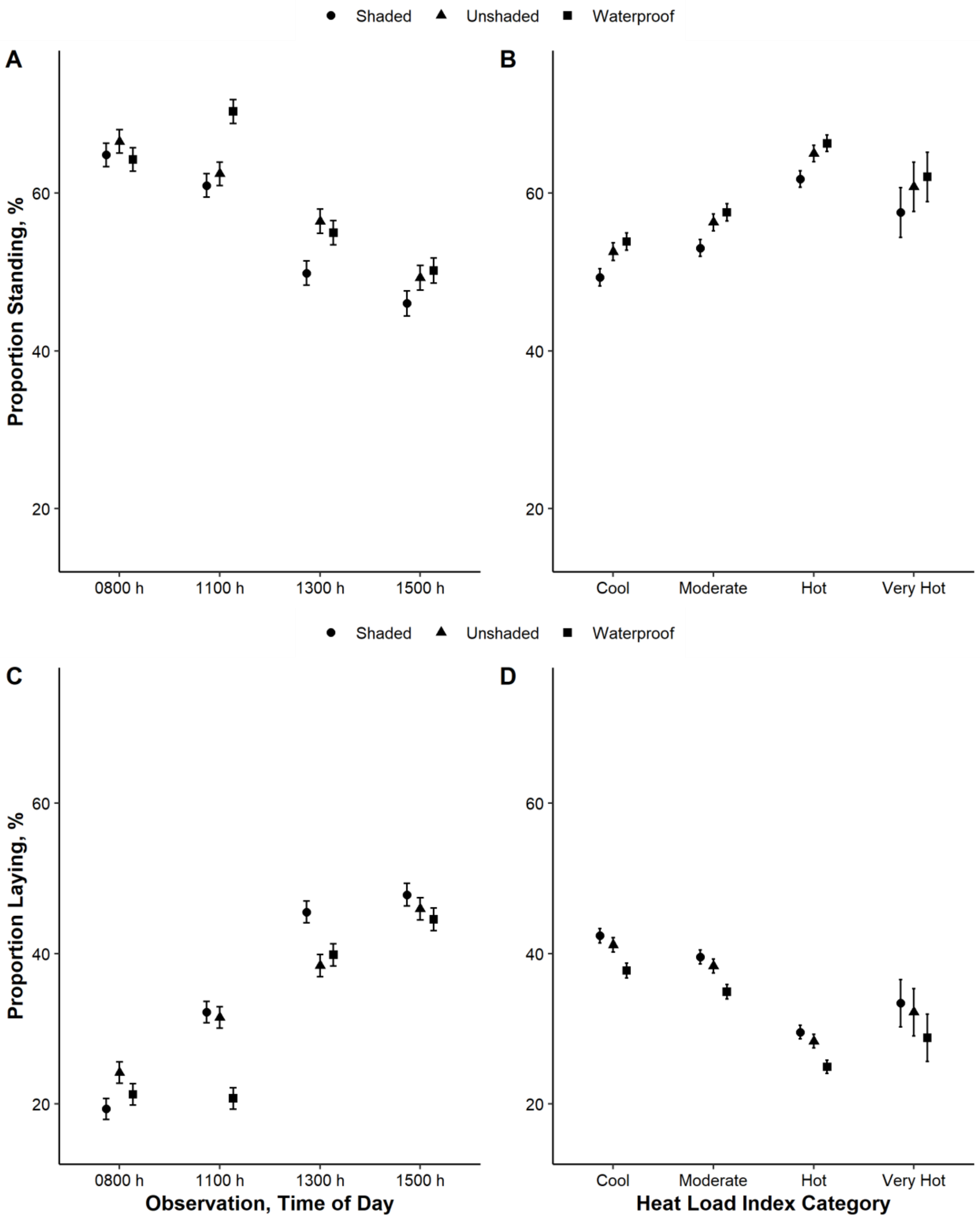

Figure 11. Proportion of cattle (emmean ± SE) in unshaded, shade cloth (shaded) and waterproof treatments A) standing during the four observation periods; B) standing across the four Heat Load Index stress categories; C) laying during the four observation periods; and D) laying across the four Heat Load Index stress categories.

Feeding

Unsurprisingly the greatest proportion of cattle observed feeding occurred at 0800 h, post feed delivery, regardless of treatment (Figure 12a). However, there were 5.23 ± 0.88 % and 6.87 ± 0.88 % less cattle feeding in the unshaded treatment compared with cattle in the waterproof ($p = 0.014$) and shade cloth treatments ($p \leq 0.0001$) at 0800 h. Heat load index category had limited influence on the proportion of cattle feeding (Figure 12b).

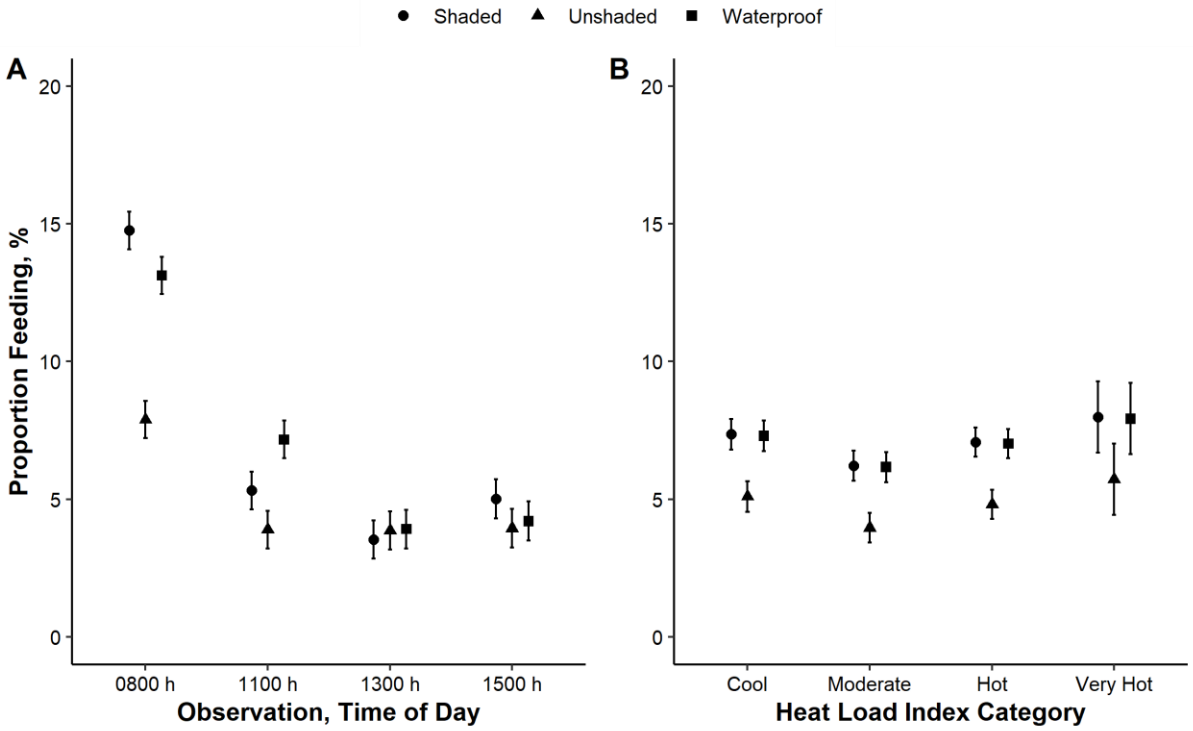

Figure 12. Proportion of cattle (emmean ± SE) in unshaded, shade cloth (shaded) and waterproof treatments A) eating during the four observation periods; and B) eating across the four Heat Load Index stress categories

Drinking

There were no differences in the proportion of cattle observed drinking between treatments or time of day ($p \geq 0.17$; Figure 13a). The proportion of cattle drinking increased as heat load index category increase from cool (HLI ≤ 70), to moderate (HLI 70.1 ≤ 86) and hot (HLI 77.1 ≤ 86), then numerically decreased between hot (HLI 77.1 ≤ 86) and very hot (HLI ≥ 86; $P \geq 0.90$; Figure 13b).

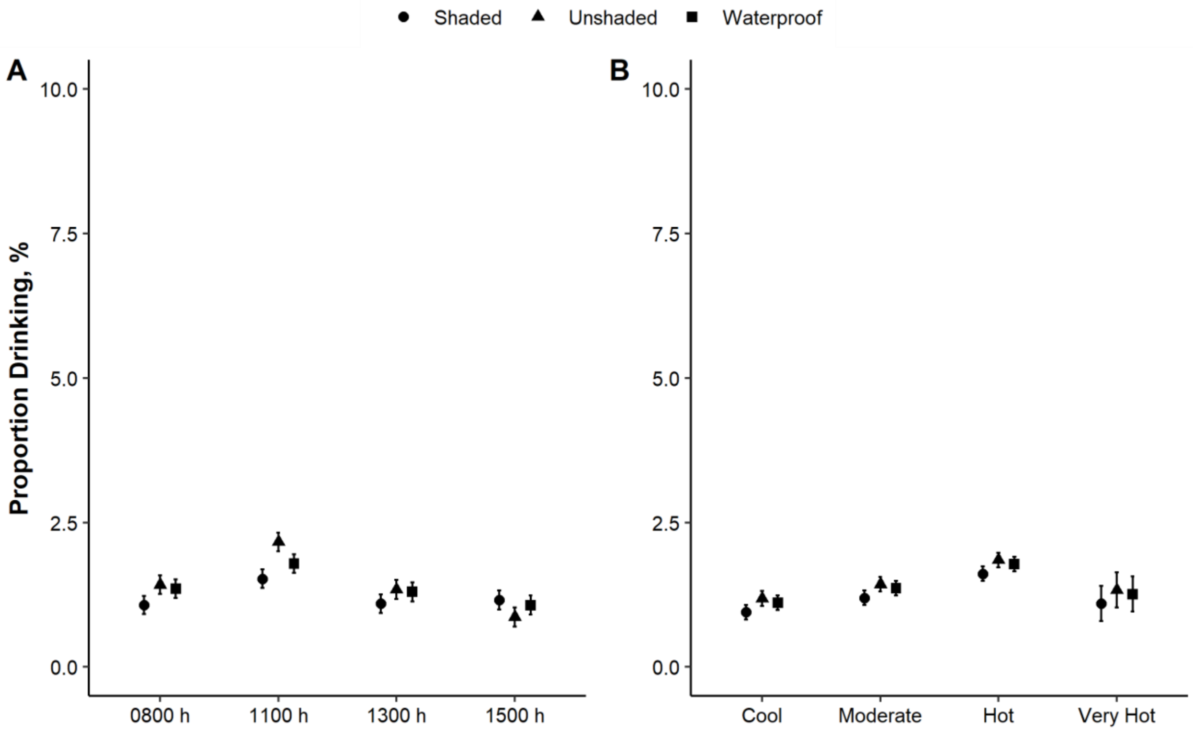

Figure 13. Proportion of cattle (emmean ± SE) in unshaded, shade cloth (shaded) and waterproof treatments A) drinking during the four observation periods; and B) drinking across the four Heat Load Index stress categories

Rumination

The proportion of cattle ruminating was variable throughout the study and rumination activity was not influenced by treatment (p = 0.37) or treatment × observation (p = 0.15). The proportion of cattle ruminating was influenced by observation time where 9.23 ± 0.27 % of cattle within each treatment were observed ruminating at 0800 h, in comparison to 3.59 ± 0.28 %, 5.48 ± 0.29 % and 7.57 ± 0.30 % at 1100 h, 1300 h and 1500 h respectively (Figure 14a). The proportion of cattle ruminating differed between cool and hot (p = 0.0009) in addition to moderate and hot (p = 0.01) conditions, however the differences between the proportion of cattle ruminating was < 1 % (Figure 14b).

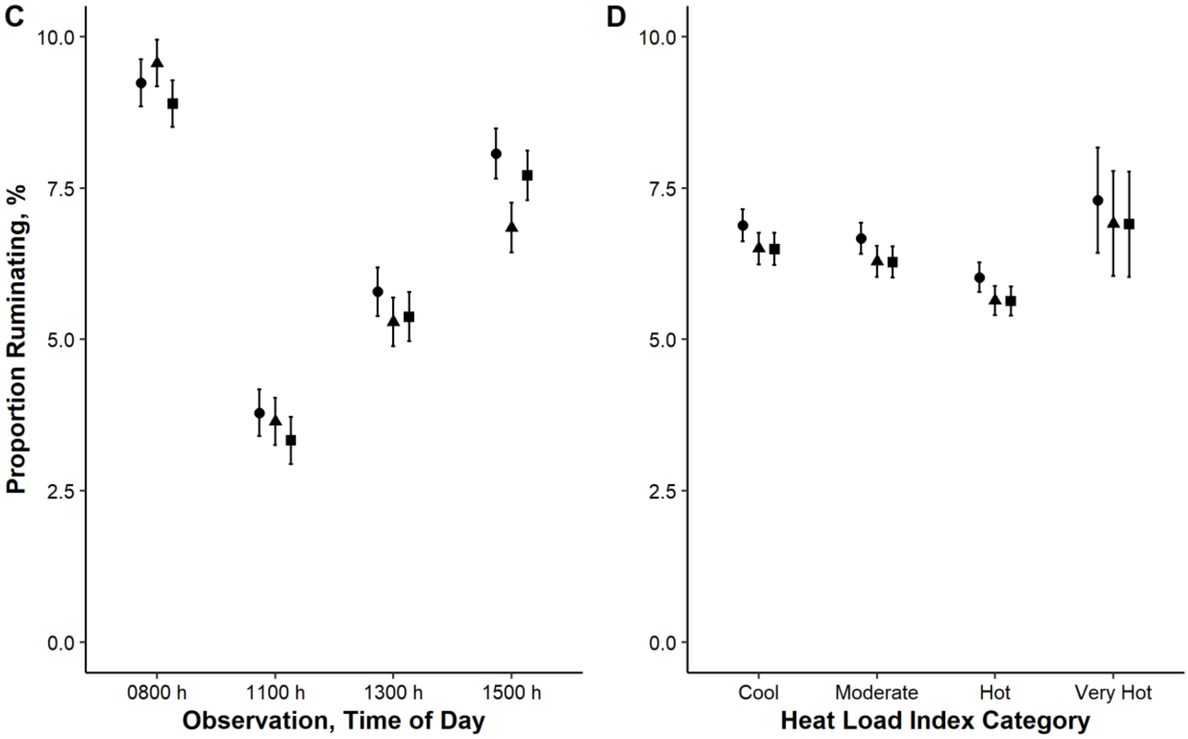

Figure 14. Proportion of cattle (emmean ± SE) in unshaded, shade cloth (shaded) and waterproof treatments A) ruminating during the four observation periods; and B) ruminating across the four Heat Load Index stress categories

3.3.7 Shade utilisation

Shade utilisation for shade cloth and waterproof treatments were highly variable throughout the study (Figure 15a). Shade utilisation was influenced by treatment ($p < 0.0001$), observation ($p < 0.0001$), treatment × observation ($p \leq 0.01$; Figure 15a) and HLI category ($p < 0.0001$; Figure 15b). Cohort had no impact on shade utilisation within this study ($p > 0.50$). Maximum shade utilisation was 58.7 ± 1.72 % and 44.7 ± 1.71 % for the waterproof and shade cloth cattle, respectively, at 1300 h (Figure 15a). Shade utilisation was 7.13 ± 1.84 % ($p = 0.05$), 9.93 ± 1.83 % ($p = 0.006$), 14.05 ± 1.88 % ($p = 0.0006$) and 14.16 ± 1.96 % ($p = 0.0008$) greater for cattle in the waterproof treatment when compared with the shade cloth cattle at 0800 h, 1100 h, 1300 h and 1500 h, respectively (Figure 15a). Shade utilisation also increased between 0800 h and 1300 h regardless of treatment ($p \leq 0.04$; Figure 15a). Furthermore, as heat load increased from cool (HLI ≤ 70) to very hot (HLI ≥ 86) there was a 12.1% increase in shade utilisation regardless of treatment (Figure 15b). However, the waterproof and shade cloth cattle exhibited a 3 % decrease in shade utilisation between cool and moderate heat load conditions ($p = 0.06$). Shade utilisation in the waterproof treatment was 11.3 % greater when compared with the shade cloth cattle across all four HLI stress categories ($p \leq 0.0001$; Figure 15b).

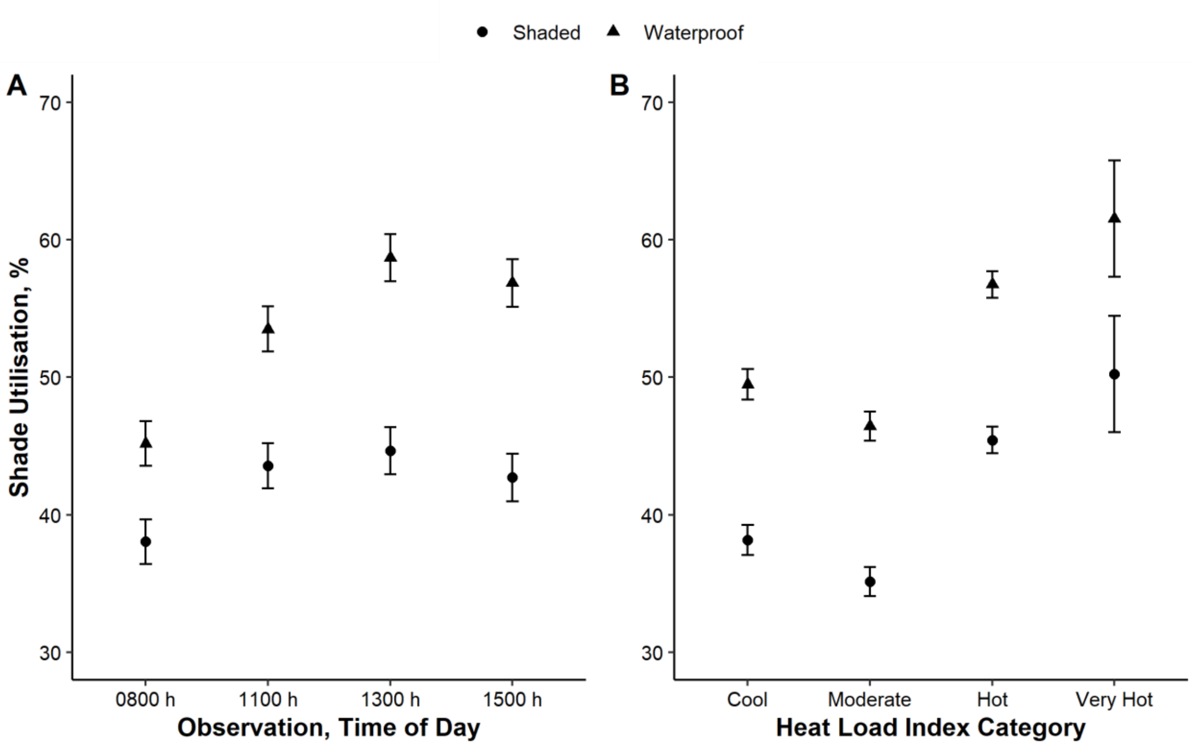

Figure 15. Proportion of cattle (emmean ± SE) in unshaded, shade cloth (shaded) and waterproof treatments utilising shade A) during the four observation periods; and B) across the four Heat Load Index stress categories

3.3.8 Mean panting score

Mean panting score across all observation timepoints within day increased for all treatments, with the greatest overall mean panting score occurring at the 1500 h regardless of treatment (Figure 16a). Mean panting score was 0.12 ± 0.02, 0.15 ± 0.25 and 0.18 ± 0.02 for the unshaded, shade cloth and waterproof treatments, respectively, at the 0800 h observation indicating no stress (Figure 16a). However, for the remaining observations mean panting score was between 0.48 ± 0.02 (waterproof at 1100 h) and 0.97 ± 0.03 (unshaded at 1500 h) regardless of treatment, suggesting that these cattle were experiencing mild to high heat stress throughout the remaining observations. Overall, mean panting score were 0.11 ± 0.01 and 0.06 ± 0.01 lower for cattle in waterproof treatment when compared with the unshaded ($p \leq 0.0001$) and shade cloth ($p = 0.03$) cattle, respectively. There were no differences in mean panting score of cattle on the unshaded or shade cloth treatments at 1100 h ($p \geq 0.9$) or 1300 h ($p = 0.41$), nor were there mean panting score differences between unshaded and waterproof cattle at 1100 h ($p = 0.11$; Figure 16a). In addition, there were no differences in the mean panting score between shade cloth and waterproof cattle at 1100 h ($p = 0.18$), 1300 h ($p = 0.18$) and 1500 h ($p = 0.70$; Figure 16a). Unshaded cattle had MPS that were 0.12 ± 0.03 greater than shade cloth cattle at 1500 h ($p = 0.04$; Figure 16a). The unshaded cattle also had MPS that were 0.16 ± 0.03 and 0.18 ± 0.03 greater than waterproof cattle at 1300 h and 1500 h, respectively ($p \leq 0.0001$; Figure 16a).

Mean panting score increased as HLI category increased from increased from cool (HLI ≤ 77) to very hot (HLI ≥ 86), regardless of treatment ($p \leq 0.0001$; Figure 16b), with the exception of mean panting score between hot and very hot conditions in the waterproof cattle (p= 0.83). Mean panting score between treatments within each heat load index category, differed where waterproof cattle had lower panting scores compared with unshaded and shade cloth cattle ($p \leq 0.05$) and shade cloth cattle had mean panting score that were lower panting scores than unshaded cattle, specifically during cool, moderate and very hot conditions ($p = 0.05$; Figure 16b). When HLI stress category was classified as very hot (HLI ≥ 86) the mean panting score of all treatment groups differed ($p \leq 0.05$), whereby waterproof cattle had mean panting score that were 0.11 ± 0.01 and 0.06 ± 0.01 lower than unshaded ($p \leq 0.0001$) and shade cloth ($p = 0.04$) counterparts. Similarly, the mean panting score of shade cloth cattle were 0.05 ± 0.01 lower than unshaded cattle ($p = 0.05$; Figure 16b).

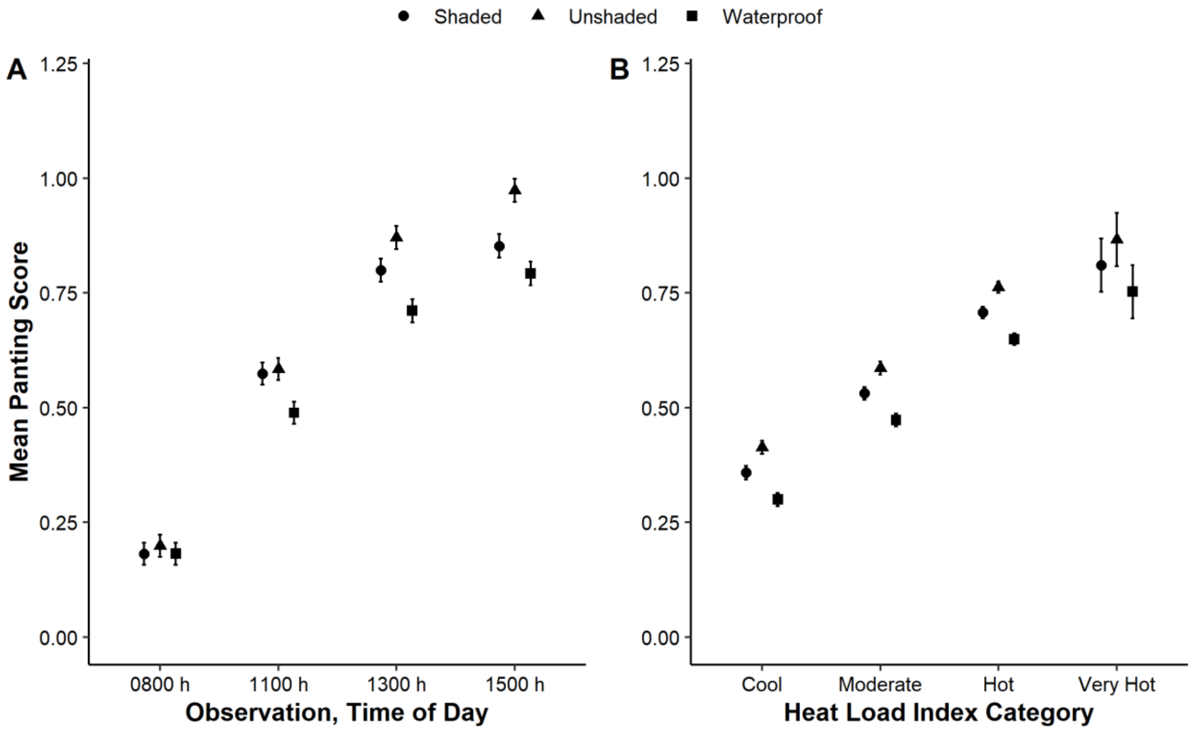

Figure 16. Mean Panting Score (emmean ± SE) of cattle in the unshaded, shade cloth (shaded) and waterproof treatments utilising shade A) during the four observation periods; and B) across the four Heat Load Index stress categories

Open mouth panting

The occurrence of open mouth panting was limited throughout the summer (Figure 17). However, the incidence of open mouth panting increased within day increased for all treatments (Figure 17a) and as HLI category increased from increased from cool (HLI ≤ 77) to very hot (HLI ≥ 86), regardless of treatment ($p < 0.001$; Figure 17b). Across the daily observation times there were no differences in open mouth panting between the shade cloth and waterproof treatments, regardless of observation time ($p \geq 0.9$; Figure 17a) and HLI category ($p \geq 0.9$; Figure 17b). The proportion of cattle with open mouth panting was between 0.55 ± 0.12 % and 0.82 ± 0.12 % greater in the unshaded cattle, when compared with the shade cloth and waterproof cattle at 1300 h and 1500 h ($p < 0.01$; Figure 17a). Open mouth panting was 0.40 ± 0.01 % greater in the unshaded cattle when compared with the waterproof cattle across all HLI categories ($p = 0.03$; Figure 17b) and tended to be 0.35 ± 0.01 % higher when compared with the shade cloth cattle ($p = 0.08$; Figure 17b).

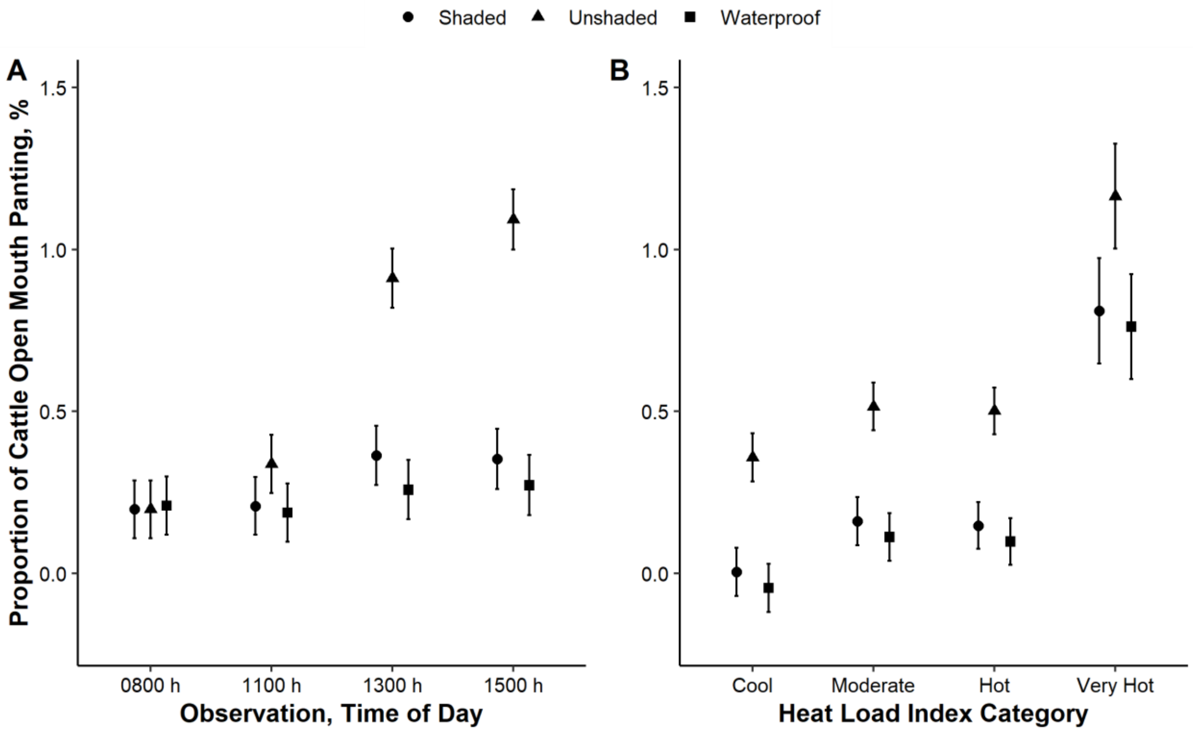

Figure 17. Proportion of cattle with open mouth panting (emmean ± SE) in the unshaded, shade cloth (shaded) and waterproof treatments utilising shade A) during the four observation periods; and B) across the four Heat Load Index stress categories

3.3.9 Rumen temperature

Largely T_{RUM} were not influenced by treatment, specifically between the shade cloth and waterproof treatments (Figure 18). Unshaded cattle tended to have higher T_{RUM} at approximately 1600 h, when compared with the shade cloth and waterproof cattle (Figure 18). This was observed regardless of cohort but was more pronounced within Cohort 2 (Figure 18).

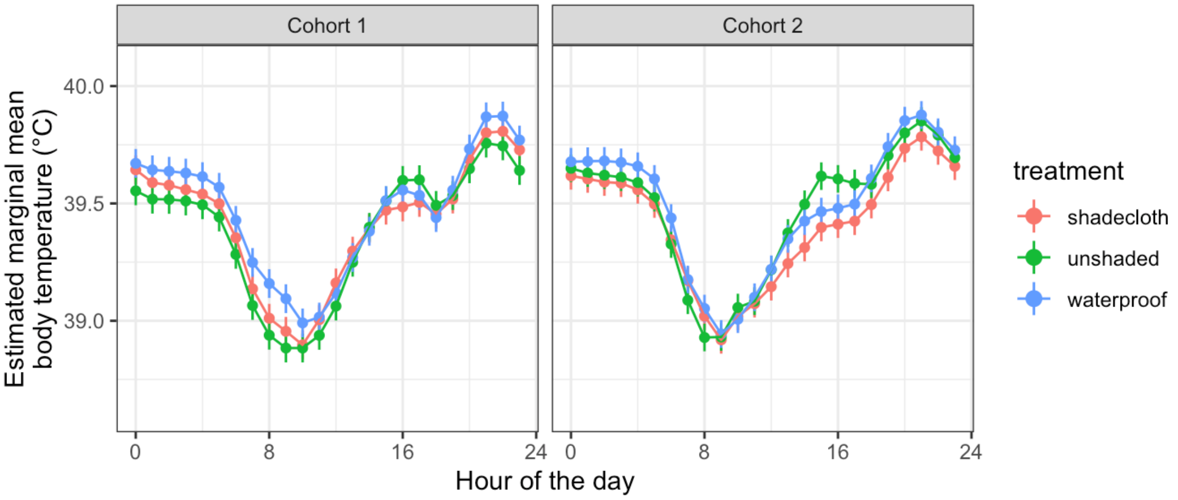

Figure 18. Mean rumen temperature (T_{RUM}, °C; emmean ± SE) of cattle in the unshaded, shade cloth (shaded) and waterproof treatments for Cohort 1 and Cohort 2

3.3.10 Animal performance

Average liveweight at induction was not different across the treatments (*p* = 0.19), nor were there differences in cattle non-fasted liveweights on d50 (*p* = 0.35) or ADG to d50 (*p* = 0.39) of the study

(Table 9). Furthermore, DMI was not influenced by treatment in the first 50d of the study (*p* = 0.72), nor were there differences in DMI over the whole feeding period (*p* = 0.53; Table 8). Subsequently, there were no differences in feed conversion efficiency a determined by the non-fasted d50 liveweights, across the three treatments (Table 8). However, cattle in the waterproof treatment were heavier, as per non-fasted d50 liveweight, when compared with the cattle within the unshaded (12.2 ± 4.2 kg; *p* = 0.03) treatment and tended to be heavier than cattle within the shade cloth (10.3 ± 4.2 kg; *p* = 0.06) treatment on exit (Table 9). These weight differences were also reflected in the final LW_{adj}, specifically cattle within the waterproof treatment were 13.4 ± 4.3 kg (*p* = 0.02) and 12.5 ± 4.3 kg (*p* = 0.03) heavier when compared with the unshaded and shade cloth cattle, respectively (Table 9). The weight differences were also reflected by the ADG and ADG_{adj}. Cattle in the waterproof treatments had ADG that were 0.16 ± 0.04 kg/d ($p \leq 0.01$) and 0.12 ± 0.04 kg/d (*p* = 0.03) greater when compared with the unshaded and the shade cloth treatments, respectively (Table 9). Additionally, the ADG_{adj} of the waterproof treatment were 0.10 ± 0.03 ($p \leq 0.01$) and 0.09 ± 0.03 ($p \leq 0.01$) greater than the shade cloth and unshaded treatments, respectively (Table 9). There were no differences in the final LW_{adj}, ADG or ADG_{adj} of cattle from the unshaded and shade cloth treatments (Table 9).

Table 9. Estimated marginal means (± SE) for liveweight at d0 (Initial LW), d50 (50 DOF LW), exit[1] (Final LW), adjusted final liveweight[2] (Final LW_{adj}), average daily gain (ADG) for the period d0 to d50, d50 to exit[1], adjusted average daily gain (ADG_{adj}) between d0 to exit[3], gain to feed (G:F) ratio for the period d0 to d50, d50 to exit[1], adjusted gain to feed ($G:F_{adj}$) between d0 to exit[3] and dry matter intake (DMI) for the period d0 to d50, d50 to exit[1]

Trait	Treatment			Significance
	Unshaded	Shade Cloth	Waterproof	
Initial LW, kg	378.6 ± 10.56	380.6 ± 10.56	382.6 ± 10.56	0.19
50 DOF LW, kg	484.5 ± 7.06	484.1 ± 7.06	487.8 ± 7.06	0.35
Final LW, kg	569.6 ± 4.17	571.5 ± 4.17	581.8 ± 4.17	≤0.01
Final LW_{adj}, kg	569.6 ± 4.29	570.5 ± 4.29	583.0 ± 4.29	≤0.01
ADG d0 to d50, kg LW/hd.d	2.12 ± 0.08	2.07 ± 0.08	2.11 ± 0.08	0.39
ADG d0 to exit, kg LW/hd.d	1.58 ± 0.19	1.62 ± 0.19	1.74 ± 0.19	≤ 0.01
ADG_{adj} d0 to exit, kg LW/hd.d	1.84 ± 0.14	1.83 ± 0.14	1.93 ± 0.14	≤ 0.01
G:F d0 to d50	0.189 ±0.0033	0.187 ± 0.0033	0.188 ± 0.0033	0.87
G:F d0 to exit	0.147 ± 0.0053	0.148 ± 0.0053	0.152 ±0.0053	0.15
$G:F_{adj}$ d0 to exit	0.147 ± 0.0051	0.148 ± 0.0051	0.153 ± 0.0051	0.03
DMI d0 to d50, kg DM/hd.d	11.19 ± 0.28	11.06 ± 0.28	11.19 ± 0.28	0.72
DMI d0 to exit, kg DM/hd.d	12.19 ± 0.21	12.07 ± 0.21	12.28 ± 0.21	0.53

[1] Cohort 1 exit, d104; Cohort exit, d109

[2] Adjusted final weight was calculated from HSCW divided by the average dressing percent (Cohort 1, 53.4 %; Cohort 2, 53.8 %) of all heifers within each cohort

[3] Adjusted ADG and adjusted G:F were calculated using the adjusted final weight

3.3.11 Morbidity and Mortality

A total of 99 animals were treated for footrot, pink eye/eye infection or bovine respiratory disease. Of the 99 animals treated 65 were from Cohort 1 and 34 were from Cohort 2. Footrot was the most prominent morbidity throughout the study with 97 % of morbidities associated with footrot. A total of 6.0 % of morbidity cases required a second treatment, and all re-treatments were associated with footrot. There were 6 mortalities throughout the study, two from unshaded pens, one from a shade cloth pen and three from the waterproof treatments. A summary of the morbidity and mortality relative to treatment is provided below in Table 10. Causes of these mortalities have been discussed previously in section 3.2.16.

Table 10. Morbidity and mortality summary

Item	Unshaded	Shade Cloth	Waterproof
Morbidity[1], %	4.2	4.0	5.6
Morbidity, % 2 Treatments	1.0	2.0	3.0
Mortality[1], %	0.28	0.14	0.42

[1] Percent relative to total number of cattle within the study

3.3.12 Carcase performance

Cattle in the waterproof treatment had HSCW that were 7.20 ± 2.31 kg and 6.69 ± 2.31 kg heavier when compared with carcasses from the unshaded ($p = 0.02$) and shade cloth ($p = 0.03$) treatments, respectively. There were no differences between the HSCW of cattle within the unshaded and shade cloth ($p = 0.97$). Treatment had no effect on carcass dressing percentage ($p = 0.49$), P8 fat ($p = 0.15$), EMA ($p = 0.43$), MSA Marbling ($p = 0.81$), ossification ($p = 0.51$) or pH_u ($p = 0.80$). Generally, there were small differences in rib fat measurements between the treatments ($p = 0.03$), however, rib fat depth in cattle from the waterproof treatment was 0.85 ± 0.32 greater when compared with cattle in the unshaded treatment ($p = 0.04$). Although, this was not considered biologically or economically significant, thus not discussed here. Nor were there difference in adrenal gland weight or relative adrenal gland weight across the three treatment groups (Table 11).

Table 11. Estimated marginal means (± SE) for hot standard carcass weight (HSCW), dressing percentage (Dressing %), P8 fat depth (P8 fat), rib fat depth (Rib fat), eye muscle area (EMA), Meat Standards Australia marbling scores (MSA Marbling), ossification score (Ossification), ultimate pH (pH_u), Meat Standards Australia index (MSA index) and adrenal gland weight (Adrenal wt) for cattle within the Unshaded, Shade cloth and Waterproof treatments

Trait	Treatment			Significance
	Unshaded	Shade Cloth	Waterproof	
HSCW, kg	305.32 ± 3.36	305.83 ± 3.36	312.52 ± 3.36	≤ 0.01
Dressing percentage, %	53.61 ± 0.23	53.5 ± 0.23	53.7 ± 0.23	0.49
P8 fat, mm	13.91 ± 0.45	14.31 ± 0.45	14.6 ± 0.45	0.15
Rib fat, mm	9.61 ± 0.37	10.09 ± 0.37	10.46 ± 0.37	0.03
EMA, cm^2	87.9 ± 1.13	88.73 ± 1.13	89.55 ± 1.13	0.43
MSA Marbling	354.28 ± 5.45	349.75 ± 5.45	353.73 ± 5.45	0.81
Ossification	193.48 ± 4.42	193.56 ± 4.42	195.46 ± 4.42	0.51
pH_u	5.59 ± 0.02	5.59 ± 0.02	5.60 ± 0.02	0.80
MSA index	54.0 ± 1.38	53.9 ± 1.42	54.0 ± 1.44	0.77
Adrenal wt, g/100 kg HSCW	4.19 ± 0.12	4.24 ± 0.12	4.10 ± 0.12	0.12

3.4 Discussion

Periods of heat stress are associated with production losses and is considered to be a major animal welfare issue. Over the last few decades several mitigation strategies have been investigated and have been successful in reducing the negative impact of hot weather conditions on the performance and welfare of feedlot cattle. In commercial industries globally, shade structures have been readily utilised as they are cost effective and relatively simplistic to implement (Lees et al., 2019).

3.4.1 Climatic conditions

Overall, the weather conditions during the study were cool and mild and there were a number of rainfall events during the study, which contributed to the moderate summer conditions. Regardless, the Bureau of Meteorology (2021) have described the 2020-2021 summer being the coolest and wettest summer in Australia since the 2016-2017 season. Despite the cool and wet conditions, the 2020-2021 summer was the 19th hottest year since Australian climatological records began (Bureau of Meteorology, 2021). Although the weather conditions were mild, they were sufficient to elicit heat load responses, as evidenced via the behavioural responses, shade utilisation and MPS changes evoked by these cattle. These cattle responses can be attributed to the 67 % of the days within the study where the HLI was classified as hot (HLI 77.1 to 86) or very hot (HLI ≥ 86.1; Figure 2). Overall, these results suggest that the weather conditions experienced throughout the study were sufficient to evoke purposeful behavioural changes in these cattle, suggesting that these cool and mild conditions were above the thermoneutral thresholds for feedlot cattle in a temperate environment. This is an important consideration as mild summers in temperate regions of Australia are becoming more infrequent (IPCC, 2021), and in future years it is probable that will greater heat stress challenges will become more prevalent in traditionally temperate climatic regions thus placing greater challenges on animal production systems.

3.4.2 Pen microclimate

Within pen microclimates, as determined by T_A, RH and THI, were largely not influenced by treatment although some differences between the front and back of pen microclimates existed across treatments (Figure 3; Figure 4; Figure 5). As determined within this study, shade structures do not alter T_A or RH which is supported by previous studies (Buffington et al., 1981; Buffington et al., 1983; Gaughan et al., 2004). The provision of shade reduces the direct exposure to direct SR, as these shaded areas can reduce the radiant heat load by 30 % (Bond et al., 1967), thus reducing BGT (Roman-Ponce et al., 1977). It is this reduced exposure to SR that alters the within pen microclimate, providing a location within pen to seek relief from hot climatic conditions and a potential area where heat dissipation can occur. Furthermore, the advantage of shade structures is that the application is passive, where animals are able to utilise shaded areas voluntarily (Eigenberg et al., 2005), allowing for the expression of natural behaviours.

3.4.3 Pad conditions

Pad moisture was not influenced by the different shade treatments within the study, suggesting that prevailing climatic conditions, specifically the rainfall experienced throughout the study, had a larger impact. There was a strong cohort effect on C:N within the current study where the C:N ratio was lower in Cohort 1 ($p < 0.0001$; Figure 8). This was largely attributed with the increased pad from Cohort 1 pens. Smith et al. (2010) defined that the ideal ratio C:N for composting is between 15 and 30 units, suggesting that the quality of compostable material from Cohort 1 was slightly reduced. Anecdotally, the protected portions of the waterproof pens (front area) remained drier and less muddy during rain events, even with increased usage from the cattle.

3.4.4 Animal behaviour

Posture

Within the current study the proportion of cattle observed standing and lying was variable across observations (Figure 11a; Figure 11c) and heat load index categories (Figure 11b; Figure 11d) and typically not influenced by the different shade type. The proportion of cattle observed standing ranged between 48.5 ± 1.10 % (1500 h) and 65.2 ± 1.03 % (0800 h) across the four observation periods, however the greater proportion at 0800 h are likely to be confounded by feed intake, i.e. once daily feed offering at between 0800 h and 0900 h daily.

Within this study under cool (HLI ≤ 70) conditions 51.9 ± 0.77 % of cattle were observed standing increasing to 64.3 ± 0.67 and 60.1 ± 3.02% when conditions were categorised as hot (HLI 77.1 ≤ 86) and very hot (HLI ≥ 86). The proportion of cattle standing within the current study was comparable to those reported by Brown-Brandl et al. (2006b), although greater than those reported by (Lees et al., 2020). Brown-Brandl et al. (2006b) indicated that in feedlot heifers standing behaviour increased from 42.0 % during thermoneutral conditions to 48.1 % during periods of heat load. Similarly, Lees et al. (2020) suggests that under cool conditions approximately 41 % of cattle were observed standing and the proportion of cattle standing increased to approximate 49 % when conditions were very hot.

Feeding

Heat load conditions are well documented to have a negative impact on DMI (Beede and Collier, 1986; Ray, 1989; Hahn et al., 1992; Hahn, 1999; Brown-Brandl et al., 2005). By reducing DMI, cattle decrease metabolic heat production within the body, thus decreasing the amount of heat that must be dissipated from the body to maintain homeostasis during hot climatic conditions. Feed intake and feeding behaviours are not considered a suitable measure of thermal status as these behaviours are intermittent (Brown-Brandl et al., 2005), however patterns in feeding behaviour can be highly repeatable (Hicks et al., 1989). Unsurprisingly, in the current study the greatest proportion of cattle observed feeding occurred at 0800 h (11.93 ± 0.45 %), which was post feed delivery. This is consistent with the findings of Lees et al. (2020), concluding that the greatest observed proportion of cattle observed feeding occurred at 1600 h and 1800 h, post feeding at 1430 h. Post feed delivery, the proportion of cattle observed feeding ranged between 3.77 ± 0.48 % (1300 h) and 5.46 ± 0.46 % (1100 h) over the remaining observations (Figure 12a). Similarly, within the current study there was little variation in the proportion of cattle observed feeding across the heat load index categories (Figure 12a).

Drinking

Observation time and heat load index category had no impact on the proportion of cattle observed drinking between (Figure 13a; Figure 13b). The greatest proportion (1.83 ± 0.11%) of cattle observed drinking occurred at 1100 h. Similarly, 1.75 ± 0.08 % of cattle were observed drinking when heat load index was categorised as hot (HLI 77.1 ≤ 86). Regardless, cattle were observed drinking across all observation times and heat load index stress categories, regardless of treatment (Figure 13a; Figure 13b). The proportion of cattle observed drinking across observation and heat load index categories are lower than those reported by Lees et al. (2020), although greater than those reported by Sullivan et al. (2011). Some of the differences between the studies by Sullivan et al. (2011) and Lees et al. (2020) can be associated with the heat load experienced throughout the respective studies. However, consideration also needs to be extended to the difference in cattle numbers, breed types utilised and observation data collection protocols. Specifically, Sullivan et al. (2011), a total of 126 Angus heifers and collected animal observational data over three periods (0600 h, 1200 h and 1800 h) on days where HLI ≤ 86 and at 2 hour intervals, between 0600 h and 1800 h, on days where HLI ≥ 86. Lees et al. (2020) utilised 36 animals consisting of three breed types (Angus, Charolais and Brahman) and obtained observational data at 2 hour intervals across 154 days.

Ruminating

The proportion of cattle ruminating was variable throughout the study (Figure 14). A greater proportion of cattle were observed ruminating at 0800 h, regardless of treatment (9.23 ± 0.27 %; Figure 14a). The proportion of cattle observed ruminating decreased by 6 % between 0800 h and 1100 h, then exhibited an increasing trend between 1100 h and 1500 h (Figure 14a). Heat load index category had a limited influence on the proportion of cattle ruminating, where the differences between the proportion of cattle ruminating was < 1 % (Figure 14a). The proportion of cattle observed ruminating within the current study are comparable with those reported by (Lees et al., 2020). Young and Hall (1993) refer to 'stage 8' or animals suffering from excessive heat load experience a as a reduction of, or a complete termination of rumination. However, it is important to consider that rumination is an essential component to digestion in cattle. As previously indicated hot climatic conditions are associated with a reduced DMI intake, therefore reduced rumination is directly related to the amount of DMI consumed, rather than a direct result of heat load on rumination.

3.4.1 Shade Utilisation

Within the current study shade utilisation increase throughout the day and as heat load index category increased, regardless of shade type. There was a marked increase in shade utilisation as heat load index category increased from moderate (HLI, 70.1 ≤ 77) to hot (HLI, 77.1 ≤ 86; P ≤ 0.0001; Figure 15b). Shade utilisation was approximately 11 % greater in the waterproof treatment across observations and heat load index categories (Figure 15a; Figure 15b). Obviously, shade utilisation could only be determined for cattle within shade cloth and waterproof treatments, however shade seeking behaviours were observed in heifers within the unshaded treatment. Cattle in the unshaded treatment sought shade from various sources around the pens, specifically along fence lines, feed bunks, water troughs and other cattle. These observations are in agreement with those of Mitlöhner et al. (2001b), Castaneda et al. (2004), Gaughan and Mader (2014) and Lees et al. (2020). These observations provide further reiterate the importance of access to shade for feedlot cattle (Lees et al., 2020), and the desire to express this natural behaviour regardless of regional climate classifications. The results from the current study support the notion that feedlot cattle will utilise shade where available regardless of climate classifications, i.e. subtropical versus temperate regions. Shade type is an important consideration, shade utilisation across all observation times was greater in waterproof treatment when compared with cattle in the shade cloth treatment (*p* ≤ 0.0001; Figure 15a). For this study, this tends to suggest that there may have been an increased preference for the shade provided within the waterproof treatment. However, it is important to consider weather conditions throughout the study were mild and wet, as such a portion of the utilisation of the shade structures, particularly the waterproof, will be attributed to these mild and wet conditions.

3.4.2 Panting score

Mean panting score increased throughout the day, regardless of treatment (Figure 16a). Shade cloth, unshaded and waterproof cattle exhibited a 21.3%, 20.9 % and 16.8 % increase in mean panting score between 0800 h and 1500 h. The greatest increase in mean panting score was observed in the unshaded cattle, the maximum mean panting score was higher in the unshaded cattle (0.97 ± 1.12) when compared with cattle in the shade cloth (0.85 ± 1.07) and waterproof (0.79 ± 1.12) treatments and are suggestive that the unshaded and shaded cattle were experiencing 'high stress' (Gaughan et al., 2008). Furthermore, as heat load index category increased from cool to very hot, mean panting score of unshaded, shade cloth and waterproof cattle exhibited a mean panting score increase of 47.7%, 44.1 % and 39.8 % (Figure 16b).

The mean panting scores were comparable with previous studies, the mean panting scores when heat load index category was classified as cool (HLI ≤ 70) appear to be greater than those reported previously (Gaughan et al., 2010b; Sullivan et al., 2011). This may indicate that further investigation into the HLI, and subsequently AHL, thresholds of southern adapted cattle are needed to ensure that the HLI thresholds are appropriately describing heat load conditions for feedlot cattle in these regions. This is of importance for feedlot enterprises located in tropical and subtropical regions that are sourcing cattle from temperate regions, as these cattle may have lower HLI thresholds than previously defined.

3.4.3 Rumen temperature

Rumen temperatures were largely not influenced by providing shade, although unshaded cattle tended to have higher T_{RUM} during the afternoon hours, when compared with the shade cloth and waterproof cattle (Figure 18). This was an unexpected outcome as it does not completely agree with previous studies investigating the influence of shade on body temperature regulation (Brown-Brandl et al., 2005; Gaughan et al., 2010a; Lees et al., 2018), however this is likely due to the differences in heat load experienced across studies and in particular that the conditions throughout this study were mild. Furthermore, when considering the mean panting scores observed within this study it is probable that these elevated panting scores were able to sufficiently compensate for the heat load conditions, preventing increased in body temperature (Brown-Brandl et al., 2006a; Gaughan et al., 2008).

3.4.4 Animal performance

The provision of shade did not influence liveweight, ADG and feed conversion, when compared with the unshaded treatment. Feed intake was not influenced by shade provision within the current study, with an average DMI consumption of approximately 12 kg/hd/d, which is comparable with previous studies (Brown-Brandl et al., 2005; Sullivan et al., 2011), although greater than those of Mitlöhner et al. (2001b), Mitlöhner et al. (2002) and Gaughan et al. (2010a). In addition, Sullivan et al. (2011) showed that different shade allocation rates (unshaded, 2.0 m^2/hd, 3.3 m^2/hd, and 4.7 m^2/hd) did not influence feed intake in study conducted in south-east Queensland. There were no differences in the ADG between the unshaded and shade cloth treatments, which is in agreement with the findings of Sullivan et al. (2011). However, within the current study the waterproof treatment had ADG that were 0.16 ± 0.04 kg/d ($p \leq 0.01$) and 0.12 ± 0.04 kg/d ($p = 0.03$) greater when compared with the unshaded and the shade cloth treatments, respectively (Table 9). Although the ADG within the current study were higher than those reported by Mitlöhner et al. (2001b), Mitlöhner et al. (2002), Sullivan et al. (2011) and Lees et al. (2018). The ADG were comparable with those of Gaughan et al. (2010a), although the ADG within the current study were approximately 300g/hd/d greater than those reported in the aforementioned study. Although HGPs were not used in the studies conducted by Gaughan et al. (2010a), Sullivan et al. (2011) or Lees et al. (2018). As such the differences in growth rates between the current study and previous studies may be associated with HGP usage and cooler climatic conditions within the current study. Furthermore, it has been widely accepted that cattle are able to adapt and respond to periods of feed restriction by exhibiting compensatory growth. It is expected that heat stressed cattle are also able to compensate for growth lost during periods of hot weather. Hahn et al. (1974) concluded that heifers exposed to moderate heat stress (30.9 °C) were able to compensate for the production loss during the heat event two weeks after conditions abated. Given that a majority of the hot day occurred in the first 68 days of the study, it is possible that these cattle were able to exhibit compensatory growth prior to the conclusion of the study.

3.4.5 Carcase performance

Within the current study Dressing percentage, P8 fat, EMA, MSA Marbling, Ossification, pH_u and MSA index were not influenced by the provision of shade, regardless of shade type (Table 11), which is in partial agreement with previous studies (Mitlöhner et al., 2001b; Mitlöhner et al., 2002; Gaughan et al., 2010a). However, within the current study, the waterproof treatment had HSCW that were 7.20 ± 2.31 kg and 6.69 ± 2.31 kg heavier when compared with carcasses from the unshaded ($p = 0.02$) and shade cloth ($p = 0.03$) treatments, respectively (Table 11). Hot carcase weight of shade cloth and unshaded treatments did not differ in this study. Conversely, Mitlöhner et al. (2002) reported that hot carcass weight of shaded heifers were 7.3 kg ($p = 0.09$) heaver when compared with unshaded counterparts. Within the Australian context, Gaughan et al. (2010a) concluded that shaded Angus steers had HSCW that were 6 kg (*p* ≤ 0.05) heavier when compared with unshaded counterparts. It is also important to note that the summer was a wet summer with considerable rainfall throughout the study. Cool and wet conditions are also reported to impact the productivity and welfare of feedlot cattle (Mader, 2003, 2014). Although not reported here in detail, during rain events cattle within the waterproof treatment spent a predominant portion of their time underneath the shade/shelter structure. Anecdotally, cattle would only leave the sheltered area briefly to consume water. The waterproof pens whilst becoming wet and muddy at the rear of the pens (outside of the shade/shelter footprint) remained dry underneath the structure, thus it is possible that during the rain events the cattle within the waterproof treatment expended less energy on i) maintaining body temperature from being wet and/or muddy, and ii) walking through muddy pens, contributing to the heavier HSCW within these cattle.

3.5 Conclusion

The results from this study highlight that there are some production benefits, namely increased ADG (+ 100 g/hd/d) and greater HSCW (≤ 7 kg), by providing shade, via the waterproof structure, to cattle during summer in temperate climates. The summer was mild with persistent wet periods, it is highly probable that these production benefits are more associated with the management of wet pens rather than heat stress *per se*. However, the climatic conditions experiences throughout the study were sufficient to evoke purposeful behavioural responses and changes in panting score that were sufficient to prevent changes in body temperature. As such, additional studies in temperate climate are needed under more typical summer conditions to ascertain the true impact of shade availability for heat stress management in temperate environments. Overall, the results from the current study have shown that there are production and welfare benefits of providing shade, particularly the waterproof structure, to feedlot cattle in temperate regions. Although no production benefits were associated with the shade cloth structure, cattle in these treatment pens had improved welfare as noted via the lower mean panting score and ability to express shade seeking behaviours.

4. Winter cattle

4.1 Introduction

It has been reported that cattle that are reared in outdoor environments have maintenance energy requirements that can be between 5 and 25% greater in winter, when compared with the energy requirements of cattle during the summer (NRC, 2000), however this is dependent on geographic location and severity of both winter and summer climatic conditions. Under winter conditions, energy requirements for maintenance can easily double, particularly when cattle become wet and/or muddy and cattle are not protected from exposure to wind (Belasco et al., 2015; Mader and Griffin, 2015). For the feedlot industry, it has been described that newly received cattle and heavy cattle 30 to 45 days from slaughter, are most susceptible to cold stress. Furthermore, it is generally accepted that cattle within these categories require shelter and/or bedding to support animal wellbeing, maintain health and stay on feed during cold climatic conditions.

When winter conditions are severe, productivity is compromised as a result of increased maintenance energy requirements that are associated with exposure to cold, wet, and/or windy conditions. There are a number of strategies that can be implemented during winter to enhance animal comfort when they are exposed to these adverse conditions. Specifically, bedding, such as stubble, saw dust, or woodchips (B.FLT.0244) can be used to help insulate cattle from the cold ground during severe cold outbreaks. Providing cattle with between 1 and 2 kg of bedding per animal/day, during periods of adverse weather with muddy conditions can negate the negative impact of these conditions on productivity (Mader, 2011). A summary of data, from the US, found that growth and feed efficiencies can be improved by 5 to 10% through the use of bedding (Mader, 2003). Heavier cattle, which are closer to finish, have a greater response to bedding when compared with lighter weight cattle (Mader, 2003). However, when ample pen space is available the production and feed efficiency benefits from bedding are not as great (Mader, 2003). Studies conducted in Nebraska found that doubling normal pen space from 23.2 m^2/hd to 46.5m^2/hd during winter was as effective in improving animal comfort as using bedding (Mader and Colgan, 2007).

It is unlikely that feedlot enterprises have the capacity to double space allocations, may have an aversion to provide bedding due to cost, or experience challenges associated with providing bedding due to supply availability. However, it is becoming increasingly important that livestock production systems maintain optimum cattle comfort not only for optimizing production efficiency but also for enhancing consumer perceptions and acceptance. Keeping cattle dry, clean, and comfortable is a critical component towards achieving this. Feeding and caring for cattle in total confinement or enclosed shelter is increasingly common in some areas, although the cost to benefit ratio needs to be taken into account before utilizing this option (Mader, 2003). However, there is limited information available regarding the benefits of providing partial shelter in outdoor environments, particularly within the Australian context. As such, the objective of this study was to evaluate the impact shelter provision on the health, animal performance and carcass characteristics of feedlot cattle during winter in a southern Australian environment, without bedding.

4.2 Materials and methods

4.2.1 General methodology

This project was conducted with the approval of the University of New England's (**UNE**) animal ethics committee (AEC 20-091, see appendix 9.1), in accordance with the guidelines described by the Australian National Health and Medical Research Council (2013). The project was undertaken in the New England district of New South Wales at the UNE research feedlot 'Tullimba' (30°28 S, 151°11 E, 950 m above mean sea level), commencing during a southern hemisphere winter (July) and concluding in spring (November).

4.2.2 Animal management

A total of 480 *bos taurus* steers were used in this study. The UNE SmartFarms sourced the cattle for this experiment via a number of local stock and station agents. Cattle were sourced between April and June 2021. Upon arrival to Tullimba cattle were vaccinated for clostridial diseases (enterotoxaemia (pulpy kidney disease), tetanus, blacks disease, malignant edema, and blackleg; Websters 5-in-1, Virbac Pty Ltd, Australia, Milperra NSW), then backgrounded on pastures[2] until feedlot induction. Two weeks prior to feedlot induction cattle were vaccinated for respiratory pathogens (Bovilis MH + IBR, inactivated *Mannheimia haemolytica* and Bovine Herpes Virus Type 1; Coopers Animal Health Intervet Australia, Macquarie Park, NSW).

Cattle were randomly allocated to 12 pens of 40 head, ensuring that breed types were equally represented across each pen. On day -6, cattle were weighed to provide preliminary weight data to ensure that and pen weights were not disproportionate. Pen groups were then randomly allocated to one of two treatments: 1) unsheltered or 2) sheltered. The cattle were weighed (non-fasted) at induction (described below), day 38 (0800 h and 1200 h) and upon exit using a single animal weighing box (Ruddweigh 600mm Weigh Beam 2000kg weighing capacity, Ruddweigh, Guyra, NSW, Australia) with solid sides, and an automated readout system (Gallagher Weigh Scale readout W310 v2 to 2kg increments, Gallagher Australia, Epping, Vic, Australia). The scales were calibrated by placing 30 × 20 kg (total weight = 600kg) certified test weight, prior to weighing. On day 38 cattle were weighed in consecutive pen order, commencing at the unsheltered pens then concluding at the sheltered pens.

On day 12, the shelter structure sustained wind damaged that resulted in cattle within the six shelter treatment pens being relocated to six pens with some shelter provided by shade cloth (black, 290/300 GSM knitted Monofilament polyethylene, 80% solar block, Architex Fabric Structures, North Richmond NSW, Australia) that provided a shade footprint of 2.78 m^2/hd (8.9 m × 12.5 m) at midday. Cattle remained in these pens until day 40, where on day 38 cattle were weighed and pens were randomly reallocated to treatments, where three pens that had initially been allocated to shelter were reallocated to unsheltered pens and three unsheltered pens were reallocated to sheltered pens. Pens that remained within the same treatment were reallocated to a new home pen, this was done to ensure that all cattle experienced a change in home pen and as such experienced a relocation event.

4.2.3 Health management

Cattle were monitored daily for health ailments. Any cattle that were treated for acute health concerns, i.e. footrot, were walked to the hospital pen, treated and returned to their home pen for monitoring. For more chronic health aliments, cattle that were pulled from their home pens and relocated to hospital pens for treatment and recovery, cattle that recovered within 4 days were returned to their home pens. Cattle that had not recovered after 4 days were removed from the study. All treatments were noted with their diagnosis and treatment. For mortality events, necropsies were conducted by veterinarian or UNE SmartFarm staff, as per the UNE SmartFarm autopsy protocol.

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[2] Rye grass (*Lolium perenne*); spear grass (*Heteropogon contortus*); corkscrew grass (*Austrostipa scabra*); Phalaris (Phalaris aquatica); prairie grass (*Bromus stamineus*); cocksfoot (*Dactylis glomerate*); Barley grass (*Hordeum glaucum, Hordeum leporinum*); tussock (*Poa labillardierei*); Clover (*Trifolium spp.*); Medics and (*Medicago spp.*)

4.2.4 Feedlot induction

Steers were inducted into the feedlot over two days, day -1 (5th July 2021) and day 0 (6th July 2021). At induction cattle were vaccinated for clostridial diseases (enterotoxaemia (pulpy kidney disease), tetanus, blacks disease, malignant edema, and blackleg; Websters 5in1, Virbac Pty Ltd, Australia, Milperra NSW) and respiratory pathogens (Bovilis MH + IBR, inactivated *Mannheimia haemolytica* and Bovine Herpes Virus Type 1; Coopers Animal Health Intervet Australia, Macquarie Park, NSW). Cattle were also treated for internal (Exifluke ® 240, 240g/L triclabendazole, Bayer Animal Health, Australia, Pymble NSW) and external parasites (Dectomax, doramectin 0.5% w/v, Zoetis Australia, Silverwater, NSW); and received a hormonal growth promotant (Component TE-200, 20 mg oestradiol 17β + 200 mg trenbolone acetate, Elanco, West Ryde, NSW).

4.2.5 Nutritional management

Cattle were gradually adapted (Table 12) to a total mixed ration finisher diet (Table 13), with a targeted DM % between 73 % and 79 % depending on the ration type. All rations were based on tempered barley, commencing at 38.5 % (as-fed basis) for the prestart ration and gradually increasing to 83 % (as-fed basis) for the finisher ration (Table 12; Table 13). Cattle were fed as a pen, once per day, at 0800 h. Feed was mixed and delivered in a Rotomix TMR 4610 mixer (1 kg scale resolution) over two or three batches per day, depending on ration and pen consumption. Cattle were fed to meet the intake of the previous day's ration using a bunk management protocol modified from Lawrence (1998). A daily grab sample was collected from each pen and batched into a daily per cohort sample. A 200 g sample of the daily feed was collected and analysed, in duplicate, for dry matter content by oven-drying at 80 °C for 36 h.

Table 12. Feeding protocol for adapting cattle to grain-based finisher ration

Ration Type	Grain Content, % as-fed basis	Days fed
Prestart	38.5	0 to 7
Start 1	45.5	8 to 12
Transition 1	60.0	13 to 18
Transition 2	68.0	19 to 22
Finisher	83.0	23 to exit

Table 13. Formulated ingredient and nutrient composition of the diets

Item	Prestart	Start 1	Transition 1	Transition 2	Finisher
Ingredient[1]					
Barley, tempered	385	455	600	680	830
Oat hay	200	130	80	50	**0**
Millrun	120	120	80	40	**0**
Water	120	120	90	60	**0**
Cottonseed, high lint	80	80	80	80	80
Wheat straw	60	60	60	45	35
Supplement	35	35	40	45	55
Formulated Nutrient Analysis[2]					
DM, %	73.82	72.98	74.49	75.87	79.48
Protein, %	13.84	14.23	14.4	14.65	14.94
Eq Prot, %	0.62	0.62	0.68	0.77	0.9
ME, MJ/kg	11.1	11.38	11.68	11.95	12.26
NEm, Mcal/kg	1.74	1.8	1.88	1.94	2.01
Neg, Mcal/kg	1.12	1.18	1.24	1.3	1.37
NDF, %	38.72	35.03	30.65	27.24	22.66
eNDF, %DM	26.65	22.44	18.28	15.09	10.64
Fat, %	4.49	4.49	4.26	4.17	3.95
Vit A, KIU/kg	1.66	1.68	1.82	2.08	2.42
Vit E, IU/kg	10.67	10.79	11.73	13.34	15.57
Calcium, %	0.61	0.59	0.61	0.66	0.74
Phosphorus, %	0.43	0.45	0.43	0.42	0.41
Monensin, ppm	15.65	15.83	17.2	19.57	22.83

[1] per 1000 kg, as-fed basis

[2] Formulated nutrient analysis on 100% DM basis

4.2.6 Feedlot description

A total of 12 pens (500 m^2; 40 m long × 12.5 m wide) within UNE research feedlot “Tullimba” were used. Six unsheltered and six sheltered pens were used. The unsheltered and sheltered pens were separated by six pens that had shade cloth over the front section of the pens that provided a shade footprint of 2.78 m^2/hd (8.9 m × 12.5 m) at midday. The pens were situated in a north-south alignment. Pen surface was soil over gravel and pens had a 5 % slope from the feed bunks towards the rear of the pens (east). Feed bunks were concrete and had a 3 m concrete apron located at the front of each pen (west). Stocking density was 12.5 m^2/animal. Each feed bunk provided a bunk space allocation of 31.25 cm/hd and the water trough (3 m long × 0.5 m wide) was shared between two pens.

4.2.7 Shelter structure

For the shelter treatment, shelter was provided by and a waterproof polyethylene material (white, 340 GSM, high UV, Architex Fabric Structures, North Richmond NSW, Australia) respectively (Figure 19). The waterproof material was attached, via a cabling system, to an angled structure which was 4.5 m at the lowest point and 5.8 m at the highest point. The waterproof material was fixed to both the front and back sections of the truss structure which also extended over the feed bunk. In addition, there was a 500 mm gap in the peak between front and back sections of the truss structure to encourage air flow. Therefore, the shelter provided a coverage of 4.22 m^2/hd (12.5 × 13.5 m).

Figure 19. A and B show the shelter structure over the Tullimba research feedlot pens

4.2.8 Rumen temperature

Rumen temperature (**T_{RUM}**, °C) were obtained from five Angus, five Charolais and five Hereford steers from each pen, thus T_{RUM} were obtained from a total 180 steers over the duration of the study. Rumen boluses (smaXtec, Bolus TX-1442A, smaXtec animal care GmbH, Austria) were orally administered at induction. Rumen temperature boluses were cylindrical (3.4 cm diameter × 10.5 cm in length) and weighed approximately 205 g. Rumen temperatures were recorded at 10 min intervals for the duration of the study. Rumen temperature data were communicated to a base station (smaXtec Base Station, smaXtec animal care GmbH, Austria), these data were then transmitted to a data server and stored in an online database (messenger.smaxtec.com) until downloaded for analysis.

4.2.9 Climatic conditions

Weather data were collected at 10 min intervals using an automated onsite weather station (atmos41 weather station, METER Group Inc., Pullman, WA, United States). Weather data included ambient temperature (T_A; °C), relative humidity (RH; %), wind speed (WS; m/s) and direction, solar radiation (SR; W/m^2), black globe temperature (BGT; °C) and 24 h daily rainfall (measured at 0900 h). From these data temperature humidity index (THI), comprehensive climate index (CCI) were calculated. The THI was calculated using the following equation adapted from Thom (1959):

$$THI = 0.8 \times T_A \left\lfloor \left(\frac{RH}{100} \times (T_A - 14.4)\right\rfloor + 46.4$$

Where RH = Relative Humidity (%) and T_A = wet bulb or dew point temperature

The Comprehensive Climate Index can be calculated as follows as described by Mader et al. (2010);

$$CCI = T_A + Eq.[1] + Eq.[2] + Eq.[3]$$

Where;

Equation [1] presents a correction factor for relative humidity;

$$= e^{(0.00182 \times RH + 1.8 \times 10^{-5} \times Ta \times RH)} \times (0.000054 \times T_A^2 + 0.00192 \times T_A - 0.0246 \times (RH - 30)$$

Equation [2] presents a correction factor for wind speed;

$$= \left[\frac{-6.56}{e\left\{\frac{1}{(2.26 \times WS + 0.23)^{0.45 \times \langle 2.9 + 1.14 \times 10^{-6} \times WS^{2.5} - LOG_{0.3}(2.26 \times WS + 0.33)^{-2} \rangle}}\right\}} \right] - 0.00566 \times WS^2 + 3.33$$

Equation [3] presents a correction factor for solar radiation;

$$0.0076 \times RAD - 0.00002 \times RAD \times T_A + 0.00005 \times T_A^2 \times \sqrt{RAD} + 0.1 \times Ta - 2$$

Where e = natural log; RH = relative humidity (%); T_A = ambient temperature (°C); WS = wind speed (m/s); and RAD = solar radiation (W/m^2)

The CCI was used to provide an indicator of exposure to cold stress conditions where the CCI was categorised into six stress categories: (1) No stress, CCI ≥ 0; (2) Mild, CCI 0 ≤ -10.0; (3) Moderate, CCI -10.1 ≤ -20.0; (4) Severe, CCI -20.1 ≤ -30.0; (5) Extreme, CCI -30.1 ≤ -40.0; and (6) Extreme danger, CCI ≤ -40.1 as described by Mader et al. (2010).

4.2.10 Pen microclimates

Pen microclimates, specifically ambient temperature (**T_A**; °C), relative humidity (**RH**; %), were recorded at 10 min intervals (HOBO ProV2, U23-001, Onset Computer Corporation, USA). Two T_A and RH data loggers were position 2 m above the pen surface in every second pen, thus there were six T_A and RH data loggers per treatment. Data loggers were positioned 5 m from the feed bunk and 5 m from the back of the pens, this meant that data loggers placed at the front of the pens so the microclimate benefits from the shelter treatments could be evaluated. From these data within pen THI was calculated using the equation adapted from Thom (1959) described above.

4.2.11 Pad conditions

Pad samples and moisture

Due to the COVID-19 pandemic, one pad sample was collected on exit, day 120, within this study. Pad samples were collected from four positions within each individual pen: 1) front, 5 m from the feed bunk; 2) middle, 2 m above of the water troughs; 3) back, 5 m from the back of the pens; and 4) very back of the pens, adjacent to the laneway. Pad sample positions 1 and 3 were in alignment with the pen microclimate T_A and RH data loggers. Three pen surface samples were collected from each the four aforementioned positions and were homogenised with a hand trowel, and a subsample was obtained for each of the four positions across the individual pens. The depth from the surface to interface layer was measured (cm) on the left, middle and right sections of the pens from the four aforementioned pen positions. Pad samples were frozen (-4 °C) until sample moisture could be determined. For pad moisture, samples were thawed to room temperature (≈ 24 °C) and then dried at 105 °C, until there was no change in the sample weight. From these data moisture content was calculated using the following formula: change in weight (wet-dried) divided by initial sample weight x 100. Samples were ground until a homogenous sample was obtained, these samples were then analysed, in duplicate, for moisture, volatile solids (VS), carbon (C) and nitrogen (N) content. For VS, C and N, a 30 g subsample sample was obtained and immediately placed on ice, and frozen at -4 °C. These samples were freeze dried at -50 °C for a 7 day period (Alpha1-4 LDplus, Martin Christ Freeze Dryers, Osterode, Germany). Samples were then split to obtain homogenous material for VS, C and N analysis.

Volatile solids

Volatile solids were determined following standard methods (APHA 2540E, 2000), the clean crucible was placed in a 550 °C muffle furnace for 10 minutes, cooled in a desiccator, then 2 g of sample was loaded in crucible and placed in 550 °C muffle furnace. The furnace gradually came to temperature allowing the sample to 'burn off', allowing complete combustion of the sample. The sample was removed and cooled in desiccator and weighed, and the process was repeated until the change was less than 5% difference in weight.

Carbon and nitrogen

For C and N, a 0.15 to 0.20 g of ground sample was weighed to four decimal places and analysed for C and N content via combustion (TruMac determinator; LECO Corporation, St Joseph, MI, USA).

4.2.12 Exit, lairage and slaughter

On day 120 cattle exited the feedlot and were transported to a commercial abattoir located in the New South Wales Northern Tablelands (Bindaree Beef, Bindaree Food Group, Inverell, NSW, Australia) the day prior to slaughter. Cattle were transported to the commercial abattoir via 8 × B double trucks, meaning that some pens were split across trucks (Table 14). To avoid treatment bias treatments were allocated to trucks so that an equal number unsheltered and sheltered pens were split across trucks. To ensure they were slaughtered within their pen groups, cattle were consigned across 12 National Vendor Declarations (**NVD**), that also represented their slaughter groups. Upon arrival at the abattoir cattle were unloaded into receival yards, prior to washing and subsequent lairage in holding pens, as per abattoir protocol.

Table 14. Transportation configuration and slaughter group allocations for winter cattle

Truck	Trailer	Treatment	Pen
1	A	20 hd × Unsheltered	16
	B	40 hd × Unsheltered	15
2	A	20 hd × Sheltered	32
	B	40 hd × Sheltered	31
3	A	20 hd × Unsheltered	16
	B	40 hd × Unsheltered	17
4	A	20 hd × Sheltered	32
	B	40 hd × Sheltered	30
5	A	20 hd × Unsheltered	18
	B	40 hd × Unsheltered	19
6	A	20 hd × Sheltered	29
	B	40 hd × Sheltered	28
7	A	20 hd × Unsheltered	18
	B	40 hd × Unsheltered	20
8	A	20 hd × Sheltered	29
	B	40 hd × Sheltered	27

4.2.13 Adrenal gland collection and carcase evaluations

Hot standard carcass weight (**HSCW**, kg) was determined once the carcasses were dressed and prior to chilling as per AUS-MEAT carcass standards (AUS-MEAT Limited, 2005). Adrenal glands were also obtained from all carcasses prior to chilling at the abattoir. Adrenal glands were chilled and returned to UNE the day after slaughter and were dissected and denuded of all external fat and weighted individually to the nearest 0.001 g.

Post-chilling, carcasses were evaluated by two independent accredited Meat Standards Australia (**MSA**) graders (Meat Standards Australia, 2007). All carcases were evaluated for hump height (mm); fat colour; meat colour; MSA marbling score; rib fat depth (mm); ossification score; ultimate pH (**pH_u**); eye muscle area (**EMA**, cm^2). Hump heights were measured using a 5 mm graduated metal ruler, and is used within the MSA program as an estimation of *Bos indicus* content (Meat Standards Australia, 2007; Watson et al., 2008). Fat colours were determined against the AUS-MEAT fat colour reference standards against the intermuscular fat positioned laterally to the rib eye muscle using a 0 (white) to 9 (deep yellow) scale (AUS-MEAT Limited, 2005). Similarly, meat colour was evaluated using the AUS-MEAT colour reference standards on the bloomed rib eye muscle (*longissimus thoracis et lumborum*) using a 1 (light pink) to 7 (deep purple) scale (AUS-MEAT Limited, 2005). MSA marbling score was evaluated as described by the MSA reference standards at the quartering site of chilled carcasses and was estimated by evaluating the amount and distribution of marbling fat deposited between individual fibres, on a scale ranging from 100 to 1100 (Romans et al., 1985; AUS-MEAT Limited, 2005; Meat Standards Australia, 2007). Rib fat depth was measured using a graduated metal ruler, at the quartering site positioned between the 12th and 13th rib (AUS-MEAT Limited, 2005). Ossification score was determined a scale between 100 and 590 in accordance with the guidelines described by the United States Department of Agriculture (Romans et al., 1985). Ossification score is an assessment of physiological age of a bovine carcass, based on the calcification of the spinous processes in the sacral, lumbar and thoracic vertebrae (AUS-MEAT Limited, 2005). Ultimate pH and loin temperature were measured in the rib eye muscle (*longissimus thoracis et lumborum)* at the time of carcase grading. Carcass temperature and pH were measured using an MSA approved temperature and pH probes (TPS MC-80 or TPS WP-80M pH Meter, TPS Pty Ltd., Springwood, Brisbane, Qld, 4127, Australia). Eye muscle area was determined for each carcase by measuring the *longissimus thoracis et lumborum* at the quartering site using a standardised grid (AUS-MEAT Limited, 2005). Carcase grading data was then used to calculate an MSA index value as described by McGilchrist et al. (2019) to estimate the predicted eating quality of each carcase.

4.2.14 Statistical Analysis

All data exploration and statistical analyses were conducted in R (R Core Team, 2019). Data merging and manipulation, data visualizations and summary data were conducted using the 'dplyr' (Wickham et al., 2019b), 'ggplot2' (Wickham et al., 2019a) and 'table1' (Rich, 2018) packages respectively.

Data Management

Due to the interruption associated with wind damage to the shelter structure all data obtained between day 0 and day 38 have been excluded, as such data pertaining from day 38 to day 120 are reported herein. However, for pen microclimate consists of data obtained between day 54 and day 120, as there were some delays gaining access to the research site associated with the COVID-19 pandemic.

Data exclusions

Data from 10 steers were excluded from analysis. One steer from the unsheltered treatments was removed from the study on day 2 for inappetence and an additional six steers were removed due to inappetence on day 10, five of these steers were from the sheltered treatment and one from the unsheltered pens. One steer from the sheltered treatment was removed from the study on day 58 due to chronic lameness from a foot abscess that failed to recover post treatment. One steer from the unsheltered treatment was removed on day 94 due bovine respiratory disease. And one steer from the unshaded treatment died on day 118, of suspected clostridial disease. Thus, data pertaining to these animals were adjusted and removed accordingly from the statistical analysis.

Animal performance and carcase traits

Data collected throughout the project was used to determine dry matter intake (**DMI**), average daily gain (**ADG**, kg/d), gain to feed ratio (**G:F**) and adjusted final liveweight (**Final LW$_{adj}$,** kg). Dry matter intake was measured on a per pen basis and reported as kg DMI/head.day. Average daily gains were determined for each individual from day 38 to exit. Gain to feed (G:F) was determined using the cumulative liveweight gain per pen (kg/head.day) divided by the cumulative feed intake per pen (kg DM/head.day) between day 38 to exit. Adjusted liveweight was calculated by dividing individual HSCW by the mean dressing percentage for cattle. Relative adrenal weight (g per 100 kg HSCW) was calculated from the heaviest adrenal gland weight (g) x 100 divided by HSCW (kg) as described by Wilson et al. (2002). The aforementioned data were then modelled using a linear mixed effects model from the 'lme4' package (Bates et al., 2019) and estimated marginal means were generated using the 'emmeans' package (Length, 2019). The model included treatment as the fixed effect.

Rumen temperature

Ten minute T_{RUM} were aggregated to hourly temperature by averaging over the 10 minute observations. Linear mixed effects models were estimated with T_{RUM} as the dependent variable and treatment, date, hour of day and treatment × hour interactions as fixed effects and animal ID as random effect. The dependence structure in the time series was accounted for with a first order autocorrelation. For Phase 1, the estimated autoregression parameter was 0.392 across 167 animals (82 sheltered and 85 unsheltered). In contrast Phase 2 had a much lower autoregression parameter of 0.243 across 102 animals (15 sheltered and 87 unsheltered). The imbalance during Phase 2 was due to substantial missingness of data was due to persistent data connectivity issues.

Pen microclimate

For each data collection phase, 10 minute T_A, RH and THI data logger data were initially converted to an hourly means. Hourly T_A, RH and THI microclimate data were then analysed using a first-order autoregressive repeated measures model. The model incorporated treatment, logger position within pen, day, hour, treatment × position, treatment × hour and treatment × position × hour as fixed effects and pen was included as the random effect.

Pad conditions

Pad measures were analysed using a linear mixed effects model incorporating treatment, position within pen and treatment × position as fixed effects and pen was included as the random effect.

4.3 Results

4.3.1 Climatic conditions

The weather conditions throughout the study were mild and cool with average T_A remaining below 20 °C, and 262.6 mm of rainfall which occurred on 42 days throughout the study. Mean hourly weather conditions are presented below in Table 15. During the study, the CCI ranged between -6.1 and 42.8. There were 31 days where CCI was classified as mild (CCI, 0 ≤ -10.0; Figure 20).

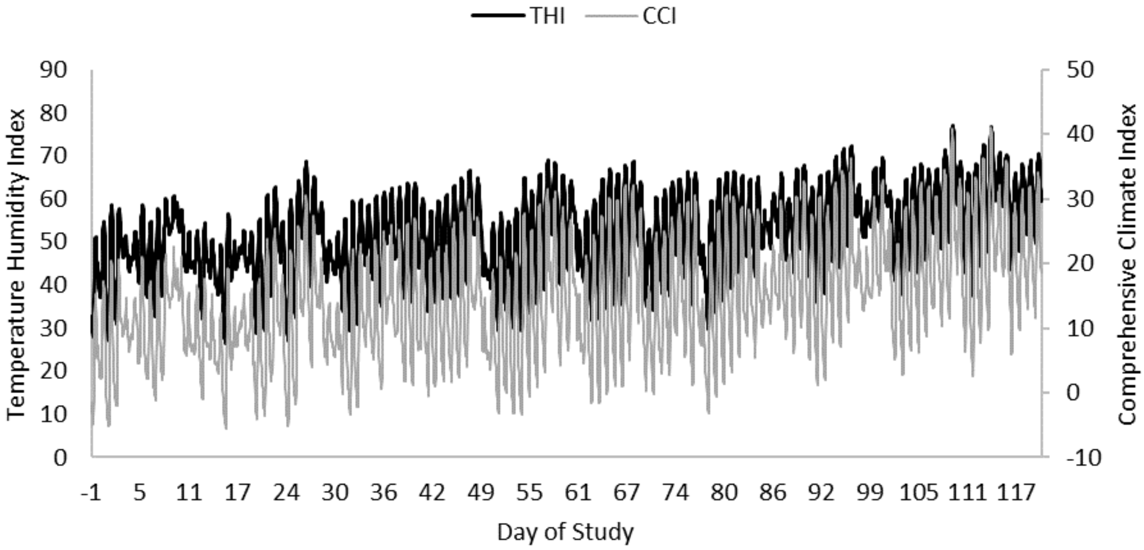

Figure 20. Comprehensive climate index (grey line) and temperature humidity index (black line) over 120 days

Table 15. Mean (± SD) hourly ambient temperature (T_A,°C), relative humidity (RH, %), wind speed (WS, m/s), solar radiation (SR, W/m2), black globe temperature (BGT, °C), temperature humidity index (THI) and comprehensive climate index (CCI) over the study period

Hour	T_A	RH	WS	SR	BGT	THI	CCI
0000	7.40 ± 4.28	84.76 ± 8.16	1.60 ± 1.22	0.00 ± 0.00	5.80 ± 4.45	46.33 ± 7.19	6.82 ± 5.84
0100	6.76 ± 4.27	86.84 ± 7.24	1.46 ± 1.05	0.00 ± 0.00	5.27 ± 4.49	45.14 ± 7.22	5.90 ± 5.76
0200	6.31 ± 4.29	88.34 ± 6.73	1.48 ± 1.11	0.00 ± 0.00	4.87 ± 4.58	44.28 ± 7.33	5.31 ± 5.85
0300	5.88 ± 4.39	89.76 ± 5.94	1.36 ± 0.96	0.00 ± 0.00	4.52 ± 4.62	43.43 ± 7.52	4.64 ± 6.00
0400	5.51 ± 4.43	90.78 ± 5.52	1.39 ± 1.04	0.00 ± 0.00	4.18 ± 4.70	42.74 ± 7.65	4.18 ± 6.06
0500	5.33 ± 4.57	91.55 ± 5.37	1.41 ± 1.08	5.62 ± 18.09	4.43 ± 5.16	42.33 ± 7.94	3.98 ± 6.22
0600	5.70 ± 4.93	92.03 ± 5.68	1.51 ± 1.21	53.19 ± 76.00	7.59 ± 7.80	42.92 ± 8.57	4.90 ± 6.97
0700	7.33 ± 5.23	91.25 ± 7.72	1.73 ± 1.41	164.97 ± 132.77	13.34 ± 8.82	45.66 ± 9.11	8.00 ± 7.76
0800	9.66 ± 5.13	87.80 ± 10.98	2.21 ± 1.72	314.32 ± 178.52	18.85 ± 8.04	49.63 ± 8.89	12.46 ± 7.98
0900	12.06 ± 4.91	80.51 ± 13.76	2.94 ± 1.95	449.74 ± 203.50	22.02 ± 7.29	53.73 ± 8.13	17.00 ± 7.70
1000	14.01 ± 4.73	72.59 ± 15.16	3.46 ± 1.92	539.53 ± 224.79	23.62 ± 7.19	56.88 ± 7.34	20.41 ± 7.29
1100	15.39 ± 4.68	66.30 ± 15.70	3.73 ± 1.81	595.09 ± 222.44	25.22 ± 7.08	58.95 ± 6.89	22.66 ± 6.93
1200	16.31 ± 4.77	61.45 ± 16.07	3.84 ± 1.71	582.67 ± 218.72	25.93 ± 7.34	60.17 ± 6.77	23.68 ± 6.78
1300	17.01 ± 4.74	57.80 ± 15.31	3.97 ± 1.70	529.39 ± 189.08	26.21 ± 7.19	61.10 ± 6.53	24.12 ± 6.50
1400	17.30 ± 4.79	55.79 ± 15.25	3.91 ± 1.69	428.18 ± 166.25	25.82 ± 7.17	61.42 ± 6.52	23.61 ± 6.38
1500	17.19 ± 4.88	55.59 ± 15.51	3.73 ± 1.58	303.50 ± 132.80	24.71 ± 7.50	61.24 ± 6.68	22.45 ± 6.45
1600	16.71 ± 4.85	55.90 ± 15.40	3.37 ± 1.47	155.41 ± 89.44	21.99 ± 6.96	60.60 ± 6.63	20.59 ± 6.07
1700	15.22 ± 4.83	58.79 ± 14.79	2.49 ± 1.35	30.45 ± 34.27	15.64 ±5.70	58.65 ± 6.76	17.36 ± 5.89
1800	13.34 ± 4.43	63.50 ± 14.00	1.94 ± 1.25	0.96 ± 3.63	11.40 ± 4.47	56.12 ± 6.48	14.46 ± 5.36
1900	11.83 ± 4.09	68.69 ± 12.36	1.71 ± 1.12	0.00 ± 0.00	9.78 ± 4.27	53.93 ± 6.21	12.51 ± 5.17
2000	10.66 ± 4.09	72.74 ± 11.74	1.62 ± 1.21	0.00 ± 0.00	8.67 ± 4.38	52.09 ± 6.40	10.96 ± 5.31
2100	9.70 ± 4.10	76.63 ± 10.92	1.50 ± 1.02	0.00 ± 0.00	7.81 ± 4.41	50.45 ±6.55	9.69 ± 5.40
2200	8.89 ± 4.15	79.93 ± 9.75	1.50 ± 0.95	0.00 ± 0.00	7.10 ± 4.46	49.04 ± 6.76	8.71 ± 5.50
2300	8.19 ± 4.21	82.37 ± 9.07	1.47 ± 0.99	0.00 ± 0.00	6.45 ± 4.50	47.78 ± 6.96	7.78 ± 5.69

4.3.2 Pen microclimates

Ambient temperature

There were no differences in T_A between the unsheltered and sheltered pens ($p = 0.85$), nor was T_A influenced by position within treatments ($p \geq 0.77$; Figure 21) or position across treatments ($p \geq 0.82$) where the average T_A at the front and back regions of the unsheltered treatment were 14.11 ± 0.29 °C and 14.44 ± 0.27 °C and in the sheltered treatment were 14.45 ± 0.30 °C14.22 ± 0.30 °C (Figure 21). The front of the unsheltered pens were 1.85 ± 0.37 °C, 1.85 ± 0.37 °C, 1.64 ± 0.37 °C and 1.59 ± 0.37 °C lower at 0800 h, 0900 h, 1300 h and 1400 h ($p \leq 0.04$; Figure 21).

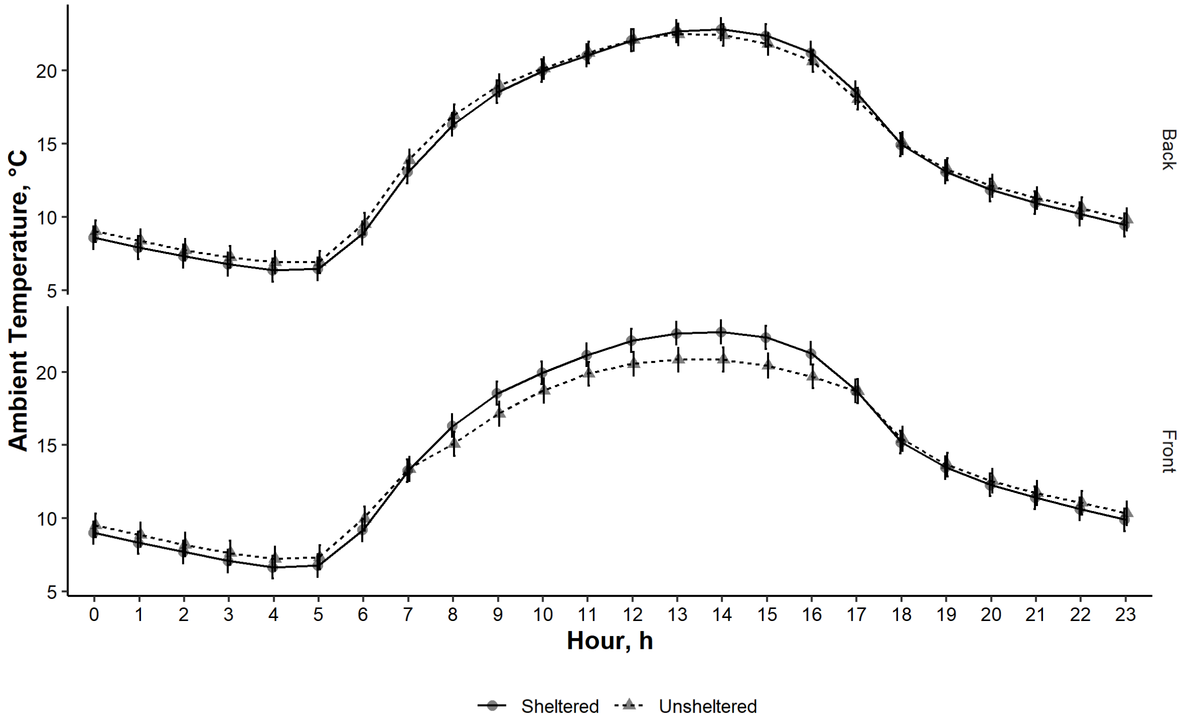

Figure 21. Average hourly ambient temperature (T_A, °C; emmean ± 95% confidence interval) at the front and back in unsheltered and sheltered pens during between day 54 and day 120

Relative humidity

Relative humidity was not influenced by shelter provision ($p \geq 0.35$), or pen position provision ($p \geq 0.46$; Figure 22). However, RH at the front of the unsheltered pens were 5.85 ± 1.15 % and 5.65 ± 1.14 % greater when compared with the back of the pens at 0800 h and 0900 h ($p \leq 0.003$; Figure 22).

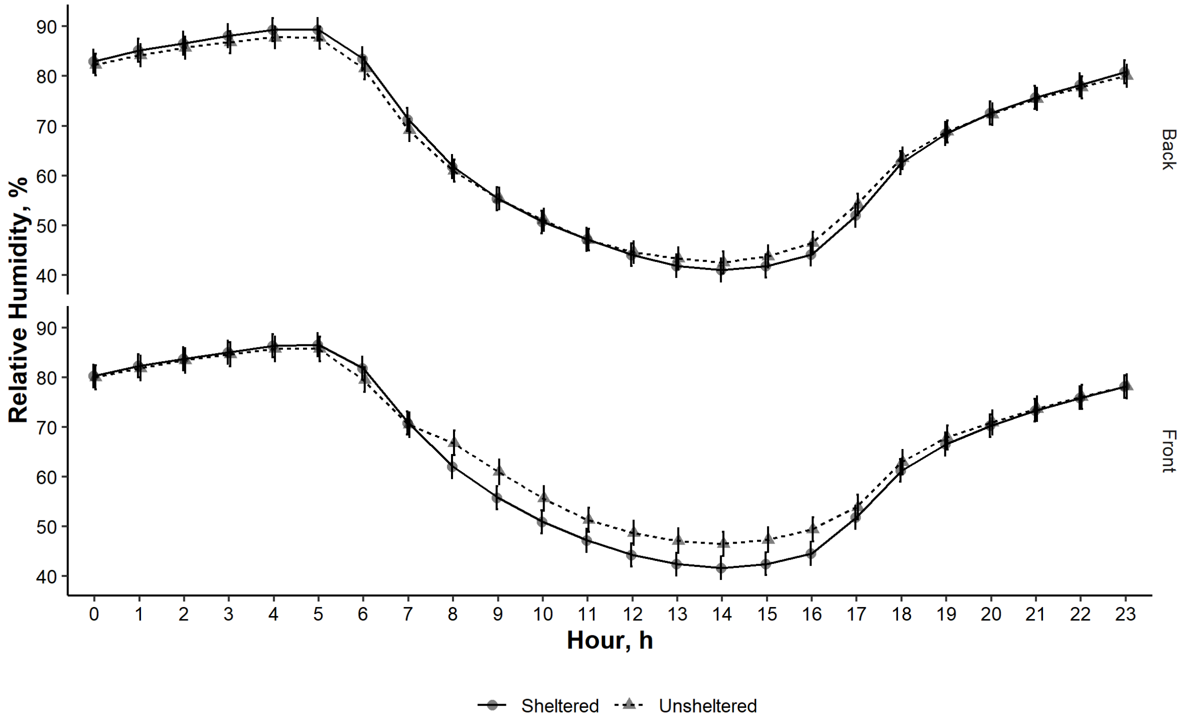

Figure 22. Average hourly relative humidity (RH, %; emmean ± 95% confidence interval) at the front and back in unsheltered and sheltered pens during between day 54 and day 120

Temperature Humidity Index

Within pen THI was no influenced by shelter provision (p = 0.73), position within pens (p = 0.93), treatment × position (p ≥ 0.80), or treatment × position × hour (p ≥ 0.1; Figure 23). However, there were differences in the THI obtained front the unsheltered pens when compared with the back of the pens, where the THI was 2.68 ± 0.55 and 2.40 ± 0.54 units higher at the back of the pens at 0800 h and 0900 h (Figure 23).

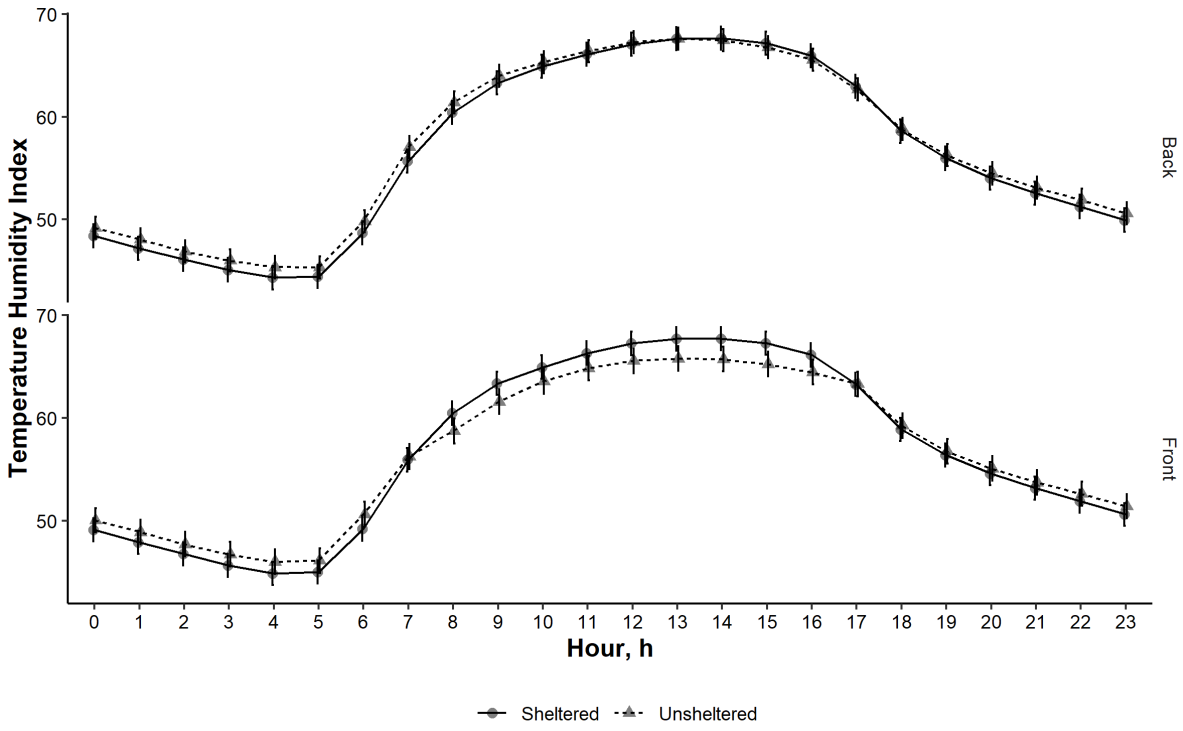

Figure 23. Average hourly temperature humidity index (THI; emmean ± 95% confidence interval) at the front and back in unsheltered and sheltered pens during between day 54 and day 120

4.3.3 Pad conditions

Pad moisture

Pad dry matter was not influenced by treatment (*p* = 0.32; Figure 24). However, pad dry matter was influenced by position within pen, where the front of the pens had a pad dry matter that were 11.09 ± 2.78 % and 15.95 ± 2.78 % greater when compared with the back and end pen positions ($p \leq 0.002$; Figure 24). In addition, dry matter in the middle pen position was 9.26 ± 2.78 % and 14.12 ± 2.78 % higher when compared with the with the back and end pen positions ($p \leq 0.01$; Figure 24). This trend persisted within treatment where within the unsheltered and sheltered treatment the pad dry matter at the front and middle pen position were greater when compared with the back and end pen positions ($p \leq 0.04$; Figure 24).

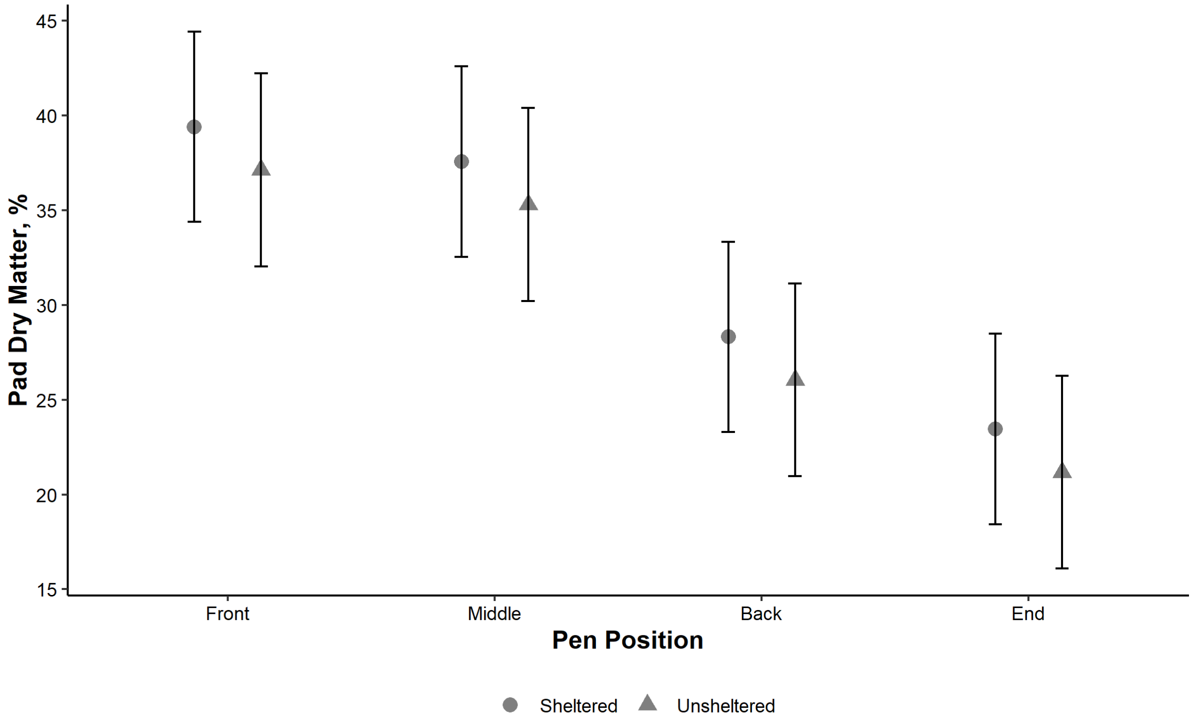

Figure 24. Pad dry matter (DM, %; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unsheltered and sheltered pens on exit

Carbon and nitrogen

Pad total carbon was influenced by treatment, where on average the total carbon in the unsheltered pens was 5.79 ± 1.25 % higher when compared with the sheltered treatment (*p* = 0.0009; Figure 25a). This difference was reflected across the four pad sampling positions where the total carbon was approximately 5 % greater in the unsheltered pens when compared with the sheltered pens (*p* = 0.01; Figure 25a). Similarly, pad total nitrogen was greater in the unsheltered treatment pens when compared with the sheltered pens (*p* ≤ 0.0001; Figure 25b). Pad total nitrogen was approximately 0.38 % lower in the sheltered pens when compared with the unsheltered pens, regardless of pen position (*p* ≤ 0.007; Figure 25b). The total nitrogen at the front of the pens positions were approximately higher when compared with the back position in both treatments (*p* = 0.017) and end pen position within the sheltered treatment (*p* = 0.044; Figure 25b). The C:N was not different between the treatments or position within pen, nor were there treatment × pen position differences (*p* ≥ 0.05; Figure 26).

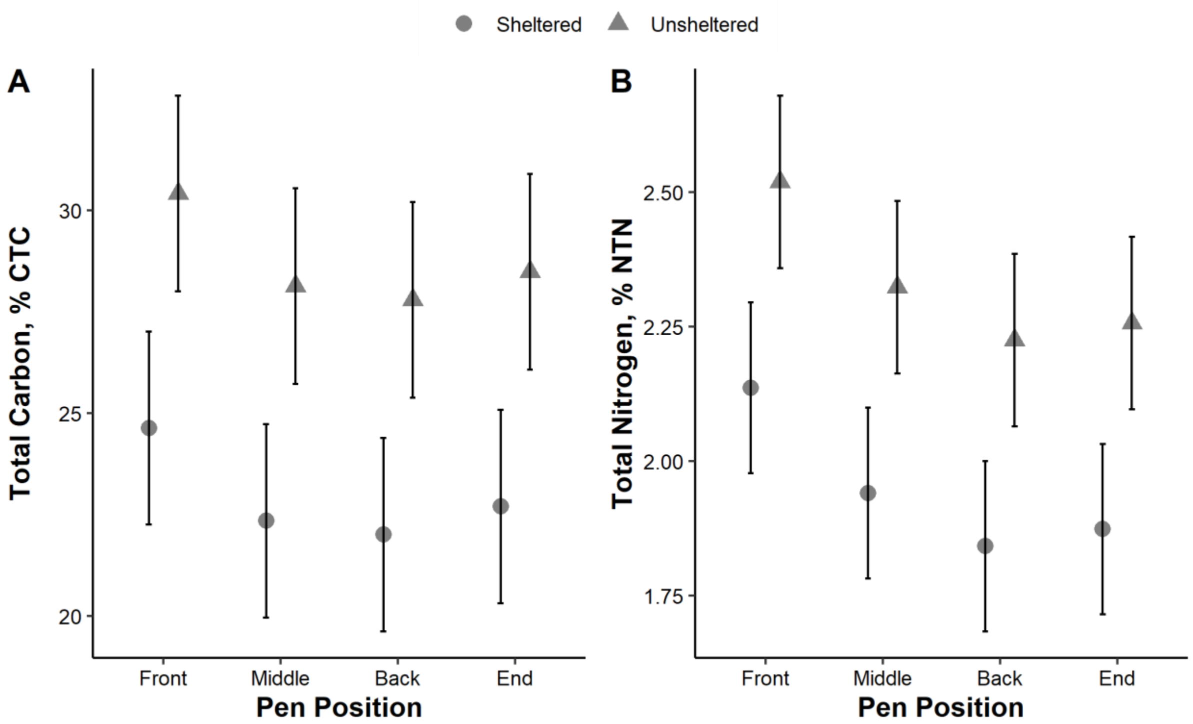

Figure 25. Pad A) total carbon (% C_{TC}; emmean ± 95% confidence interval) and B) total nitrogen (% N_{TN}; (emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unsheltered and sheltered pens on cattle exit.

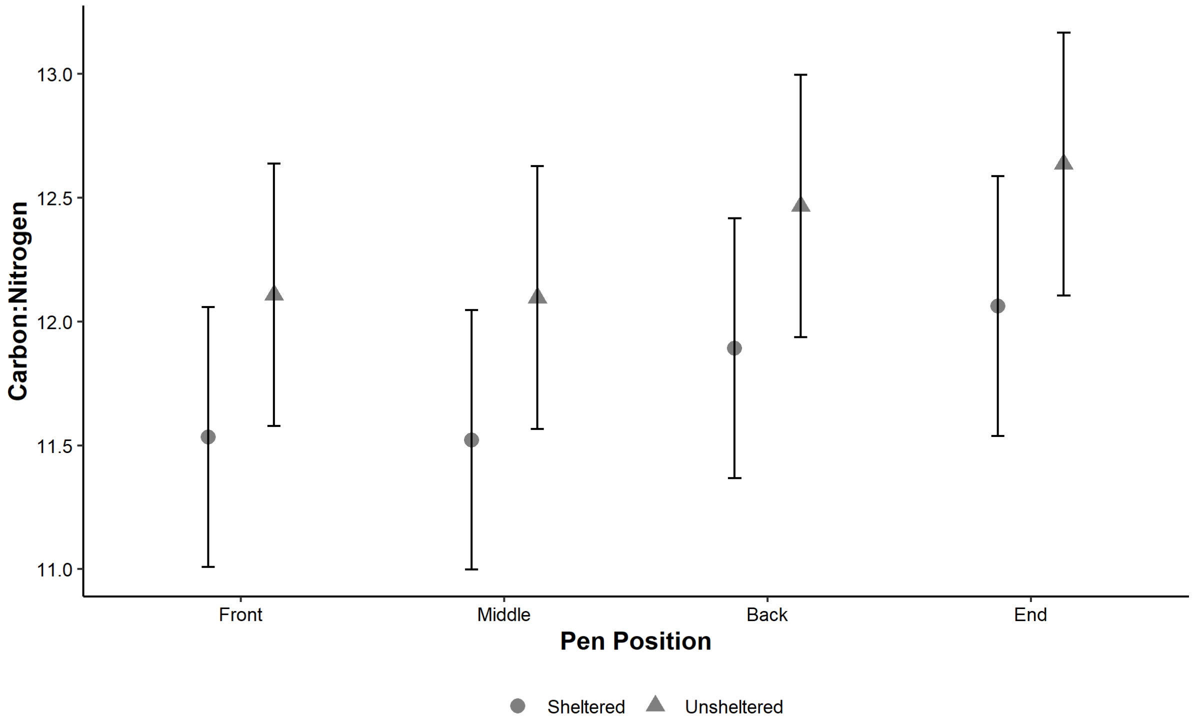

Figure 26. Pad total carbon to total nitrogen (C:N; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unsheltered and sheltered pens on cattle exit.

Volatile Solids

The volatile solid content of the sheltered pens was on average 11.47 ± 2.95 % lower when compared with the unsheltered pens, regardless of position within pen ($p \leq 0.04$; Figure 27). Volatile solids were also influenced by pen position where middle, back and end sections of the pen were 8.97 ± 2.28, 7.25 ± 2.28 and 5.78 ± 2.28 lower when compared with the front of the pen ($p \leq 0.07$; Figure 27).

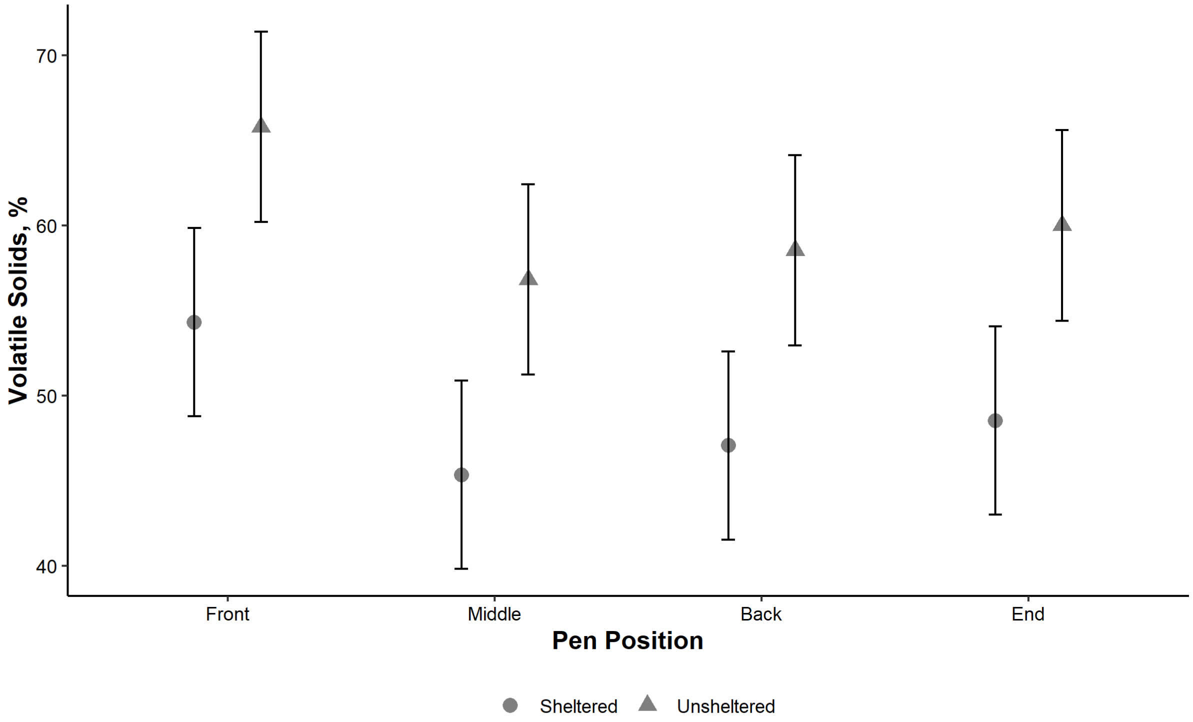

Figure 27. Pad volatile solids (%; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unsheltered and sheltered pens on cattle exit.

Pad depth

Pad depth on the left side of the pens was influenced by position within pen, where the back and end pen positions had pad depths that were 3.75 ± 1.13 cm and 4.04 ± 1.13 cm lower than the middle pen position for both sheltered and unsheltered pens ($p \leq 0.04$; Figure 28a). In the middle section of the pens there the front section of the pens had a pad depth that were 3.25 ± 1.19 cm deeper when compared with the back of the pen ($p = 0.05$), however there were no differences in pad depth across the treatment × within pen position for the middle of the pens ($p \geq 0.14$; Figure 28b). Similarly, on the right hand side of the pens there was a decreasing pad depth between the middle and end position within pen ($p = 0.04$; Figure 28c), although similar across the treatment × within pen position for the right side of the pens ($p \geq 0.13$; Figure 28c).

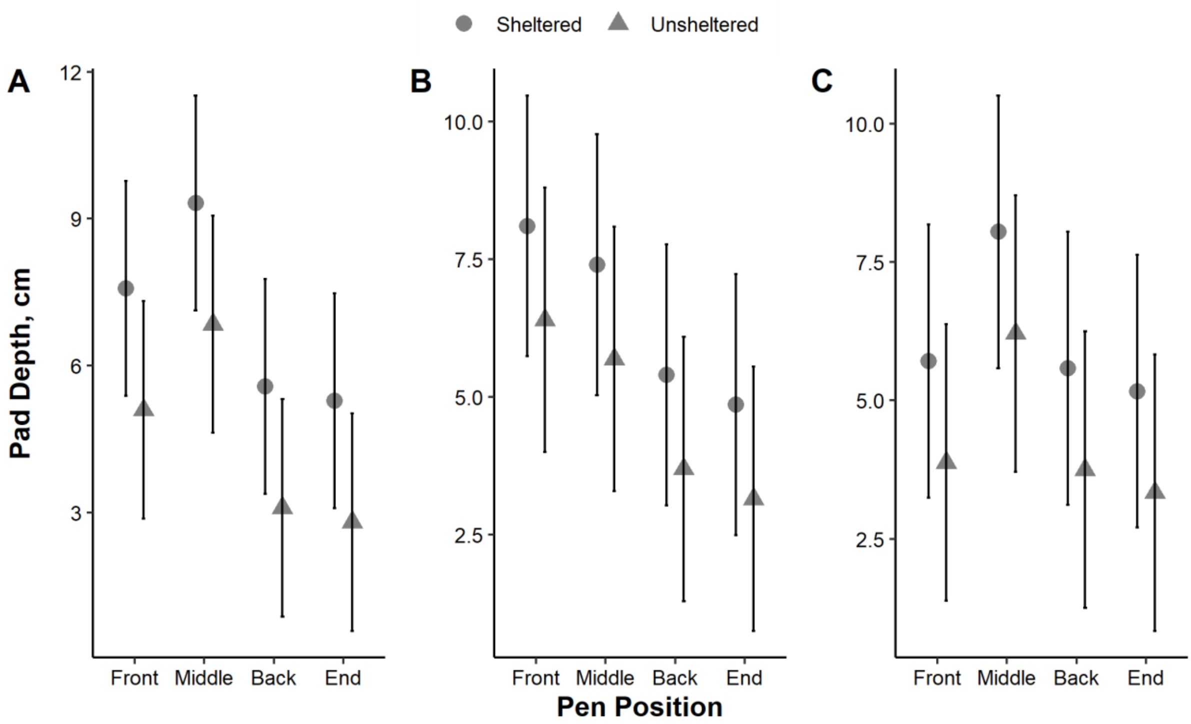

Figure 26. Pad depth (cm; emmean ± 95% confidence interval) at the Front, Middle, Back and End of the unsheltered and sheltered pens on the A) left, B) middle and C) right hand side of the pens on cattle exit

4.3.4 Rumen temperature

There was a tendency throughout the day for the unsheltered cattle to have T_{RUM} that were marginally, but consistently, higher when compared with cattle in the sheltered treatment (Figure 29). However, this data needs to be interpreted with some caution given the imbalance in data availability between the treatments as discussed in section 4.2.14.

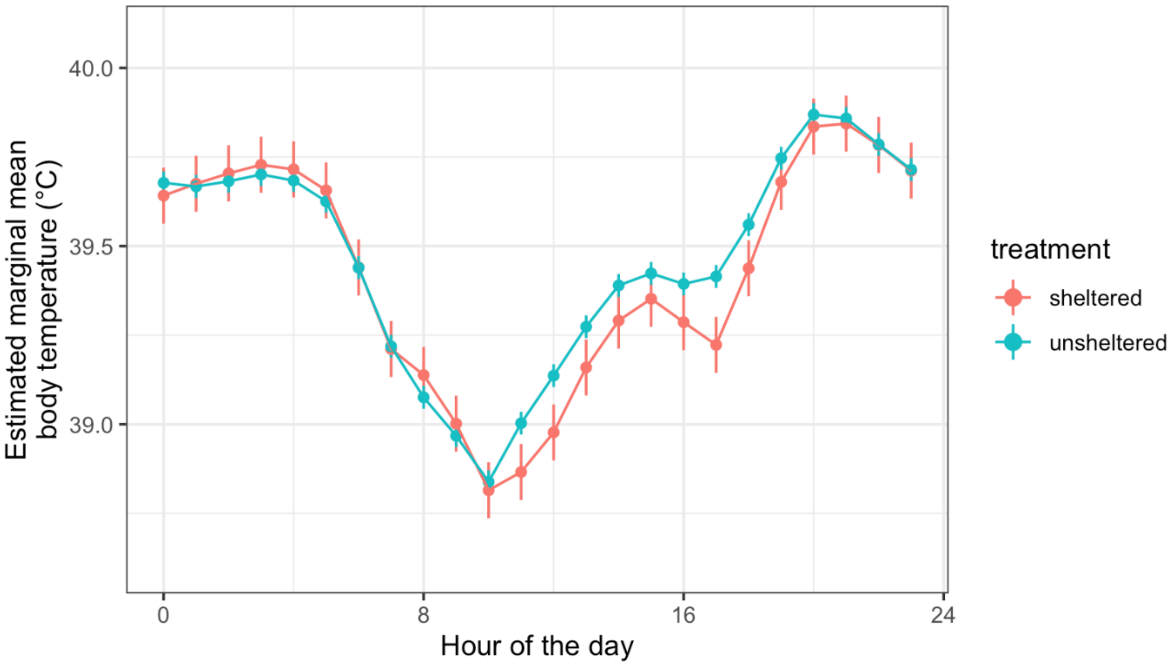

Figure 29. Mean rumen temperature (T_{RUM}, °C; emmean ± SE) of cattle in the unsheltered and sheltered treatments for the winter cattle (Cohort 3) between day 38 and exit

4.3.5 Animal performance

Average liveweight at induction was not different across the treatments (*p* = 0.77), nor were there differences in cattle liveweights at exit (*p* = 0.52; Table 16). Furthermore, feed consumption (*p* = 0.90), ADG (*p* = 0.25) or G:F (*p* = 0.41) were not influenced by treatment (Table 16). When adjusted exit weight, ADG and G:F were evaluated there was a tendency for sheltered cattle to have exit weights that were 9 kg heavier than the unsheltered cattle (*p* = 0.07; Table 16). In addition, the ADG_{adj} (*p* = 0.003) and $G:F_{adj}$ (*p* = 0.01) were greater for cattle in the sheltered treatment when compared with the unsheltered cattle (Table 16).

Table 16. Estimated marginal means (± SE) for liveweight at d0 (Initial LW), d38 (38 DOF LW), exit (Final LW), adjusted final liveweight[1] (Final LW_{adj}), average daily gain (ADG) for the period d0 to d38, d38 to exit[1], adjusted average daily gain (ADG_{adj}) between d0 to exit[2], gain to feed (G:F) ratio for the period d0 to d38, d38 to exit[1], adjusted gain to feed ($G:F_{adj}$) between d38 to exit[3] and dry matter intake (DMI) for the period d0 to d38, d38 to exit[1]

Trait	Treatment		Significance
	Unsheltered	Sheltered	
Initial LW, kg	374.0 ± 2.70	374.0 ± 2.28	0.77
38 DOF LW, kg	452.0 ± 2.97	458.0 ± 3.01	0.19
Final LW, kg	649.0 ± 3.54	652.0 ± 3.53	0.52
Final LW_{adj}, kg	646.0 ± 3.55	655.0 ± 3.55	0.07
ADG d38 to exit, kg LW/hd.d	2.37 ± 0.02	2.41 ± 0.02	0.25
ADG_{adj} d38 to exit, kg LW/hd.d	2.33 ± 0.03	2.44 ± 0.03	0.003
G:F d38 to exit	0.151 ± 0.0025	0.154 ± 0.0025	0.41
$G:F_{adj}$ d38 to exit	0.149 ± 0.0017	0.157 ± 0.0017	0.01
DMI d38 to exit, kg DM/hd.d	15.6 ± 0.13	15.6 ± 0.15	0.90

[1]Adjusted final weight was calculated from HSCW divided by the average dressing percent

[2]Adjusted ADG and adjusted G:F were calculated using the adjusted final weight

4.3.6 Morbidity and mortality

A summary of the morbidity and mortality experienced throughout the study is presented below in Table 17. A total of 26 animals were treated for footrot, blight/eye infection or bovine respiratory disease. Of these 26 animals, 19 were treated for footrot. Seven morbidity cases required follow up treatment, with one steer receiving five treatments prior to be removed from the study. All retreatments were associated with footrot. There was one mortality throughout the study, from unshaded pen as discussed previously in section 4.2.15.

Table 17. Morbidity and mortality summary

Item	Unsheltered	Sheltered
Morbidity[1], %	3.3	2.7
Morbidity, % 2 Treatments	15.4	11.5
Morbidity, % ≥ 3 Treatments	3.8	0
Mortality[1], %	0.21	0

[1] Percent relative to total number of cattle within the study

4.3.7 Carcase performance

Cattle from the sheltered treatment tended to have HSCW that were 5 kg heavier than the unsheltered cattle ($p = 0.08$; Table 18). Carcase dressing percentage and rib fat depth were greater in the sheltered cattle when compared with the unsheltered cattle ($p \leq 0.05$; Table 18). In addition, relative adrenal weight was greater in the unsheltered cattle when compared with the sheltered cattle ($p = 0.001$; Table 18). Ultimate pH was determined as numerically significant ($p = 0.003$; Table 18), however as these values were within the pH compliance threshold described by MSA this was not considered biologically or economically significant, thus not discussed here. There were no differences in P8 fat depth, EMA, MSA marbling, ossification or MSA index (Table 18).

Table 18. Estimated marginal means (± SE) for hot standard carcass weight (HSCW), dressing percentage (Dressing %), P8 fat depth (P8 fat), rib fat depth (Rib fat), eye muscle area (EMA), Meat Standards Australia marbling scores (MSA Marbling), ossification score (Ossification), ultimate pH (pH_u), Meat Standards Australia index (MSA index) and adrenal gland weight (Adrenal wt) for cattle within the unsheltered and sheltered treatments

Trait	Treatment		Significance
	Unsheltered	Sheltered	
HSCW, kg	356.0 ± 1.96	361.0 ± 1.96	0.08
Dressing percentage, %	54.86 ± 0.12	55.34 ± 0.12	0.004
P8 fat, mm	16.8 ± 0.36	16.8 ± 0.36	0.86
Rib fat, mm	9.69 ± 0.27	10.43 ± 0.27	0.05
EMA, cm^2	89.6 ± 0.62	89.7 ± 0.62	0.85
MSA Marbling	362 ± 4.12	359 ± 4.12	0.57
Ossification	163 ± 1.27	164 ± 1.27	0.65
pH_u	5.49 ± 0.004	5.51 ± 0.004	0.003
MSA index	55.82 ± 0.11	55.72 ± 0.11	0.53
Adrenal wt, g/100 kg HSCW	3.93 ± 0.05	3.72 ± 0.05	0.001

4.4 Discussion

4.4.1 Climatic conditions

The CCI was used to quantify exposure to cold stress conditions, during the study 31 days where CCI was classified as mild (CCI, 0 ≤ -10.0; Figure 20), suggesting that there was some exposure to cold stress conditions throughout the study albeit mild. This is not surprising as Australia is not necessarily prone to extreme cold stress events as experienced other regions of the world, and it is uncharacteristic for Australia to receive significant snowfalls. However, this does not mean that cold stress does not occur within the Australian industry, as animal comfort and productivity can be compromised during exposure to cold, wet and/or windy conditions (Mader and Griffin, 2015). Furthermore, the effects of cool conditions can be exaggerated by wind (Belasco et al., 2015). Under winter conditions, energy requirements for maintenance can easily double, particularly if the animal is wet and/or muddy and not protected from the wind (Belasco et al., 2015; Mader and Griffin, 2015), however under Australian conditions this can largely be compensated for by increased DMI. However, feed intake may not always increase as reduced daylight hours during winter combined with the cold condition's cattle may not aggressively frequent feeding areas.

4.4.2 Pen microclimate

Within pen microclimates, as determined by T_A, RH and THI, were not influenced by treatment throughout phase 1 and phase 2 of this (Figure 21; Figure 22; Figure 23). Regardless Mader (2003) suggests that the quickest methods of minimizing exposure to cold stress is to provide insulation or shelter for cattle. Remembering that it is not the intention to directly T_A or RH, rather to provide an opportunity to maintain thermal comfort. Given the rainfall that occurred during the study, the sheltered area provided the cattle with an opportunity to seek protection from inclement weather conditions whilst remaining dry and on a dry surface as noted within the pad conditions (see section 4.3.3). Providing cattle with access to a dry area during these periods and reduced exposure to mud addresses the issues associated with mud as highlighted by Grandin (2016).

4.4.3 Pad Conditions

Pad moisture was not influenced by shelter provision within the study, however both treatments exhibited a decreasing dry matter from the front of the pens to the back of the pens, suggesting that there was an increased moisture accumulation towards the back of the pens (Figure 24). The sheltered treatment had lower total carbon and total nitrogen when compared with the unsheltered pens (Figure 25a). This did not contribute towards a significant difference in the C:N ratio (Figure 26). However, the C:N ratio for both unsheltered and sheltered pens was lower than those reported by Smith et al. (2010) for compositing.

4.4.4 Rumen temperature

Rumen temperatures were unaffected by the provision of shelter within this study. It is well accepted that cattle can compensate for prolonged exposure to cold weather conditions by increasing body fat content and growing thicker coats to provide increased insulation (Van laer et al., 2014). In addition, the climatic conditions were not sufficient to fall below the lower critical temperature of growing feedlot cattle where the cattle were not be able to compensate for the cold climatic conditions.

4.4.5 Animal performance

The provision of shelter largely did not influence animal performance and productivity, until liveweights were adjusted for carcase dressing percentage (Table 16). When adjusted weights were considered ADG and G:F were greater for the sheltered cattle between day 38 to exit (Table 16). These findings are comparable with those of Mader et al. (1997). Mader et al. (1997) compared the benefits unsheltered areas compared with sheltered areas with providing different levels of wind protection. The benefits within this study are further confounded by the 24 day period where the sheltered cattle were housed in shade cloth pens where the shade cloth structure was permeable to rain and as such provided a within pen microclimate that differed from the sheltered structure that was not permeable to rain.

4.4.6 Carcase performance

Carcase performance within the current study for most carcase traits was not influenced by shelter provision (Table 18). Cattle from the sheltered pens had HSCW that tended to be heavier when compared with the unsheltered cattle. However, cattle from the sheltered pens had a higher dressing percentage, more rib fat coverage and had lower relative adrenal weights (Table 18). Dressing percentage is an unusual outcome, but this likely associated with the increased rib fat depth in these cattle (Table 18). This is supported by Mader et al. (1997), unprotected cattle have greater fat thickness and intramuscular fat deposition during winter conditions. However, within the current study, the unsheltered cattle had numerically greater MSA Marbling scores but lower rib fat depth. Whilst this was not observed within the current, Mader (2003) suggested that fat deposition becomes enhanced in cattle exposed to moderate cold stress and sustained by cattle exposed to more severe cold stress, even when productivity is reduced. As such there is a high priority for depositing fat in the winter, which makes physiological sense as a mechanism for providing body insulation in response to cold stress (Mader et al., 1997). Furthermore, the climatic conditions experienced by these cattle are not comparable with those of Mader et al. (1997), where there were on average 27.2 cm of snowfall during the winter studies. Interestingly, relative adrenal weight was greater in the unsheltered cattle when compared with the sheltered cattle (Table 18). Increased relative adrenal weight likely associated with increased cortisol production and the expansion of associated tissues in the kidney (Wilson et al., 2002) and could be attributed with increased exposure to cold climatic conditions as a chronic stressor (Tucker et al., 2007). However, without being able to quantify animal behavioural responses and utilisation of the shelter structure, due to COVID-19 impacts, it is difficult to completely elucidate these responses.

4.5 Conclusion

It is becoming increasingly important that livestock production systems maintain optimum cattle comfort not only for optimizing efficiency but also for enhancing consumer perceptions and acceptance of industry practices. Keeping cattle dry, clean, and comfortable is critical for accomplishing this goal, whether cattle are housed in outdoor environments or housed under more confined structures. There were some production benefits of providing shelter within this study namely adjusted ADG and G:F between day 38 and exit. In addition, the relative adrenal weight was greater in the unsheltered cattle. Overall, these results suggest that there are some production and welfare benefits associated with providing feedlot cattle with shelter from winter conditions in temperate environments.

5. Project Outcomes

The outcomes from this project provide evidence that the provision of shade and shelter have production and welfare benefits for feedlots positioned in temperate environments, during both summer and winter conditions. The outcomes from this project suggest that implementing shade and shelter solutions in Australia’s feedlot industry are feasible, however each individual feedlot will need to investigate the most viable shade and shelter options for their needs. This will ensure that the maximum value in regards to production and welfare while ensuring that economic viability can be safeguarded.

6. Future research and recommendations

The following future research opportunities and recommendations that have been considered based on the results from this study are:

- Even though the summer conditions were mild, cattle still exhibited a high utilisation of the structures highlighting that the cattle had a preference to utilise the shade structures. In addition, mean panting scores were lower in the shade cloth and waterproof treatments when compared with the unshaded cattle. Overall highlighting that these cattle were exposed to heat stress conditions and as such evoked purposeful behavioural responses and changes in respiratory dynamics, by increased mean panting score.
- Mean panting scores were higher than anticipated, relative to prevailing climatic conditions, suggesting that further investigation into the HLI, and subsequently AHL, thresholds of southern adapted cattle are needed to ensure that the HLI thresholds are appropriately describing heat load conditions for feedlot cattle in these regions.
- The studies conducted within this project have provided further evidence that shade and shelter provision have a positive impact on production and welfare outcomes for feedlot cattle. Further studies are needed to evaluate the impact of shade/shelter allocation per head (m^2/hd).
- A more comprehensive evaluation of within pen microclimates is needed to understand the impact that shade and shelter structures have for the thermal comfort of feedlot cattle, during both summer and winter conditions.
- Progress towards understanding the behavioural responses of cattle to shelter during winter conditions is needed.

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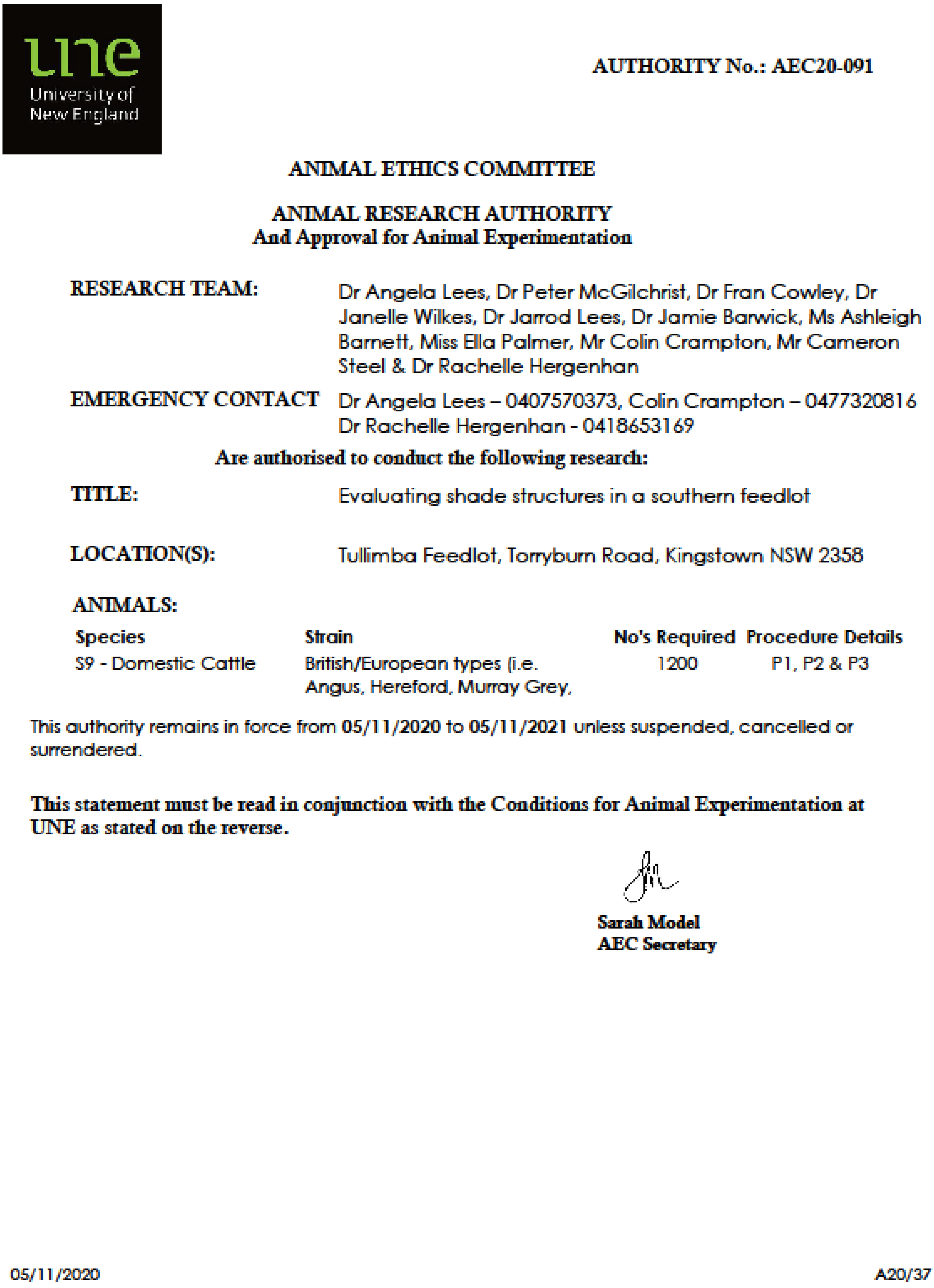
8. Appendix

8.1 Animal Ethics Certificate



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University of
New England

AUTHORITY No.: AEC20-091

ANIMAL ETHICS COMMITTEE

ANIMAL RESEARCH AUTHORITY
And Approval for Animal Experimentation

RESEARCH TEAM:	Dr Angela Lees, Dr Peter McGilchrist, Dr Fran Cowley, Dr Janelle Wilkes, Dr Jarrod Lees, Dr Jamie Barwick, Ms Ashleigh Barnett, Miss Ella Palmer, Mr Colin Crampton, Mr Cameron Steel & Dr Rachelle Hergenhan
EMERGENCY CONTACT	Dr Angela Lees – 0407570373, Colin Crampton – 0477320816 Dr Rachelle Hergenhan - 0418653169

Are authorised to conduct the following research:

TITLE:	Evaluating shade structures in a southern feedlot
LOCATION(S):	Tullimba Feedlot, Torryburn Road, Kingstown NSW 2358

ANIMALS:

Species	**Strain**	**No's Required**	**Procedure Details**
S9 - Domestic Cattle	British/European types (i.e. Angus, Hereford, Murray Grey,	1200	P1, P2 & P3

This authority remains in force from **05/11/2020** to **05/11/2021** unless suspended, cancelled or surrendered.

This statement must be read in conjunction with the Conditions for Animal Experimentation at UNE as stated on the reverse.

Sarah Model
AEC Secretary

05/11/2020 A20/37