Final report

Evaluation of the benefits of shade for feedlot cattle in a temperate climatic region

Project code: B.FLT.4013

Prepared by: David W Miller, Fiona Anderson, Anne Barnes, Teresa Collins, Liselotte Pannier, Joshua Aleri and *Shane K Maloney

Murdoch University and *The University of Western Australia

Date published: 19-June-2023

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

With an expected increase in environmental temperatures in the future, the productivity and welfare of cattle in feedlots requires investigation across a range of management scenarios and environmental conditions. Currently there are limited examples of cattle performance, health and welfare responses to shade in Australia, especially under large-pen commercial conditions.

This experiment, conducted under commercial conditions, used black Angus cattle in a 100-day grain-fed program at a feedlot classified as being in a temperate climatic zone (situated in the central wheat belt of Western Australia). There were 6 groups of cattle inducted into the feedlot over 2 summers (2021/22 and 2022/23) with 80 cattle shaded and 80 cattle unshaded from each group to test the impact that the provision of shade had to production and welfare indices. Parameters assessed, in a total of 960 black Angus steers, included feed intake, weight gain, rumen temperature, drinking, overall health, and behavior. The data collected aimed to provide insights into the impact of shade on the welfare, health, and performance of black Angus cattle feedlot cattle during a typical Western Australian (WA) summer under commercial conditions.

Over the months of October through to May under which this experiment was conducted, the findings demonstrated production increases with the provision of shade with a modest increase in average daily gain (ADG) of 0.13 kg/day. Using this ADG benefit in a sensitivity analysis model, the shade capital cost payback period could range from about 2 to 10 years given variable shade capital costs and $/kg hot carcass weight (HCW). This has the potential to enhance profitability by reducing feed costs per kg of production and reduce feeding times to achieve market specifications. The early turn off-of cattle and increased productivity is supportive of improved emissions intensity and offers potential marketing advantages. The physiological markers of health (rumen temperature and blood analysis) revealed that, even during to hottest times of the experiment, the cattle were quite able to thermoregulate to maintain physiological homeostasis. The thermoregulatory measures we observed that aided this were the increased heat loss via increased panting and seeking shade (if available) to reduce solar radiation load. In addition, we were also able to show the effect of heat stress and shade provision on the affective state of the cattle. Qualitative behavioural assessment was used to indicate that the shaded cattle in the ‘moderate stress’ THI category displayed the most positive demeanour, being described as more ‘settled and sociable’ compared to the unshaded cattle.

There were benefits of shade shown in this study in terms of performance and welfare. Shade provision for lot-fed black Angus cattle in the temperate climatic region of WA sets a benchmark for feedlot producers in these types of climatic regions in Australia to assess the advantages of adopting a shade solution. The production benefits of shade may vary with the amount and type of shade provided to cattle and future research could occur in variety of temperate environments for these factors. Better knowledge of the benefits of various shade designs to animal health and welfare may facilitate further adoption of shade in the Australian feedlot industry, an industry that has pledged to have all beef feedlots shaded by 2026. This would provide the industry with powerful information for public education and greater product awareness.

Executive summary

Predictions from climate change models are suggesting that there will be more extreme thermal events and that the duration of these events will be longer in the near future. The provision of shade in feedlot pens can provide cattle with an option to escape extreme heat events, or even just to regulate their physiology to minimize thermoregulatory effort ('zone of comfort'). Due to the increase in performance and animal well-being associated with improving cattle comfort, this should be an important area of focus for all animal producers in Australia. Indeed, heat stress caused by lack of shade access was identified by Professor Temple Grandin as one of the three major welfare issues for outdoor feedlots. However, there are limited examples of cattle performance, health and welfare responses to shade in Australia, especially under large-pen commercial conditions. Moreover, there has been increasing interest from lotfeeders, particularly in southern temperate climates, in the production and welfare benefits of providing shade. This project was designed to assess the relative performance and welfare benefits of black Angus cattle in two treatments (shaded v unshaded) over summer in a temperate climatic region of WA, and under commercial conditions.

Key findings relating to production parameters include:

- Over the months of October through to May under which this experiment was conducted, shaded cattle demonstrated a modest 0.13 kg overall increase in average daily gain (ADG) across the 70-day feedlot period. The difference in ADG varied in the 2 time periods: from day 0 to 30 the shaded cattle had an ADG 0.10 kg higher than unshaded cattle and this increased to 0.15 kg in the 31-70 day time period.
- The physiological markers of health (rumen temperature and blood analysis) revealed that, even during to hottest times of the experiment, the cattle were quite able to thermoregulate to maintain physiological homeostasis.
- The thermoregulatory measures we observed that aided this were the increased heat loss via increased panting and seeking shade (if available) to reduce the solar radiation load.
- In addition, we were also able to show the effect of heat stress and shade provision on the affective state of the cattle. Qualitative behavioural assessment was used to indicate that the shaded cattle in the 'moderate stress' THI category displayed the most positive demeanour, being described as more 'settled and sociable' compared to the unshaded cattle.
- There are financial incentives to install shade in this geographical region as provision of shade in the summer months increased ADG, allowing cattle to reach target weights earlier. Reduced feeding costs to gain weight and less numbers of days on feed will result in less inputs per kg turned off to slaughter.

The findings from this project fit within the framework of the Red Meat Advisory Council (Red Meat 2030) where it is identified that there is a "responsibility to focus on adoption of best practice in animal health and welfare … that will deliver better business performance and provide greater consistency in both practices and product". The MLA Strategic Plan to 2025 has a similar focus on continuous improvement in the welfare of animals, and ALFA has launched the initiative that asks all Australian feedlots to make a pledge to provide cattle under their care with access to shade by 2026. The benefits (performance, health, welfare) of shade provision for lot-fed black Angus cattle in the temperate climatic region of WA sets a benchmark for feedlot producers in these types of climatic regions in Australia to assess the advantages of adopting a shade solution. Black Angus cattle not only represent the major genotype lot-fed in this region, but they are also one of the higher risk genotypes in an extreme heat event, thus providing a highly relevant model. Better knowledge of the benefits of various shade designs to animal performance, health and welfare may facilitate further adoption of shade in temperate Australian environments.

Table of contents

1. Background

Currently there are limited examples of cattle performance, health and welfare responses to shade in Australia, especially under large-pen commercial conditions. Gaughan and colleagues have shown increased dry matter intakes (DMI) and average daily weight gains (ADG) when black Angus cattle are provided with shade (Gaughan et al., 2010) and improved welfare regardless of the percentage of shade allocation per animal (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 was unclear whether these benefits of shade are applicable across other climatic zones within Australia. Recently, MLA commissioned a study in the New England district of New South Wales at the UNE research feedlot 'Tullimba', which receives weather systems from both northern and southern influences (Lees et al., 2022). In the summer period of this study there were no differences in cattle performance between the shaded and unshaded treatments, though there were welfare improvements, i.e. lower mean panting scores.

To cope with heat stress, cattle exhibit changes in behavior and physiology (Mitlöhner et al., 2002). Respiration rate increases and feed intake generally decreases (Nienaber et al., 2003). Cattle will also seek shade when heat stressed (Robertshaw, 1985). If these behavioural and physiological coping strategies are insufficient then body temperature will increase, and this can result in hyperthermia and death (Entwistle et al., 2000). Moreover, even if the coping mechanisms are successful, they come at a cost to production performance (Hahn, 1999; Mitlöhner et al., 2002; Mader, 2003), whilst also reflecting compromised animal welfare.

There has been increasing interest from lotfeeders, particularly in southern temperate climates, in the production and welfare benefits of providing shade, and also the cost-benefit and payback period for installation of a shade solution. This interest has been enhanced by the Australian Lot Feeders' Association (ALFA) announcing an initiative to encourage all feedlots to provide cattle with access to shade by 2026, and to ensure continuous improvement of animal welfare which is essential for maintaining consumer and community support for grain-fed beef.

This project, led by Murdoch University, sub-contracted a leading WA commercial feedlot to test the benefit of shade provision for black Angus cattle in a 100-day grain-fed program at a feedlot classified as being in a temperate climatic zone (situated in the central wheat belt of Western Australia). The experimental design tested cattle performance, health and welfare responses to either the provision of shade or no shade during the first 70 days of the 100-day program, replicated at different '70-day windows' over two consecutive summers (2021/22 and 2022/23).

2. Objectives

The project objectives were:

a) Subcontract a commercial shade provider to install a solution with a feedlot collaborator in Western Australia.
b) Subcontract a feedlot collaborator to execute a defined research methodology in consultation with the research organization.
c) Execute research methodology to evaluate the shade solution under large pen research conditions (> 80 head) in an unbiased fashion.
d) Evaluate the effects of shade on animal welfare, health, and cattle performance over the course of two summer periods relative to conventional production practices at that feedlot.
e) Determine the cost-benefit and payback period to adoption of the shade solution.
f) Make recommendations on the feasibility of the shade or shelter solution to the Australian feedlot industry.

3. Introduction

Cattle possess remarkable adaptability to environmental stressors, demonstrating their ability to adjust physiologically, behaviorally, and immunologically to minimise adverse effects (Hahn, 1999). However, when exposed to high temperature and humidity, along with solar radiation and low air movement, cattle can exceed their stress tolerance, leading to decreased productivity and potential mortality (Hahn & Mader, 1997; Gaughan et al., 2000; Lefcourt & Adams, 1996; Mader et al., 1999). Strategies for environmental modification typically aim to reduce temperature or solar load and increase air movement. One effective approach is the use of shade structures, which can reduce solar load by up to 30% (Bond & Laster, 1975). Shade structures have gained attention as a passive and practical means of mitigating heat stress during summer (Brown–Brandl et al., 2001; Bond & Laster, 1975; Paul et al., 2000. Unlike active systems that require operator control, shade structures allow animals to seek shade as needed. Recognizing the potential severity of heat stress events and providing access to stress-reducing measures such as shade structures can minimize losses in performance and mortality.

Physiological responses to thermal heat loads are complex and dynamic, influenced by factors such as genotype, age, body condition, nutrition, and health status (Hahn, 1999). Animals integrate environmental conditions and respond adaptively. Various indicators can be used to assess heat stress, including behavioral observations, growth rate, feed intake, immune function, core body temperature, and respiration rate (breaths per minute). Of particular interest as a physiological response is the respiration rate, as extensive research supports a positive correlation between respiration rate and elevated temperature, humidity and solar radiation (Kibler & Brody, 1949; McLean, 1973; Ingram & Mount, 1975; Spain & Spiers, 1996; Hahn et al., 1997; Mader et al., 1999; Gaughan et al., 2000; Mitlohner et al., 2001; Eigenberg et al., 2000). The main behavioural responses that indicate that thermoregulatory measures are being undertaken by the animal to maintain physiological homeostasis include increased panting to increase heat loss (Gaughan et al. 2010; Lees et al. 2020), and seeking shade (if available) to reduce the solar radiation load (Robertshaw 1985; Lees et al. 2020).

This study was designed to test the benefit of shade provision for black Angus steers in a 100-day grain fed program at a feedlot classified as being in a temperate climate, across two summer periods, with the hypothesis that the provision of will improve performance (growth, feed efficiency), health and well-being (blood and behavioural markers), and affective state (assessed by QBA).

4. Materials and Methods

4.1 General methodology

This project was conducted with the approval of Murdoch University's animal ethics committee (AEC R3277/20; Appendix 11.1), in accordance with the guidelines described by the Australian (National Health and Medical Research Council, 2013).

The project was undertaken on a commercial feedlot 180 km east of Perth, in the central wheat belt region of Western Australia (250 m above mean sea level), with the climate in the region classified as a temperate Mediterranean climate (Csa) with a hot dry summer, as per the Köppen climate classification system, and typically a winter dominant rainfall pattern with an annual average rainfall of 355 mm. The commercial feedlot has been operating since 2000 and has built capacity of 5000 head of cattle in the main feedlot facility with an additional capacity of 3200 head in a designated conditioning area. The main feedlot yards footprint area is 65000 sqm of pens with 1150 m of concrete feed bunks. There is a total of 32 pens in the main feedlot. All pens are constructed of steel and cable fencing with cattle rail gates, with the surface of the pens being the natural free-draining deep sand.

All pens have 25 x 3 m wide concrete feed aprons and are serviced by a minimum of one large rectangular (4 m length) concrete water trough in the rear of the pen per 80 head. These troughs are sewered away from pens for ease of cleaning. All pens have access to drovers lanes which direct cattle to the induction and working yards. In this project we will utilised 8 pens (4 shaded and 4 unshaded) in opposite rows, with dimensions of 25 m x 47 m (1425 sqm; 80 head per pen; approx. 17.8 m^2/h; Figure 1).

At induction, all cattle are fitted with visual and RFID ear tags, which together with a StockAid Elynx system on the crush allows for 100% traceability. Water supply is of a very high quality being a mix of underground water via a borefield, stored catchment water (dams) and government supplied reticulation. There is a total of 680,000 litres storage in tanks plus the dam catchment of 10,000 CuM ensuring that there is large volume of water available in contingency. The feedlot has a grain tempering facility with high quality components to ensure that grain utilisation is maximized. The tempering facility has a capacity of 40 tonne of processed grain per day. There is grain storage capacity of 1500 tonne in a combination of sealed silos and grain bunker.

The shade structure installed by Westarp was based on a similar design currently on the Australian market. The shadecloth utilised in the design was rated as a 75-80% UVR block, and has the dimensions of 6m high, 10m wide and spanning the 25m width of the pen in a north-south alignment (Figure 1). Theses specifications provide a minimum of 3.125 m^2 of shade per animal (based on 80 animals per pen).

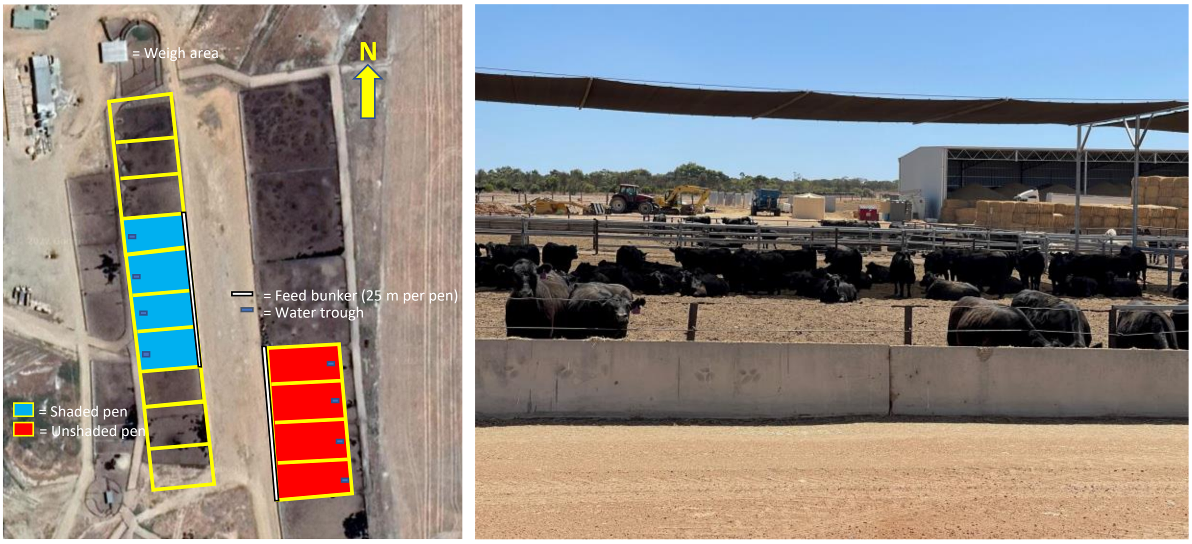

Figure 1. Treatment pen layout and shade structure

4.2 Experimental design

This study was designed to test the benefit of shade provision for black Angus steers in a 100-day grain fed program at a feedlot classified as being in a temperate climate, across two summer periods, with the hypothesis:

> *Provision of feedlot shade for Angus steers in a temperate climate will improve performance (growth, feed efficiency), health and well-being (blood and behavioural markers), and affective state (assessed by QBA).*

The experimental design tested cattle responses to two treatments: either the provision of shade (shaded) or no shade (unshaded). Cattle were not treated with hormonal growth promotants (HGP) to comply with being raised for the Coles Finest brand.

For two consecutive summers (2021/22 and 2022/23), treatment cattle (shaded vs. unshaded) were maintained and monitored in 6 blocks of 80 animals for 70 days. After Day 70 the commercial basis of the feedlot necessitated that cattle be reallocated to slaughter groups leading up to exit at approximately Day 100, and therefore cattle could not be strictly maintained in their allocated shade or unshaded groups. In each block, cattle were allocated to alternate treatment groups on an individual basis as they entered the feedlot, with six entry times (1 pen shaded + 1 pen unshaded at each entry block) staggered over the months of October to May (Figure 2). Experimental pens in each group block were cleaned prior to cattle entry.

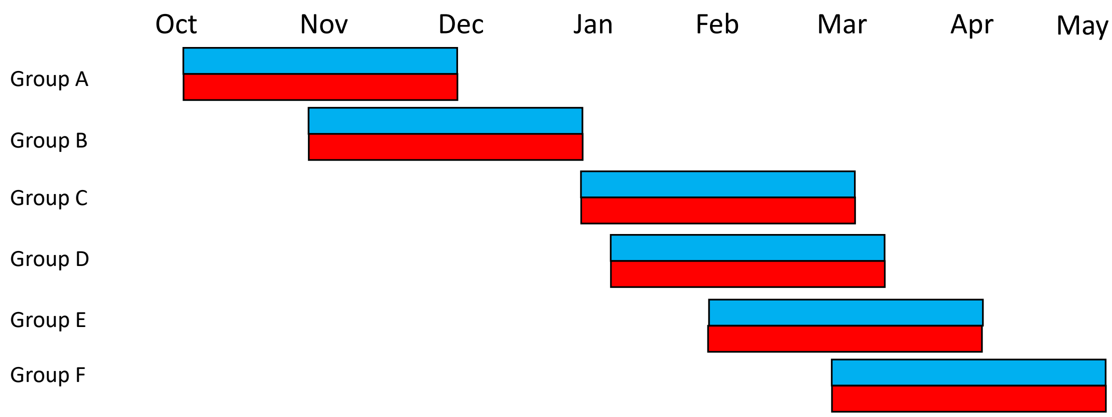

Figure 2. Group block allocation by month, with Groups A – D inducted in 2022 and Groups E – F. inducted in 2021. Blue (shaded) and red (unshaded) bars indicate approximate induction and monitoring duration times.

4.3 Animal management

A total of 960 Black Angus (*Bos taurus)* steers were used within this study, sourced from local south-west WA suppliers, ensuring cattle from the same source were allocated to group blocks at induction. Upon induction at the feedlot, cattle were vaccinated for clostridial diseases (pulpy kidney disease, tetanus, blacks disease, malignant edema, and blackleg (Websters 5-in-1; Virbac Pty Ltd, Australia, NSW, Australia), and respiratory pathogens (Bovilis MH + IBR, inactivated *Mannheimia haemolytica*; Coopers Animal Health, Intervet, NSW, Australia).

The cattle were weighed (non-fasted) at induction (day 0), day 30, and day 70, with weighing occurring between 08:00 h and 10:00 h; using a calibrated single weigh-crush (Silencer Hydraulic, Catagra Group, NSW, Australia) with an automated readout system. At induction, cattle were weighed in race order, with 4 consecutive animals then assigned to the unshaded treatment, and then the next 4 consecutive animals assigned to the shaded treatment, with this system repeated until there were 80 animals per treatment pen. Every 4th animal also had an intra-ruminal temperature logger inserted (see below for details), resulting in 20 animals per treatment pen having a rumen temperature logger.

4.4 Health management

Pens were walked daily by trained feedlot staff. Cattle showing any signs of health concern were recorded and 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 (Appendix 11.2). There were no mortality events.

4.5 Nutritional management

The cattle were fed a 'starter' total mixed ration diet for the first 30 days before being fed a 'finisher' diet from day 31 until exit (Table 1). Feeding times ranged between 10:00 h and 12:00 h. Both rations were based on tempered barley, commencing at 43.2 % (as-fed basis) for the starter ration and increasing to 69.5 % for the finisher ration (Table 1). Monensin (Rumensin©, Elanco Australasia Pty Ltd, NSW, Australia) was added to the ration at 9.4 ppm for the starter ration and 28.1 ppm for the finisher ration.

Table 1. Formulated ingredient and nutrient composition of the diets.

Item	Starter	Finisher
Ingredient[1]		
Barley, tempered	432	695
Oaten hay	275	90
Lupins	160	45
Silage (cereal)	100	60
Water	20	45
Pre-mix	12	35
Vegetable Oil	0	30
Formulated Nutrient Analysis[2]		
DM, %	78.48	73.52
Protein, %	14.76	14.10
Eq Prot, %	0.69	2.05
ME, MJ/kg	11.55	12.90
NEm, Mcal/kg	1.68	2.00
Neg, Mcal/kg	1.07	1.35
NDF, %	32.55	20.42
eNDF, %DM	23.08	11.03
Fat, %	3.22	7.23
Vit A, KIU/kg	1.28	3.82
Vit E, IU/kg	3.2	9.55
Calcium, %	0.41	0.74
Phosphorus, %	0.33	0.36
Monensin, ppm	9.41	28.14

[1]per 1000 kg, as-fed basis
[2]formulated nutrient composition 100 % DM basis

4.6 Climatic conditions

Ambient air temperature (T_A; °C), relative humidity (RH; %), wind speed (WS; m/s) and direction, solar radiation (SR; W/m^2), black globe temperature (BGT) and rainfall were collected at 15 min intervals via a bespoke on-site weather stations (Origo Farm, Perth WA, Australia), placed centrally within the experimental pen area. Temperature-humidity index (THI), heat load index (HLI) and accumulated heat load (AHL) were calculated from these recordings (see below). The feedlot also utilizes the online 'Cattle Heat Load Toolbox' that captures site-specific climate data and weather forecasting for a Risk Analysis Program (RAP). This toolbox generates predictions based on climate data and stock details to allow the feedlot to increase observations during predicted Extreme Heat Events to allow them to make decisions on mitigation strategies. As part of the feedlot's mitigation strategy standard operating procedure (SOP), during Extreme Heat Events cattle could not be moved for any procedural measurements, unless it was movement for temporary shade relief or to the sick pen.

The THI, HLI and AHL were calculated using the following equations, and based on the category of cattle used, Black Angus steers on a 100-day feeding regimen:

The THI was calculated using the following equation adapted from Thom (1959):

- $THI = (0.8 \times T_A) + \{[(RH/100) \times (T_A - 14.4)] + 46.4\}$

Additionally, for this study, THI was divided into four stress categories: (1) no stress, THI≤72; (2) mild stress, THI 72 ≤ 78; (3) severe stress, THI 78 ≤ 88; and (4) very severe stress, THI > 88.

The hourly HLI was calculated using the following equations:

- $HLI_{high\ BGT \geq 25\ C} = 8.62 + (0.38 \times RH) + (1.55 \times BGT) - (0.5^{*} \times WS) + (EXP(2.4 - WS))$
- $HLI_{low\ BGT < 25\ C} = 10.66 + (0.28 \times RH) + (1.3 \times BGT) - WS$

The weighting factor to calculation actual HLI (HLI_{ACC}) is calculated and used as:

- $FRAC_{high} = 1.0 / (1.0 + EXP(-(BGT - 25)/2.25))$
- $HLI = (FRAC_{high} \times HLI_{high}) + ((1 - FRAC_{high}) \times HLI_{low})$

*If any calculation of HLI yields a value less than 50, this value must be set to 50 as the dissipation of heat does not increase below this point.

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

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

Pen microclimate and surface temperatures

During the times of collection of the behavioural observations (see below), within pen measurements of ambient temperature ($T_{A\ PEN}$), relative humidity (RH_{PEN}), wind speed (WS_{PEN}), solar radiation (SR), and black globe temperature (BGT) were recorded and used to calculate a within-pen THI and HLI category score, ranging from 1 = no stress to 4 = very severe stress for THI, and 1 = cool to 4 = very hot for HLI. The surface temperature (5 replicates per pen) of the ground in the shaded (T_{GS}) and unshaded (T_{GU}) areas of the pen, along with the water in the drinking trough (T_W), were obtained using a FLIR E6 digital infrared camera (FLIR Systems, Inc., Wilsonville OR, USA). The FLIR camera was also utilized to capture surface skin temperatures of the cattle (5 animals per pen), both in shaded ($T_{S\ SKIN}$) and unshaded ($T_{U\ SKIN}$) areas of the pens. The resolution for each infrared image was set at the maximum possible for the camera model (160 by 120 pixels). The FLIR camera then converted the animal's emitted radiation at a 10- to 12- mm wavelength into an electrical signal, which was then processed into a thermal pattern. The camera can detect temperature differentials as small as 0.1°C. The emissivity value used was 0.95. The infrared pictures were taken approximately 100 cm from the ground/water surface, or about 5 m from the animal. Prior to collecting images for water temperature, the water in the trough was briefly stirred by hand to mix any layers of differing temperature. The infrared pictures were analysed using FLIR Tools software (FLIR Systems, Inc., Wilsonville, OR, USA). For determining ground/water temperature, the software was used to determine an average temperature along a linear line connecting bisecting the image area (Figure 3a). For determining skin temperature, the software was used to determine an average temperature along a linear line midway down the ribcage (flank), from the end of the rump to the beginning of the shoulder (Figure 3b).

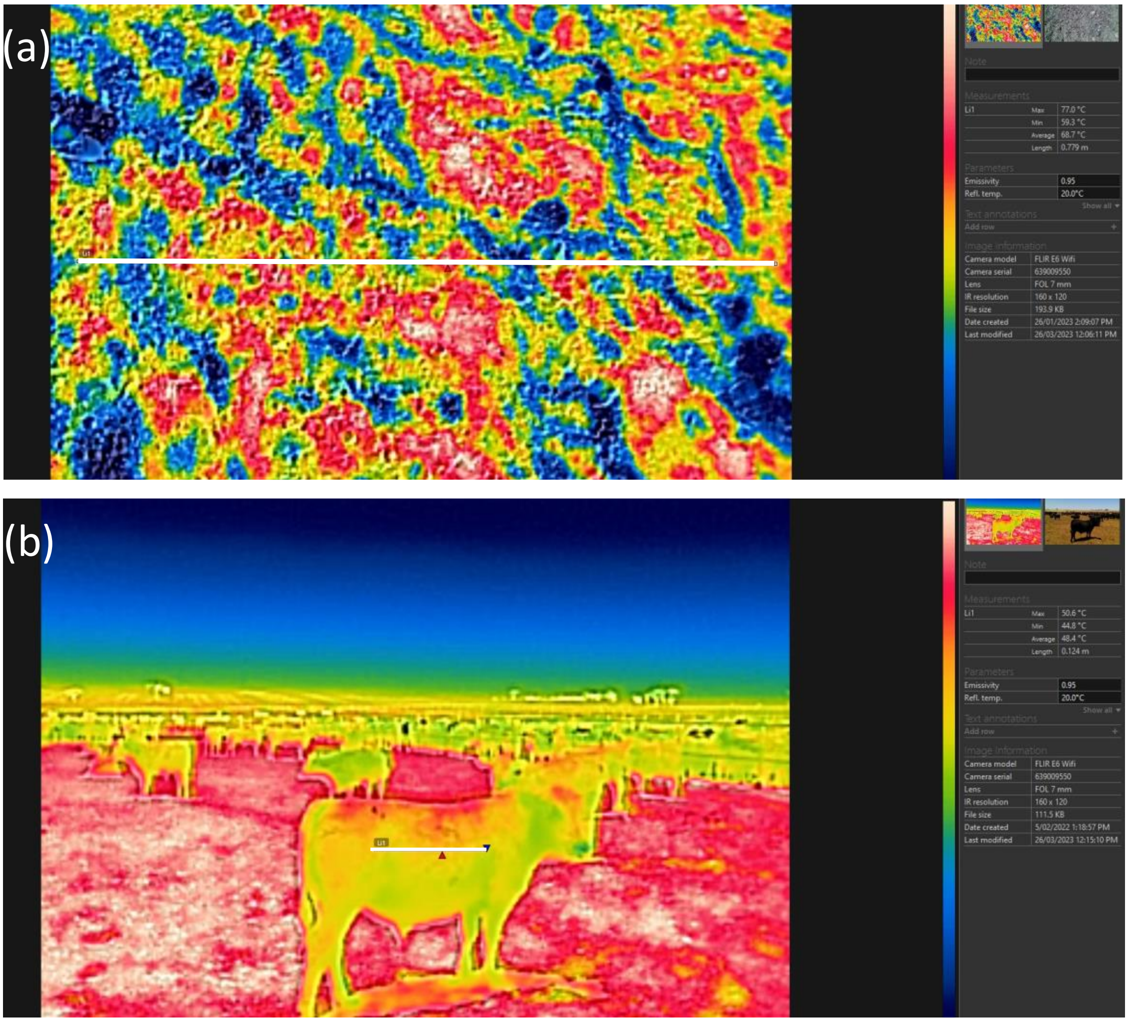

Figure 3. Representative infrared (FLIR) images depicting placement of the measurement line (FLIR Tools) on the (a) ground surface, or (b) skin surface of cattle.

4.7 Rumen loggers (temperature, drinking and activity)

Rumen temperature has been shown to reliably reflect core temperature over a range of different environmental conditions (Beatty et al. 2008, Lees et al. 2018). Rumen temperatures (T_{RUM}, °C) were obtained from 240 Angus steers (20 animals from each treatment pen) for the duration of the study. Rumen boluses (SmaXtec, Bolus TX-1442A, SmaXtec Animal Care GmbH, Austria) were orally administered to 20 animals from each pen on day 0. Rumen temperature boluses were cylindrical (3.4 cm diameter × 10.5 cm in length) and weighed approximately 205 g. Rumen temperatures and steps taken (accelerometer-based) were recorded at 10-minute intervals for the duration of the study. Rumen bolus data were communicated, by telemetry, to a base station located on the feedlot (SmaXtec Base Station, SmaXtec Animal Care GmbH, Austria), then transmitted by wi-fi to a data server and stored in an online database (messenger.smaxtec.com). The database software also generated ‘water drinking events’ based on acute declines in the rumen temperature data (> 1 SD). For any time where the logger failed to connect to the repeater and upload data, the data collected was adjusted to reflect the missing days.

The maximum, minimum and average T_{RUM} was calculated for all time periods (0-30, 31-70 and 0-70 days). To identify cattle that had had a high core temperature, considered outside the normal physiological range, when T_{RUM} was greater than 41.5 °C it was assigned as being a high T_{RUM}. A single time point of 10 minutes was not considered to be a ‘high temperature event’, however if 2 consecutive timepoints of T_{RUM} > 41.5 °C occurred this was included and the duration of the event was also recorded. This enabled an average number of 'high temperature events' within each time period to be determined, along with the amount of time spent above 41.5 °C . Within each treatment the proportion of cattle which had at least 1 'fever event' was determined for comparisons between treatments (shaded v unshaded).

Drinking events were determined by acute drops (> 1 SD) in temperature for greater than a 10-minute period. The average number of drinking events and the cumulative duration of drinking events was adjusted to the number of days the recording was collected for in the 0-30, 31-70 and 0-70 time periods.

Average activity, as registered by the rumen loggers as accelerometer-based steps, was also determined for each time period (0-30, 31-70 and 0-70 days).

4.8 Blood sampling and analysis

On Days 0, 30 and 70, blood was collected from each animal using venepuncture of the tail vein and placed into one 9 ml lithium heparin (Vacuette®) and one EDTA (BD Vacutainer®) blood tube. Following blood collection all samples were immediately placed in ice. The lithium heparin samples were centrifuged within 4 hours of collection (3200 rpm, 10 minutes at 4°C) before being transferred to microcentrifuge containers in 1 mL aliquots and frozen at -20°C.

The EDTA blood samples were refrigerated and sent to the VetPath laboratory (Vetpath Laboratory Services, Jandakot, WA, Australia) for complete blood count and determination of fibrinogen within 24 hours of collection. Automated red cell and white cell counts were performed on a Cell Dyn 3700 hematology analyser (GMI Inc., Ramsey MN, USA), with a manual differential from blood film also performed. Fibrinogen was determined using a Stago Start 4 hemostasis analyser (GMI Inc., Ramsey MN, USA).

Plasma heat shock protein (HSP)-70 levels were determined using a commercial ELISA kit (Bovine HSP-70, CSB-E13452B, Cusabio, Houston TX, USA) as per the kit's instructions. The sensitivity of the assay was 1.25 ng/mL with intra-assay and inter-assay precision of 3.8 % (CV) and 7.5 % (CV), respectively.

4.9 Behavioural observations

4.9.1 Flight speed

As a measure of cattle temperament (Coombes et al. 2014), flight speed (FS: m/sec) of the cattle exiting the weigh-crush over a measured distance of 3 m, was conducted at induction (Day 0), Day 30 and Day 70. A fixed-mounted video camera (GoPro Hero3+: GoPro Inc., San Mateo, CA, USA) was positioned directly adjacent to the weigh-crush exit with a 3-metre marker from the exit painted on the fence opposite. Flight speed (FS: m/sec) was calculated using frame-by-frame analysis of the video footage, given the known frame rate of the video camera (25 frames/sec), to count the number of frames from when the animal first exited the crush to when it first crossed the 3-m marker.

4.9.2 Pen position, posture and activity

Behavioural monitoring (panting score, position in pen, posture, activity) was conducted, from a distance using binoculars, at two time periods per pen (mid-morning and mid-afternoon) on approximately the day before (or after) the routine weights were taken on Days 0, 30 and 70, and at several other timepoints to capture behaviours in a range of climatic conditions (recording sheet: Appendix 11.3). Posture was defined as either percentage of animals 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). Position in pen was described *in situ* as percentage of animals under shade (if available) or in sun. Utilisation of shade was defined as ≥ 50 % of the body covered by shade, as described by Kendall et al. (2006). Animal activity, i.e. feeding and drinking, was determined by recording the percentage of animals undertaking that activity 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 (Mitlöhner et al., 2001a), although it could not be ascertained if they were actively eating. Similarly, drinking was defined as the animal standing with their head near the water trough (Lees et al., 2020), although it could not be ascertained if they were actively drinking.

4.9.3 Panting score

Panting scores were evaluated based on the open and closed mouth panting of cattle using a 0 to 4.5 scale as per Table 2 below (Brown-Brandl et al., 2006a; Gaughan et al., 2008; Lees, 2016; Lees et al., 2022). Panting scores were recorded at the same time as the posture/location/activity recording (recording sheet: Appendix 11.4). During the recording periods, measurements were repeated 4 times per pen with a 15 minute gap between replicates. Observed panting scores (pen percentages) were used to calculate a mean panting score for or each observation timepoint, using the equation described by Gaughan et al. (2008);

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

Where N_i = the number of cattle observed at PS_i

Table 2. 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/foam 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. Flanks often 'heave' with forced breathing.

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

4.9.4 Qualitative Behavioural Assessment (QBA)

On the observation days, short video clips (30 – 60 seconds) of several animals in each pen, conducted between the morning and afternoon behaviour recording sessions above, were collected using a video camera mounted outside the pen, and used later to ascertain the affective state (demeanor) of the cattle using the methodology of Qualitative Behavioural Assessment (QBA). A sub-group of video clips from 10 cattle from each temperature-humidity index (THI) category (see below) were randomly selected for QBA. About 30 observers were recruited for this study from Murdoch University School of Veterinary Sciences, staff and students. Observers were given detailed instructions on completing the QBA scoring sessions but were not given any details on the animals, location or the experimental treatments. Observers also completed a short survey regarding their past experiences with cattle and other domestic livestock species prior to the QBA assessment procedure. To complete the QBA assessment procedure the observers used a Fixed List procedure where a list of 10 terms (Alert, Active, Settled, Inquisitive, Sociable, Frustrated, Anxious, Listless, Agitated, Uncomfortable) that were provided to them for use in assessing the cattle (recording sheet: Appendix 11.5). These terms were generated from a previous QBA Free Choice Profiling procedure carried out on feedlot cattle (Stockman et al., 2012) and represented the highest ranking terms in the top two dimensions of this previous study. Observers viewed and scored the video clips of the cattle using the provided list of terms by placing an 'X' on a 100 mm visual analogue scale next to each descriptive term. Maximum on the scale indicates the animal could not show a behavioural expression more strongly and minimum reflects the absence of expression of that particular demeanour, and the distance between the minimum-point and their mark on the scale reflects the intensity of each animal's expression on that term. To analyse the observer's QBA recording sheets, the distance from the start of the visual analogue scale to where the observer had made a mark for each term was measured (where minimum= 0 and maximum= 100) and these data were analysed by means of Generalised Procrustes Analysis and Principal Components Analysis (see below).

4.10 Statistical analyses

Animal performance

Data was analyzed using linear mixed effects models in SAS (SAS Version 9.1, SAS Institute, Cary, NC, USA). Individual cattle performance data, blood parameters, and rumen logger data were used as the dependent variable, with treatment (shaded v unshaded) included as a fixed effect, with Group (A, B, C, D, E, F) and pen within treatment included as a random term.

Data was collected at day 0, day 30 and day 70 on cattle weight which allowed the calculation of average daily gain (ADG kg/d) for the time periods 0-30, 31-70 and 0-70 days. Dry matter (DM) intake was determined on a pen level to give DM (kg)/head /day over the 3 time periods to allow the calculation of feed (DM) to gain ratio (kg/DM/day per ADG).

Rumen data was analyzed in 3 time periods: day 0-30, day 31-70 and day 0 to 70. For each of the three time periods models were tested for differences between shaded and unshaded cattle for rumen temperature: minimum, maximum, average. The proportion of cattle which registered at least 1 event of $T_{RUM} > 41.5$ °C was determined. In these cattle the duration of high temperature events, average minimum, maximum and mean T_{RUM} were also analyzed. Temperature parameters were tested one at a time as the dependent variable with treatment as a fixed effect and Group and pen within treatment as a random term. Drinking events (number and duration) were included as dependent variables to test for differences in number and duration. Differences between accelerometer-based activity (average) for shaded and unshaded cattle was also determined.

Blood samples from day 0, 30 and 70 were analyzed and the results tested for treatment differences in packed cell volume (PCV), total plasma protein (TPP), leucocyte numbers, neutrophil:lymphocyte ratio (N:L), fibrinogen, and heat shock protein 70 (HSP) in linear fixed effects models. These parameters were included as the dependent variable, with treatment (shade, unshaded) included as a fixed effect and Group and pen within treatment included as a random term.

Microclimate and surface temperatures

The data were also correlated to the black globe temperature (BGT) by means of Spearman rank order correlation.

Behavioural responses

Flight speed (FS: m/sec) was calculated for each steer on exit from the crush at weighing and included as a dependent variable, with treatment as a fixed effect and Group as a random term. To analyze changes in FS between days (0, 30 and 70), FS from each visit was included in the data, with day included as a fixed effect and Group and VID(Group) included as random terms.

Pen observational data were average proportions of animals utilizing shade; standing; lying; drinking or feeding within each pen for the four replicates for each observation. Average (of four replicates) of the panting score data were used to calculate mean panting score for each pen by observation time point, using the equation (see above) described by Gaughan et al. (2008). All quantitative behavioural data were analyzed for treatment differences (and also the interaction of treatment by the THI (or HLI) category level on the day of filming). Shade utilization was only be determined in the shaded pens.

QBA data was generated using Generalised Procrustes Analysis (GPA) and Principle Component Analysis (PCA) using Genstat (Genstat 2008, VSN International, UK). GPA is a multivariate technique that calculates the level of consensus between observer assessments of the individual animals. The statistical process whereby this best-fit pattern, termed the consensus profile, is identified takes place independently of the meaning of descriptive terms used by observers. The percentage of variation between observers (in their assessment of individual animals) that is explained by the consensus is captured as the Procrustes statistic. The statistical performance of the consensus profile above chance is calculated by comparing the Procrustes statistic (using a one-sample t-test) to the mean of a simulated distribution of 100 Procrustes statistics generated through 100 iterations of the analysis, where the data is randomised in a different permutation each time. Significance values in that test of $P < 0.001$ or better can be taken as evidence that the consensus profile was not a methodological artefact and represents a common pattern identified by observers. The consensus profile is then simplified to a smaller number of dimensions, explaining the majority of variation between observed animals, by probabilistic PCA. To allow semantic interpretation of these main dimensions, the individual observer's terms that have the strongest correlation coefficients with the consensus dimension scores are identified. This process is entirely *post hoc* to the computation of the consensus profile. At the end of these analyses, each assessment clip (animal) receives a score on the main GPA consensus dimensions. It is these scores that are analyzed for treatment differences (and also the interaction of treatment by the THI (or HLI) category level on the day of filming). The GPA scores were also correlated to the panting scores measured from the video clips by means of Spearman rank order correlation.

5. Results

5.1 Climatic conditions

The weather conditions throughout the study were typical for the time of year, based on 30-year historical averages from 1991-2023 (BOM, 2023). Mean monthly ambient temperature (T_A) comparisons from October to May are presented in Figure 4 below, representing the 30-year data (1991-2023) from the BOM Cunderdin weather station and composite data from the 2022 and 2023 feedlot's on-site weather station.

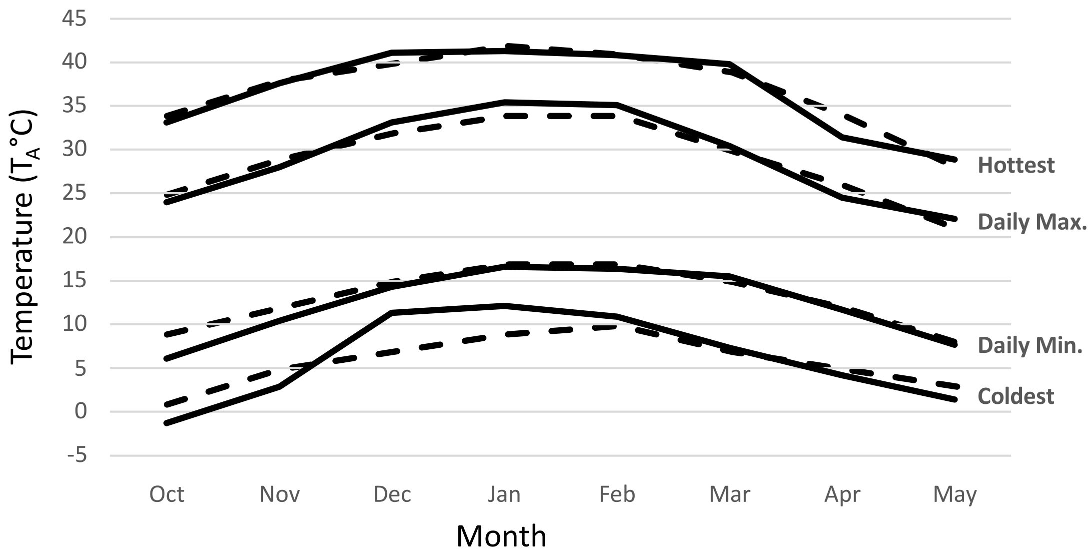

Figure 4. Mean monthly ambient temperatures (TA °C) comparison (daily maximum temperature, daily minimum daily temperature, hottest daily temp, coldest daily temperature) from October to May for the 30-year data (1991-2023) from the BOM Cunderdin weather station (dashed lines) and composite data from the 2022 and 2023 on-site feedlot weather station (solid lines).

The average minimum and maximum T_A were approximately 9°C and 37°C, respectively, throughout the study period, and exhibited a typical seasonal variation (Table 3). The average maximum T_A exceeded 40°C in the period of Day 0-30 in Groups C, D and E, corresponding with the months of January and February. The average minimum T_A (night time) dropped below 10°C in the period of Day 0-30 in Groups A and B, and in the period of Day 31-70 in Groups E and F, corresponding with the months of October, November, March and April. The average relative humidity (RH) ranged from about 45% in January and February to about 70% in October and April, corresponding to a typical 'dry' summer for this Mediterranean (Csa: Köppen climate classification system) climate (Table 3).

Temperature humidity index (THI)

During the whole study period (Figure 5, Table 4), about 24% of the time the THI was classified as mild stress (THI 72.1 to 78), 11% of the time the THI was classified as severe stress (THI 78.1 to 88), and less than 1% of the time the THI was classified as very severe stress (THI > 88).

There were 6 time-periods in the groups where the maximum THI was >10% of the total time in the severe and very severe heat stress categories (Table), these corresponded with the Day 0-30 period for Group C (Severe = 19%), Group D (Severe = 21%), Group E (Severe = 29%, Very Severe = >1%), and the Day 31-70 period for Group B (Severe = 15%), Group C (Severe = 17%), and Group D (Severe = 13%).

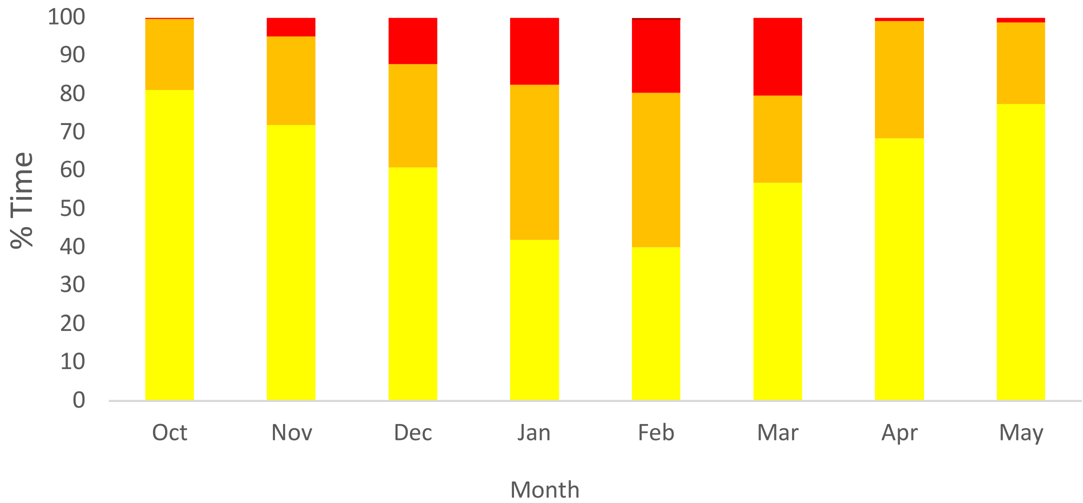

Figure 5. Composite of 2021 and 2022 of mean (% time) temperature humidity index (THI) data. No Stress (yellow: THI ≤ 72), Moderate Stress (orange: THI 72.1 ≤ 78), Severe Stress (red: THI 78.1 ≤ 88), Very Severe Stress (burgundy: THI > 88).

Heat load index (HLI)

During the whole study period (Figure 6; Table 5) about 12% of the time the HLI was classified as moderate (HLI 70.1 to 76), 5% of the time the HLI was classified as hot (HLI 76.1 to 86), and less than 1% of the time the HLI was classified as very hot (HLI > 86).

There were 2 time periods in the groups where the maximum HLI was >10% of time in the hot and very hot heat load categories (Table 5), these corresponded with the Day 0-30 period for Group D (Hot = 15%) and Group E (Hot = 16%, Very Hot = 3%).

There were 6 time-periods in the groups where there was accumulated heat load (AHL), these corresponded with the Day 0-30 period for Group B (AHL = 2), Group E (AHL = 51), Group F (AHL = 3), and the Day 31-70 period for Group A (AHL = 2), Group C (AHL = 17), and Group E (AHL = 2). Night-time conditions were very mild throughout the study, with the minimum HLI ≤ 35, indicating that the cattle were able to dissipate any AHL throughout night-time hours, thus returning to a thermal equilibrium based on the threshold for unshaded black Angus.

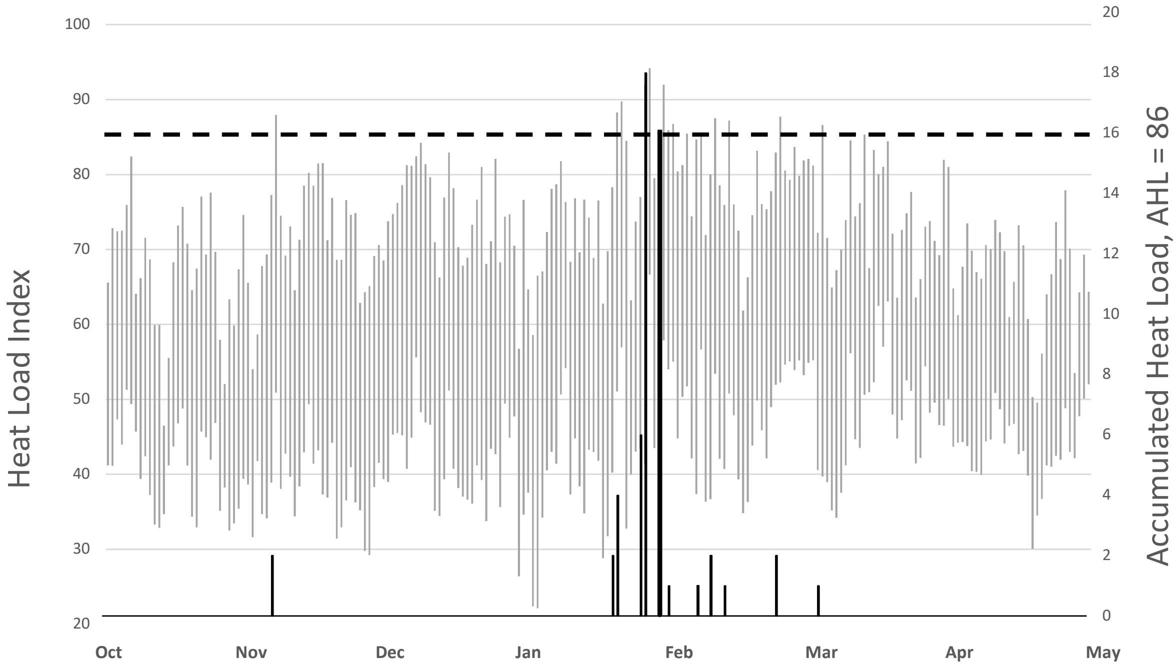

Figure 6. Composite of 2021 and 2022 heat load index (HLI: grey lines) and accumulated heat load (AHL: black lines) calculated based on an upper threshold of 86 for black Angus cattle. The dashed line represents the heat load index threshold of 86.

Table 3. Mean (± SD) of Groups A-F for maximum and minimum ambient temperature (T_A, °C), relative humidity (%), wind speed (m/s), maximum solar radiation (W/m2), and black globe temperature (BGT, °C).

Group	Feeding Period	Start (End) Date	T_A Maximum	T_A Minimum	Relative humidity (%)	Wind speed (m/sec)	Maximum solar radiation (W/m²)	Black globe temperature °C
A	0-30	18-Oct	33.5 ± 3.62	4.1 ± 1.54	64.4 ± 7.66	11.6 ± 2.04	1126 ± 201.3	38.4 ± 3.67
A	31-70	17-Nov	36.1 ± 3.53	5.4 ± 0.83	51.7 ± 6.85	13.4 ± 1.13	1118 ± 141.0	44.7 ±3.37
A	0-70	(22 Dec)	34.8 ± 3.59	4.8 ± 1.09	58.0 ± 7.22	12.5 ± 1.63	1122 ± 167.9	41.5 ± 3.54
B	0-30	9-Nov	36.1 ± 3.74	5.4 ± 0.74	56.2 ± 7.38	12.4 ± 1.88	1118 ± 143.8	44.7 ± 3.70
B	31-70	7-Dec	39.1 ± 4.28	10.4 ± 1.27	43.5 ± 8.04	14.4 ± 1.24	727 ± 112.2	47.2 ± 3.92
B	0-70	(19 Jan)	37.6 ± 3.91	7.9 ± 0.93	49.9 ± 7.70	13.4 ± 1.39	922 ± 127.3	45.9 ± 3.84
C	0-30	11-Jan	40.5 ± 4.40	12.7 ± 0.78	45.1 ± 11.42	12.7 ± 1.50	980 ± 158.5	49.5 ± 5.61
C	31-70	14-Feb	38.6 ± 4.13	10.0 ± 0.88	47.2 ± 7.64	12.7 ± 1.42	846 ± 112.9	42.6 ± 4.84
C	0-70	(23 Mar)	39.5 ± 4.23	11.3 ± 0.82	46.1 ± 9.82	12.4 ± 1.34	833 ± 137.1	46.0 ± 5.32
D	0-30	19-Jan	40.5 ± 3.75	12.7 ± 1.12	46.0 ± 8.38	12.0 ± 1.72	980 ± 193.4	49.5 ± 4.08
D	31-70	23-Feb	35.9 ± 3.22	10.1 ± 0.95	51.6 ± 8.05	10.0 ± 1.45	955 ± 228.1	44.0 ± 4.13
D	0-70	(27 Mar)	38.2 ± 3.54	11.4 ± 1.01	48.8 ± 8.25	11.0 ± 1.52	967 ± 209.4	46.8 ± 4.12
E	0-30	1-Feb	43.0 ± 3.97	11.9 ± 0.85	42.6 ± 11.03	12.5 ± 2.27	1093 ± 274.3	52.8 ± 4.46
E	31-70	1-Mar	38.4 ± 4.18	9.4 ± 0.76	65.1 ± 9.46	10.7 ± 1.03	946 ± 265.3	47.6 ± 4.67
E	0-70	(13 Apr)	40.7 ± 4.03	10.6 ± 0.80	53.8 ± 9.93	11.6 ± 1.68	1019 ± 268.3	50.2 ± 4.57
F	0-30	8-Mar	38.4 ± 3.74	11.4 ± 0.88	65.3 ± 8.42	11.0 ± 1.34	946 ± 226.6	47.6 ± 5.54
F	31-70	6-Apr	29.7 ± 3.43	5.8 ± 0.84	70.8 ± 8.13	7.6 ± 1.20	837 ± 168.5	37.0 ± 5.57
F	0-70	(16 May)	34.1 ± 3.52	8.6 ± 0.86	68.0 ± 8.39	9.3 ± 1.29	726 ± 192.6	42.3 ± 5.53
Averages			**37.5 ± 3.53**	**9.1 ± 3.10**	**54.1 ± 9.94**	**11.8 ± 1.77**	**973 ± 126.8**	**45.5 ± 4.59**

Table 4. Mean (± SD) for Groups A-F for maximum and minimum temperature humidity index (THI), and count of daily hours (% day) THI in no stress, moderate stress, severe stress, or very severe stress (VSS) category, over the 0 to 70 day) study period.

Group	Feeding period (days)	Start (End) Date	THI Maximum	THI Minimum	No stress: Hours THI (%)	Moderate stress: Hour THI (%)	Severe stress: Hour THI (%)	Very severe stress: Hours THI (%)
A	0-30	18-Oct	76.3 ± 8.27	40.2 ± 7.63	22.2 (92.7)	1.7 (7.3)	0.0 (0.0)	0.0 (0.0)
A	31-70	17-Nov	79.1 ± 8.73	42.9 ± 7.52	16.7 (69.7)	6.1 (25.6)	1.1 (4.7)	0.0 (0.0)
A	0-70	(22 Dec)	77.7 ± 8.51	41.5 ± 7.45	19.5 (81.2)	3.9 (16.4)	0.6 (2.4)	0.0 (0.0)
B	0-30	9-Nov	79.1 ± 8.72	42.9 ± 6.98	18.7 (78.0)	4.6 (19.1)	0.7 (3.0)	0.0 (0.0)
B	31-70	7-Dec	81.2 ± 8.74	52.0 ± 6.19	12.9 (53.7)	7.5 (31.4)	3.5 (14.7)	0.0 (0.0)
B	0-70	(19 Jan)	80.1 ± 8.78	47.4 ± 6.63	15.8 (65.8)	6.1 (25.3)	2.1 (8.9)	0.0 (0.0)
C	0-30	11-Jan	82.2 ± 7.75	55.1 ± 7.94	12.0 (49.9)	7.5 (31.2)	4.6 (19.0)	0.0 (0.0)
C	31-70	14-Feb	83.5 ± 8.99	51.4 ± 6.94	12.7 (53.1)	7.2 (29.9)	4.1 (17.0)	0.0 (0.0)
C	0-70	(23 Mar)	82.8 ± 8.34	53.3 ± 7.30	12.4 (51.5)	7.3 (30.5)	4.3 (18.0)	0.0 (0.0)
D	0-30	19-Jan	83.1 ± 9.80	55.6 ± 7.21	11.1 (46.1)	7.9 (32.9)	5.0 (21.0)	0.0 (0.0)
D	31-70	23-Feb	81.0 ± 9.52	46.4 ± 8.77	14.3 (59.5)	6.6 (27.5)	3.1 (13.0)	0.0 (0.0)
D	0-70	(27 Mar)	82.1 ± 9.64	51.0 ± 7.96	12.7 (52.8)	7.3 (30.2)	4.1 (17.0)	0.0 (0.0)
E	0-30	1-Feb	92.0 ± 9.38	54.7 ± 6.89	9.8 (40.7)	7.3 (30.3)	6.9 (28.8)	0.1 (0.3)
E	31-70	1-Mar	82.5 ± 9.17	50.3 ± 6.84	17.1 (71.1)	5.6 (23.1)	1.4 (5.6)	0.0 (0.0)
E	0-70	(13 Apr)	87.3 ± 9.23	52.5 ± 6.83	13.4 (55.9)	6.4 (26.7)	4.1 (17.2)	0.0 (0.1)
F	0-30	8-Mar	82.5 ± 9.35	53.4 ± 6.22	15.9 (66.2)	6.3 (26.2)	1.8 (7.7)	0.0 (0.0)
F	31-70	6-Apr	76.1 ± 9.90	43.8 ± 7.40	22.7 (94.8)	1.2 (5.2)	0.0 (0.1)	0.0 (0.0)
F	0-70	(16 May)	79.3 ± 9.78	48.6 ± 7.11	19.3 (80.5)	3.8 (15.7)	0.9 (3.9)	0.0 (0.0)
Average			**81.6 ± 4.13**	**49.1 ± 5.52**	**15.5 ± 4.17 (64.6 ± 17.47)**	**5.8 ± 2.23 (24.1 ± 9.23)**	**2.7 ± 2.19 (11.2 ± 9.13)**	**0.0 ± 0.03 (0.0 ± 0.09)**

Table 5. Mean (± SD) maximum and minimum for Groups A-F for heat load index (HLI), and count of daily hours (% day) HLI in cool, moderate, hot, very hot category, and total count of accumulated heat load (AHL_{86}), over the 0 to 70 day study period.

Group	Feeding period	Start (End) Date	HLI Maximum	HLI Minimum	Cool: Hours HLI (%)	Moderate: Hours HLI (%)	Hot: Hours HLI H (%)	Very hot: Hours HLI (%)	Accumulated heat load (AHL_{86})
A	0-30	18-Oct	72.7 ± 8.14	19.9 ± 3.58	23.8 (99.3)	0.2 (0.8)	0.0 (0.0)	0.0 (0.0)	0
A	31-70	17-Nov	81.6 ± 8.58	21.5 ± 4.12	21.6 (90.0)	2.2 (9.2)	0.2 (0.8)	0.0 (0.0)	2
A	0-70	(22 Dec)	77.2 ± 8.43	20.7 ± 3.75	22.7 (94.6)	1.2 (5.0)	0.1 (0.4)	0.0 (0.0)	2
B	0-30	9-Nov	81.6 ± 9.92	26.8 ± 3.77	22.0 (91.5)	1.8 (7.7)	0.2 (0.9)	0.0 (0.0)	2
B	31-70	7-Dec	80.4 ± 9.15	21.5 ± 3.25	20.1 (83.8)	3.7 (15.3)	0.2 (0.7)	0.0 (0.0)	0
B	0-70	(19 Jan)	81.0 ± 9.69	24.1 ± 3.41	21.0 (87.6)	2.8 (11.5)	0.2 (0.8)	0.0 (0.0)	2
C	0-30	11-Jan	87.1 ± 8.91	8.6 ± 1.56	21.6 (75.3)	4.3 (18.0)	1.6 (6.5)	0.0 (0.0)	0
C	31-70	14-Feb	79.2 ± 8.90	24.5 ± 4.25	19.8 (89.9)	2.2 (9.2)	0.1 (0.3)	0.0 (0.0)	17
C	0-70	(23 Mar)	83.1 ± 8.93	16.5 ± 4.00	12.4 (82.6)	3.3 (13.6)	0.8 (3.4)	0.0 (0.0)	17
D	0-30	19-Jan	87.1 ± 10.20	14.0 ± 2.89	17.1 (71.2)	4.5 (19.0)	2.4 (10.1)	0.0 (0.0)	0
D	31-70	23-Feb	86.4 ± 8.75	15.2 ± 3.01	18.5 (77.2)	3.8 (15.8)	1.5 (6.4)	0.0 (0.1)	0
D	0-70	(27 Mar)	86.7 ± 9.67	14.6 ± 2.92	17.8 (74.2)	4.2 (17.4)	2.0 (8.2)	0.0 (0.0)	0
E	0-30	1-Feb	100.5 ± 12.88	25.1 ± 3.78	15.4 (64.0)	4.1 (17.2)	3.8 (15.9)	0.7 (2.9)	51
E	31-70	1-Mar	85.4 ± 9.83	31.1 ± 3.89	19.6 (81.7)	3.2 (13.4)	1.1 (4.6)	0.0 (0.0)	2
E	0-70	(13 Apr)	92.9 ± 11.52	28.1 ± 3.84	17.5 (72.9)	3.7 (15.3)	2.5 (10.2)	0.3 (1.5)	53
F	0-30	8-Mar	85.4 ± 7.20	31.1 ± 4.11	18.5 (77.0)	3.9 (16.1)	1.7 (6.9)	0.0 (0.0)	3
F	31-70	6-Apr	81.6 ± 9.42	28.7 ± 3.77	23.3 (97.7)	0.6 (2.7)	0.1 (0.3)	0.0 (0.0)	0
F	0-70	(16 May)	83.5 ± 8.63	29.9 ± 3.96	20.9 (87.0)	2.3 (9.4)	0.9 (3.6)	0.0 (0.0)	3
Average			**84.1 ± 6.62**	**22.3 ± 7.02**	**20.1 ± 2.50 (83.2 ± 10.79)**	**2.9 ± 1.45 (12.0 ± 6.05)**	**1.1 ± 1.18 (4.5 ± 4.97)**	**0.1 ± 0.20 (0.3 ± 0.84)**	**6 ± 14.8**

Pen microclimate and surface temperatures

A total of 23 site visits to collect pen microclimate, surface temperatures and behavioural observations were conducted through the months of October to May. These visits occurred on the day before (or after) the routine weights were taken on Days 0, 30 and 70, and at several other timepoints to a range of climatic conditions.

Compared to within-pen black globe temperature (BGT, °C), positive relationships were found with temperature of the unshaded ground surface (T_{GU}: $R^2 = 0.76$; $P < 0.01$), shaded ground surface (T_{GS}: $R^2 = 0.79$; $P < 0.01$), and trough water (T_W: $R^2 = 0.67$; $P < 0.05$) (Figure 7).

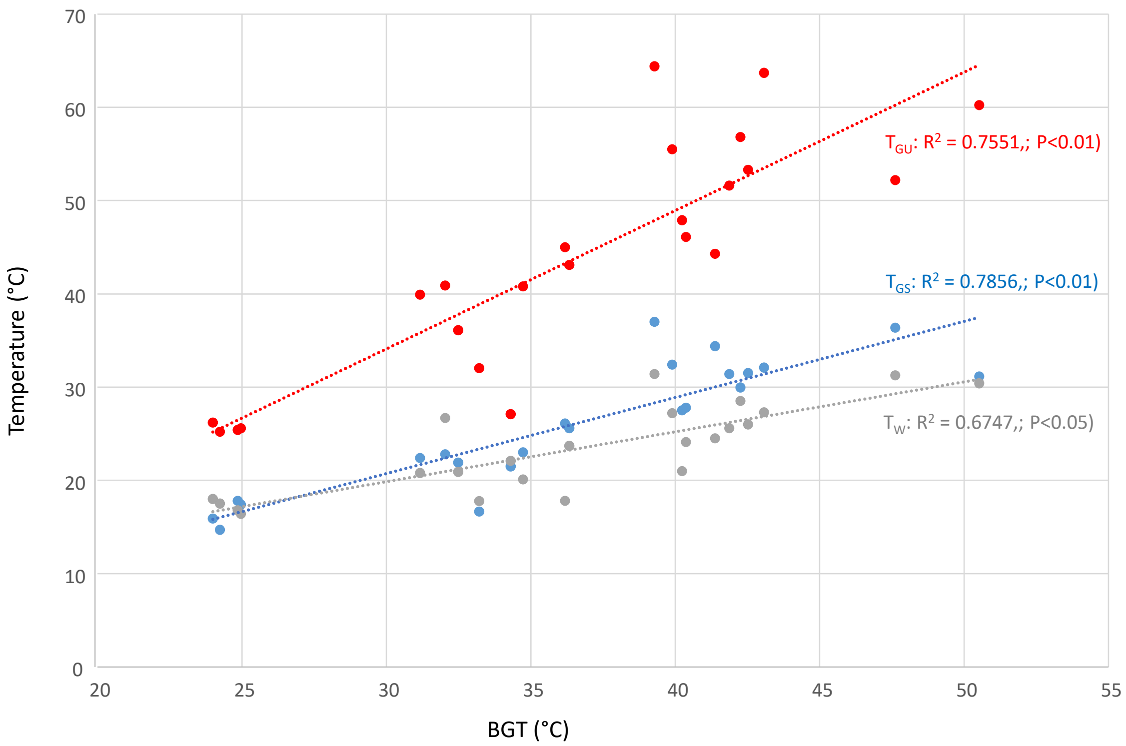

Figure 7. Relationships between black globe temperature (BGT; °C) and water temperature (TW, °C) in the feedlot pen troughs (grey), ground surface temperature (TGS, °C) under shade (blue), and ground surface temperature (TGU, °C) with no shade (red).

Compared to within-pen black globe temperature (BGT, °C), positive relationships were found with skin temperature of the unshaded black Angus cattle ($T_{U\ SKIN}$: $R^2 = 0.91$; $P < 0.001$), and shaded cattle ($T_{S\ SKIN}$: $R^2 = 0.73$; $P < 0.01$) (Figure 8) along with shaded ground surface (T_{GS}: $R^2 = 0.79$; $P < 0.01$).

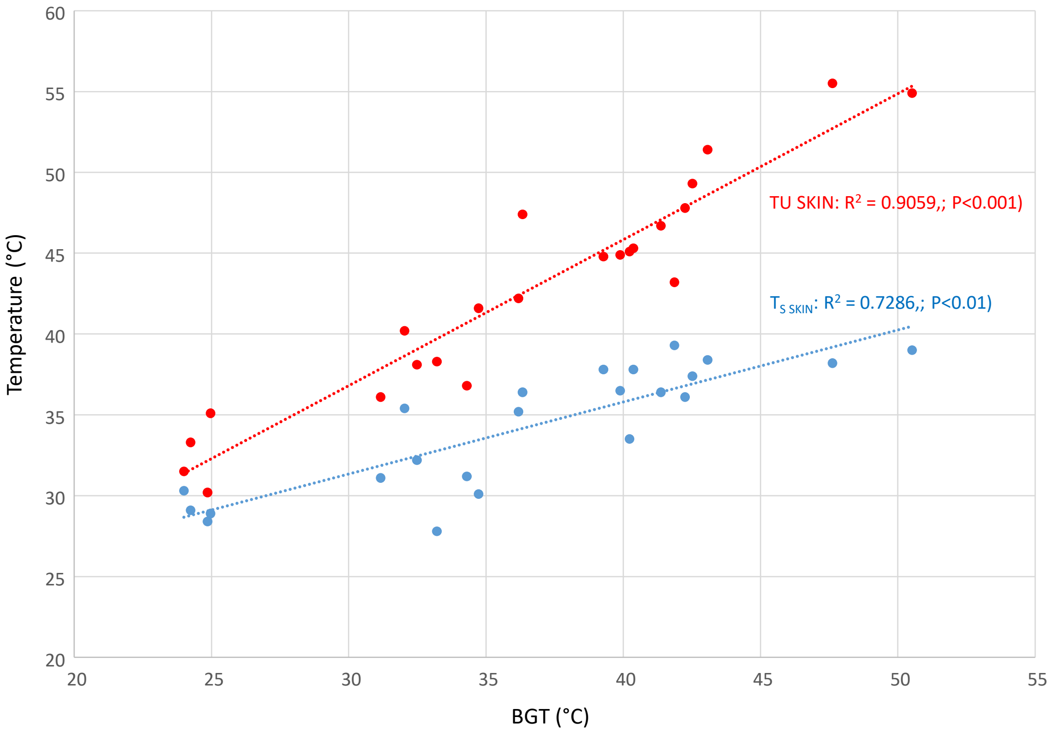

Figure 8. Relationships between black globe temperature (BGT; °C) and surface skin temperature (flank; °C) for black Angus cattle under shade (TS SKIN: blue), and with no shade (TU SKIN: red).

5.2 Animal performance

Data was collected at induction to the feedlot (Day 0), Day 30 and Day 70 as described in the methods. The raw data for cattle growth is shown in Table 6. The raw data for DMI, DM intake per kg body weight and feed:gain are shown in Table 7.

Table 6. Raw mean ± SD (minimum, maximum) for the Groups (A, B, C, D, E, F) of cattle that were housed in shaded and unshaded pens for: live weight (kg) (induction, day 30, day 70), weight gain (kg) (day 30, day 70, induction to day 70) and average daily gain (kg) (day 30, day 70, induction to day 70).

	Group A		Group B		Group C		Group D		Group E		Group F	
	Shaded	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**
	Mean ± SD (min, max)	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**	**Mean ± SD (min, max)**
	n = 77	**n = 80**	**n = 79**	**n = 78**	**n = 80**	**n = 79**	**n = 80**	**n = 76**	**n = 79**	**n = 78**	**n = 81**	**n = 80**
	Live weight (kg)											
Induction	376 ± 36.5 (300, 456)	381 ± 39.7 (292, 460)	400 ± 28.6 (324, 462)	404 ± 28.0 (354, 458)	384 ± 30.4 (302, 452)	382 ± 31.1 (322, 454)	372 ± 23.2 (320, 432)	369 ± 27.7 (318, 440)	390 ± 31.0 (322, 454)	394 ± 30.3 (328, 454)	378 ± 20.4 (346, 446)	384 ± 22.7 (332, 442)
Day 30	468 ± 49.4 (322, 562)	473 ± 46.3 (380, 580)	460 ± 31.8 (380, 526)	467 ± 33.7 (390, 534)	455 ± 34.6 (370, 536)	457 ± 37.5 (362, 562)	438 ± 27.6 (376, 502)	433 ± 31.8 (338, 502)	448 ± 35.2 (372, 536)	438 ± 38.7 (354, 520)	433 ± 28.6 (366, 504)	433 ± 30.0 (360, 496)
Day 70	544 ± 48.9 (406, 618)	539 ± 50.0 (414, 646)	553 ± 40.7 (462, 638)	550 ± 41.6 (420, 642)	522 ± 34.5 (446, 600)	525 ± 39.5 (424, 630)	484 ± 28.2 (434, 554)	485 ± 35.5 (392, 570)	538 ± 41.6 (456, 626)	515 ± 44.4 (398, 606)	512 ± 40.0 (398, 598)	504 ± 35.2 (421, 586)
	Weight gain (kg)											
Induction to Day 30	92 ± 26.7 (0, 156)	94 ± 19.3 (56, 136)	60 ± 18.0 (8, 92)	64 ± 14.0 (32, 106)	72 ± 16.1 (32, 108)	75 ± 16.6 (20, 114)	66 ± 16.0 (10, 104)	63 ± 16.5 (20, 102)	58 ± 15.2 (24, 106)	44 ± 17.0 (6, 96)	55 ± 21.8 (8, 100)	49 ± 20.5 (4, 82)
Day 31 to 70	76 ± 14.1 (42, 114)	66 ± 18.1 (-12, 116)	93 ± 20.0 (26, 134)	83 ± 15.4 (30, 120)	67 ± 13.6 (-10, 92)	68 ± 14.5 (30, 96)	46 ± 11.7 (4, 66)	52 ± 11.6 (24, 78)	90 ± 15.7 (56, 130)	77 ± 18.3 (30, 120)	79 ± 22.8 (24, 112)	69 ± 21.0 (12, 114)
Induction to Day 70	168 ± 28.7 (84, 234)	158 ± 27.1 (48, 220)	153 ± 27.5 (90, 210)	146 ± 27.9 (18, 200)	139 ± 21.1 (68, 184)	142 ± 19.9 (82, 188)	112 ± 20.3 (56, 164)	115 ± 19.8 (70, 154)	148 ± 21.8 (102, 190)	120 ± 27.3 (36, 176)	134 ± 36.3 (41, 194)	120 ± 32.5 (49, 180)
	Average daily gain (kg)											
Induction to Day 30	3.16 ± 0.92 (0.00, 5.38)	3.17 ± 0.87 (-1.86, 4.69)	2.22 ± 0.67 (0.30, 3.41)	2.34 ± 0.61 (-0.44, 3.93)	2.17 ± 0.49 (0.97, 3.27)	2.27 ± 0.50 (0.61, 3.46)	1.94 ± 0.47 (0.29, 3.06)	1.86 ± 0.49 (0.59, 3.00)	2.15 ± 0.56 (0.89, 3.93)	1.61 ± 0.63 (0.22, 3.56)	1.96 ± 0.78 (0.29, 3.57)	1.77 ± 0.73 (0.14, 2.93)
Day 31 to 70	2.12 ± 0.39 (1.17, 3.17)	1.84 ± 0.50 (-0.33, 3.22)	2.11 ± 0.45 (0.59, 3.05)	1.89 ± 0.35 (0.68, 2.73)	1.77 ± 0.36 (-0.26, 2.42)	1.78 ± 0.38 (0.79, 2.53)	1.39 ± 0.36 (0.12, 2.00)	1.57 ± 0.35 (0.73, 2.36)	2.05 ± 0.36 (1.27, 2.96)	1.74 ± 0.42 (0.68, 2.73)	1.92 ± 0.56 (0.59, 2.73)	1.69 ± 0.51 (0.29, 2.78)
Induction to Day 70	2.58 ± 0.44 (1.29, 3.60)	2.43 ± 0.42 (0.74, 3.39)	2.15 ± 0.39 (1.27, 2.96)	2.06 ± 0.39 (0.25, 2.82)	1.95 ± 0.30 (0.96, 2.59)	2.00 ± 0.28 (1.16, 2.65)	1.58 ± 0.29 (0.79, 2.31)	1.62 ± 0.28 (0.99, 2.17)	2.09 ± 0.31 (1.44, 2.68)	1.69 ± 0.38 (0.51, 2.48)	1.94 ± 0.53 (0.59, 2.81)	1.74 ± 0.47 (0.71, 2.61)

Table 7. Raw means for the Groups (A, B, C, D, E, F) of cattle that were housed in shaded and unshaded pens for: dry matter intake (kg) (induction, day 30, day 70), and dry matter intake per kg weight gain (kg) (day 30, day 70).

	Group A		Group B		Group C		Group D		Group E		Group F	
	Shaded	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**	**Shaded**	**Unshaded**
	Pen average dry matter per head per day (kg)											
Day 0 to 30	7.5	7.3	7.3	11.8	11.8	11.4	8.9	9.5	11.4	8.9	9.5	8.0
Day 31 to 70	13.4	13.3	13.3	12.3	12.3	12.5	10.8	11.6	12.5	10.8	11.6	10.6
Day 0 to day 70	10.7	9.4	11.9	11.9	9.73	10.4	10.2	10.41	9.41	8.63	9.8	9.1
	Pen feed conversion rate (kg feed/hd/day: average daily gain)											
Day 0 to 30	2.37	2.30	3.29	5.05	5.45	5.03	4.59	5.10	5.30	5.51	4.85	4.53
Day 31 to 70	6.34	7.25	6.30	5.52	6.96	7.03	7.76	7.38	6.09	6.19	6.03	6.26
Day 0 to day 70	4.14	3.87	5.53	5.78	4.98	5.19	6.47	6.42	4.50	5.09	5.06	5.24

Cattle performance data

There was no difference between the liveweight of shaded and unshaded cattle at the time of induction or Day 30. At Day 70, there was a trend for an effect of shade on live weight, where the shaded cattle were on average 6.0 kg heavier than the unshaded group (P = 0.18, Table 8). The groups with the largest differences in weight between shaded and unshaded pens were groups E and F and the groups with the least differences Group C and D.

There were modest differences in ADG (kg) between shaded and unshaded cattle with the magnitude of these differences varying between time points. There was a trend for the ADG of the shaded cattle to be 0.15 kg higher from Day 31 to Day 70 (P = 0.13, Table 8). The groups with the largest differences in ADG between shaded and unshaded pens were groups E and F and the groups with the least differences Group C and D.

Dry matter intake per head per day was calculated based on the pen average. There were no differences in DMI (kg) or feed to gain ratio between shaded and unshaded cattle at any time point (Table 8).

Table 8. Predicted least square means ± SE for cattle liveweight at day 0, 30, 70, average daily gain (kg) and dry matter intake, feed:gain over the time periods day 0-30, day 30-70 and day 0-70.

	Treatment		Significance
Time period	**Shaded**	**Unshaded**	
	Liveweight		
Induction	383.4 ± 5.59	386 ± 4.59	0.25
Day 30	450.4 ±6.48	450.2 ± 6.48	0.94
Day 70	525.6 ± 9.96	519.6 ± 9.96	0.18
	Average daily gain (kg)		
Day 0 to 30	2.27 ± 0.21	2.17 ± 0.21	0.37
Day 31 to 70	1.90 ± 0.08	1.75 ± 0.08	0.13
Day 0 to day 70	2.05 ± 0.13	1.92 ± 0.13	0.13
	Dry matter intake (kg)		
Day 0 to 30	9.4 ± 0.76	9.48 ± 0.76	0.94
Day 31 to 70	12.3 ± 0.42	11.9 ± 0.42	0.27
Day 0 to day 70	10.3 ± 0.43	9.97 ± 0.43	0.34
	Dry matter intake (kg) / gain in weight (kg)		
Day 0 to 30	4.78 ± 0.61	4.98 ± 0.61	0.43
Day 31 to 70	6.55 ± 0.36	6.84 ± 0.36	0.31
Day 0 to day 70	5.56 ± 0.28	5.3 ± 0.28	0.26

5.3 Rumen logger data

There were few differences between shaded and unshaded cattle with respect to rumen temperature over the entire project. The minimum T_{RUM} was on average higher in the shaded cattle ($P < 0.05$) in all time periods: induction to Day 30 (0.6°C), Day 31 to Day 70 (0.3°C) and induction to Day 70 (0.5°C). There was no difference between mean and maximum T_{RUM}.

The percentage of the cattle with rumen loggers registering T_{RUM} > 41.5°C on at least one occasion approached significance ($P < 0.08$) over the time period from induction to Day 70. For the shaded cattle with rumen loggers, 92% of the cattle had one or more episodes of rumen temperature > 41.5°C compared to 95% of the unshaded cattle ($P = 0.08$, Table 9).

Table 9. Predicted least square means ± SE for average minimum rumen temperature (°C), % of cattle with > one occurrence rumen temperature > 41.5 °C, average number of drinking per day over the time periods day 0-30, day 31-70 and day 0-70.

	Treatment		
Time period	**Shaded**	**Unshaded**	**Significance**
	Average minimum rumen temperature°C		
Day 0 to Day 30	34.9 ± 0.34	34.3 ± 0.34	0.03
Day 31 to 70	34.5 ± 0.25	34.2 ± 0.25	0.16
Day 0 to Day 70	34.1 ± 0.30	33.6 ± 0.30	0.08
	% cattle with at least one episode of rumen temp > 41.5°C		
Day 0 to Day 30	87.7 ± 8.1	86.7 ± 8.1	0.82
Day 31 to 70	61.8 ± 7.4	70.6 ± 7.3	0.44
Day 0 to Day 70	92 ± 3.93	95 ± 3.93	0.07
	Average no drinks per day		
Day 0 to Day 30	4.5 ± 0.14	4.2 ± 0.15	0.05
Day 31 to 70	3.7 ± 0.26	3.7 ± 0.26	0.77
Day 0 to Day 70	4.2 ± 0.16	4.1 ± 0.16	0.25

Of the cattle that had at least one episode of T_{RUM} over 41.5 °C there was no difference between treatments for mean and maximum temperature. The minimum T_{RUM} was consistently higher in the shaded cattle across both time periods ($P < 0.05$). From the time of induction to Day 30 the average minimum T_{RUM} temperature in shaded cattle was 0.6°C and from Day 31 to Day 70, 0.3°C higher than the unshaded cattle. For cattle that had at least one episode of T_{RUM} over 41.5°C there was no difference in the number of minutes spent above T_{RUM} 41.5°C between shaded and unshaded treatment groups.

On average, from induction to Day 30, the cattle in the shaded pens had 0.3 more drinking events compared to the cattle in unshaded pens ($P = 0.05$, Table 9). The amount of time spent drinking was used as an estimation of water consumption, and despite shaded cattle drinking more frequently in some instances, there were no differences between the time shaded and unshaded cattle drank for over the 70 days.

Across all time periods there was no significant difference in activity of shaded and unshaded cattle as measured by the rumen loggers ($P > 0.05$).

5.4 Blood parameters

There were few effects of shade on the blood parameters that measured association with heat stress and dehydration. There was no difference between shaded and unshaded cattle for PCV, total plasma protein and heat shock protein at any blood collection timepoint (Day 0, Day 30 and Day 70) ($P>0.05$).

There were no differences between shaded and unshaded cattle in the concentration of fibrinogen (g/L) at any timepoint (P>0.05). At the time of induction, the raw mean fibrinogen of Group A and B was slightly greater than the upper limit of normal, however for the remainder of the time points both groups fell within normal limits. The raw mean white cell and neutrophil numbers were within normal limits at all time points in all groups. When comparing the white cell parameters between shaded and unshaded cattle there were no differences in white cell, neutrophil or lymphocyte numbers (P>0.05). At day 30, the unshaded cattle had greater neutrophils than the shaded cattle (P < 0.05, Table 10). This resulted in a N:L that was higher than that of the shaded cattle (P = 0.05, Table 10). At day 70 blood collection, there was no difference between shaded and unshaded cattle for white cell, neutrophil, lymphocyte or N:L ratios (P > 0.05)).

Table 10. Predicted least square means ± SE for total white cell count (x10³/µL), neutrophil and lymphocyte numbers (x10³/µL) and neutrophil:lymphocyte.

	Treatment		
Time period	**Shaded**	**Unshaded**	**Significance**
	White cell count (x10³/µL)		
Day 0	9.15 ± 0.26	9.45 ± 0.26	0.36
Day 30	8.77 ± 0.41	9.34 ± 0.41	0.23
Day 70	9.18 ± 0.18	9.45 ± 0.18	0.34
	Neutrophil (x10³/µL)		
Day 0	2.79 ± 0.23	2.76 ± 0.23	0.85
Day 30	2.54 ± 0.34	2.98 ± 0.33	0.04
Day 70	3.16 ± 0.22	3.02 ± 0.22	0.58
	Lymphocyte (x10³/µL)		
Day 0	5.43 ± 0.34	5.67 ± 0.34	0.37
Day 30	5.40 ± 0.36	5.44 ± 0.36	0.83
Day 70	5.18 ± 0.19	5.55 ± 0.19	0.25
	N:L		
Day 0	0.57 ± 0.09	0.56 ± 0.09	0.87
Day 30	0.50 ± 0.08	0.61 ± 0.08	0.05
Day 70	0.68 ± 0.07	0.60 ± 0.07	0.42

Table 11. Raw mean ± SD (minimum, maximum) for the Groups A- E for results of packed cell volume (%), total plasma protein (g/L), white cell count (x103/µL), and neutrophil:lymphocyte for cattle in shaded and unshaded pens at day 0, 30 and 70.

	Normal range[1]	Group A		Group B		Group C		Group D		Group E		Group F	
		Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded
		Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)
		Packed cell volume											
Day 0		0.40 ± 0.03 (0.35, 0.45)	0.41 ± 0.03 (0.36, 0.46)	0.40 ± 0.03 (0.35, 0.43)	0.40 ± 0.03 (0.37, 0.44)	0.42 ± 0.04 (0.35, 0.51)	0.42 ± 0.03 (0.38, 0.48)	0.40 ± 0.02 (0.36, 0.46)	0.40 ± 0.04 (0.35, 0.51)	0.41 ± 0.04 (0.34, 0.48)	0.41 ± 0.03 (0.34, 0.46)	0.36 ± 0.04 (0.30, 0.44)	0.35 ± 0.02 (0.30, 0.40)
Day 30	0.23-0.46	0.37 ± 0.03 (0.31, 0.41)	0.38 ± 0.02 (0.34, 0.41)	0.38 ± 0.04 (0.27, 0.44)	0.38 ± 0.04 (0.32, 0.45)	0.36 ± 0.03 (0.31, 0.41)	0.36 ± 0.03 (0.32, 0.42)	0.35 ± 0.02 (0.30, 0.40)	0.36 ± 0.03 (0.32, 0.45)	0.34 ± 0.04 (0.26, 0.40)	0.34 ± 0.03 (0.27, 0.39)	0.37 ± 0.05 (0.29, 0.48)	0.41 ± 0.06 (0.29, 0.53)
Day 70		0.39 ± 0.02 (0.35, 0.42)	0.39 ± 0.03 (0.33, 0.44)	0.40 ± 0.03 (0.36, 0.46)	0.40 ± 0.04 (0.32, 0.46)	0.37 ± 0.03 (0.32, 0.43)	0.38 ± 0.02 (0.33, 0.42)	0.39 ± 0.03 (0.32, 0.43)	0.38 ± 0.03 (0.33, 0.44)	0.39 ± 0.05 (0.30, 0.50)	0.39 ± 0.03 (0.34, 0.44)	0.42 ± 0.04 (0.35, 0.52)	0.44 ± 0.04 (0.37, 0.53)
		Total plasma protein (g/L)											
Day 0		74.2 ± 4.10 (68.0, 80.0)	73.0 ± 6.56 (59.0, 88.0)	67.5 ± 4.20 (6.00, 72.0)	67.9 ± 4.65 (60.0, 74.0)	70.7 ± 6.13 (60.0, 82.0)	72.6 ± 3.80 (67.0, 80.0)	74.9 ± 3.81 (65.0, 80.0)	72.9 ± 3.31 (66.0, 80.0)	70.8 ± 2.65 (66.0, 76.0)	69.6 ± 3.44 (64.0, 76.0)	73.0 ± 4.98 (66.0, 82.0)	76.1 ± 5.11 (70.0, 90.0)
Day 30	67-88	69.7 ± 3.42 (62.0, 78.0)	68.5 ± 3.34 (60.0, 74.0)	69.0 ± 3.27 (62.0, 74.0)	68.8 ± 3.61 (62.0, 74.0)	74.1 ± 4.60 (64.0, 82.0)	73.0 ± 3.15 (65.0, 79.0)	75.2 ± 4.21 (68.0, 81.0)	74.1 ± 4.27 (68.0, 82.0)	71.9 ± 3.96 (66.0, 78.0)	75.6 ± 8.27 (66.0, 102.0)	70.8 ± 3.25 (66.00, 76.00)	72.9 ± 3.36 (68.0, 78.0)
Day 70		69.6 ± 4.73 (62.0, 82.0)	70.7 ± 3.18 (66.0, 80.0)	73.3 ± 5.15 (66.0, 88.0)	74.0 ± 3.90 (70.0, 82.0)	73.2 ± 3.39 (68.0, 79.0)	71.6 ± 3.32 (66.0, 76.0)	76.4 ± 3.61 (71.0, 82.0)	74.0 ± 3.74 (69.0, 82.0)	79.6 ± 5.80 (70.0, 90.0)	77.7 ± 7.10 (68.0, 96.0)	74.7 ± 3.86 (70.0, 80.0)	75.3 ± 4.84 (70.0, 89.0)
		White Cell Count ($x10^3$/µL)											
Day 0		8.7 ± 1.87 (5.30, 12.40)	8.7 ± 1.60 (6.20, 12.10)	8.9 ± 2.22 (6.00, 12.40)	10.8 ± 4.18 (6.80, 20.80)	8.9 ± 1.70 (5.20, 12.20)	8.6 ± 1.92 (6.00, 12.70)	9.2 ± 2.51 (5.80, 13.30)	9.4 ± 1.94 (6.40, 12.90)	9.1 ± 1.98 (5.80, 12.90)	10.1 ± 2.27 (6.60, 14.80)	10.0 ± 1.78 (7.50, 14.00)	9.8 ± 2.16 (6.30, 14.60)
Day 30	4.9 - 12.0	8.4 ± 2.69 (4.80, 17.40)	9.1 ± 1.78 (5.60, 12.80)	7.9 ± 1.63 (4.40, 10.70)	9.3 ± 2.09 (6.40, 14.20)	10.1 ± 1.61 (7.10, 13.20)	9.9 ± 2.15 (5.20, 14.10)	9.8 ± 1.91 (5.70, 13.00)	10.5 ± 1.80 (7.80, 14.30)	6.6 ± 1.74 (2.40, 9.10)	8.5 ± 1.83 (4.90, 11.70)	9.8 ± 2.00 (4.80, 12.30)	8.8 ± 2.48 (4.50, 13.40)
Day 70		9.0 ± 2.10 (6.80, 14.10)	9.0 ± 1.05 (7.10, 11.00)	9.3 ± 2.20 (5.90, 13.10)	9.8 ± 2.10 (6.60, 14.10)	9.6 ± 2.12 (6.40, 13.80)	9.5 ± 1.70 (7.00, 12.60)	8.8 ± 2.17 (2.80, 11.20)	9.7 ± 1.74 (7.10, 13.90)	9.1 ± 2.18 (5.80, 13.40)	9.9 ± 1.73 (7.70, 13.60)	9.4 ± 1.87 (6.30, 12.70)	8.8 ± 2.17 (5.90, 13.60)
		Fibrinogen (g/L)											
Day 0		4.9 ± 1.51 (2.20, 7.10)	5.0 ± 1.36 (2.00, 7.49)	4.6 ± 0.81 (3.60, 6.30)	4.6 ± 1.41 (2.50, 7.50)	3.1 ± 0.41 (2.27, 3.80)	3.4 ± 0.51 (2.70, 4.40)	3.1 ± 0.70 (1.44, 4.32)	3.2 ± 0.53 (2.24, 4.58)	3.2 ± 0.82 (0.97, 4.54)	2.9 ± 1.00 (1.06, 5.81)	3.4 ± 0.85 (1.51, 5.58)	3.8 ± 0.79 (1.49, 5.12)
Day 30	< 4	3.2 ± 0.89 (2.20, 5.80)	3.1 ± 0.49 (2.20, 3.98)	2.9 ± 0.52 (2.01, 4.58)	3.3 ± 0.91 (1.31, 5.70)	3.6 ± 0.55 (2.70, 4.46)	4.0 ± 0.87 (2.70, 6.14)	3.1 ± 0.69 (1.60, 5.01)	3.1 ± 0.54 (1.49, 4.09)	3.4 ± 0.94 (1.30, 5.24)	3.4 ± 0.89 (1.94, 5.12)	2.8 ± 0.79 (0.63, 3.78)	2.2 ± 0.97 (0.50, 3.78)
Day 70		3.2 ± 0.51 (2.41, 4.01)	2.9 ± 0.54 (1.84, 4.40)	3.0 ± 1.24 (1.96, 7.57)	2.8 ± 0.64 (1.89, 4.17)	3.1 ± 0.78 (1.17, 4.37)	2.7 ± 0.59 (1.70, 3.60)	2.6 ± 0.47 (1.69, 3.50)	2.7 ± 0.83 (1.02, 4.33)	2.3 ± 0.73 (1.00, 3.72)	2.2 ± 0.66 (1.32, 3.55)	3.3 ± 0.62 (2.36, 4.90)	3.2 ± 1.12 (1.28, 6.06)
		Neutrophil:Lymphocyte											
Day 0		0.98 ± 0.82 (0.33, 4.11)	0.86 ± 0.68 (0.30, 3.17)	0.6 ± 0.17 (0.31, 0.78)	0.8 ± 1.04 (0.16, 3.47)	0.5 ± 0.27 (0.14, 1.18)	0.5 ± 0.25 (0.13, 1.00)	0.4 ± 0.13 (0.18, 0.76)	0.3 ± 0.13 (0.13, 0.61)	0.6 ± 0.29 (0.13, 1.17)	0.4 ± 0.20 (0.17, 0.84)	0.5 ± 0.14 (0.29, 0.81)	0.6 ± 0.26 (0.28, 1.15)
Day 30	0.4:2.34	0.40 ± 0.20 (0.13, 0.98)	0.59 ± 0.30 (0.26, 1.28)	0.5 ± 0.17 (0.29, 0.79)	0.6 ± 0.31 (0.15, 1.39)	0.8 ± 0.58 (0.21, 2.35)	1.0 ± 0.64 (0.24, 2.88)	0.3 ± 0.14 (0.12, 0.62)	0.5 ± 0.22 (0.09, 0.94)	0.4 ± 0.23 (0.11, 1.02)	0.4 ± 0.18 (0.25, 0.93)	0.5 ± 0.18 (0.22, 0.90)	0.5 ± 0.14 (0.20, 0.73)
Day 70		0.68 ± 0.30 (0.27, 1.23)	0.70 ± 0.35 (0.18, 1.67)	0.5 ± 0.32 (0.23, 1.56)	0.5 ± 0.40 (0.17, 1.87)	0.5 ± 0.33 (0.18, 1.57)	0.4 ± 0.14 (0.19, 0.80)	0.6 ± 0.20 (0.28, 0.82)	0.6 ± 0.34 (0.24, 1.59)	1.2 ± 0.64 (0.44, 2.96)	0.7 ± 0.25 (0.41, 1.28)	0.6 ± 0.32 (0.28, 1.42)	0.6 ± 0.49 (0.13, 2.00)

[1] Smith, B. P., Van Metre, D. C., & Pusterla, N. (2020). *Large animal internal medicine* (N. Pusterla, Ed.; Sixth edition.). Elsevier, Inc.

Table 12. Raw mean ± SD (minimum, maximum) for Groups A-F for cattle were housed in shaded and unshaded pens for heat shock protein (ng/ml) at day 0, 30 and 70.

	Group A		Group B		Group C		Group D		Group E		Group F	
	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded
	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)
Day 0	2.4 ± 0.32 (1.88, 2.82)	2.3 ± 0.35 (1.83, 2.88)	2.4 ± 0.33 (1.80, 2.88)	2.2 ± 0.28 (1.87, 2.61)	2.3 ± 0.32 (1.80, 2.84)	2.4 ± 0.33 (1.82, 2.90)	2.7 ± 0.37 (1.99, 3.53)	2.7 ± 0.41 (2.00, 3.53)	2.8 ± 0.37 (2.25, 3.69)	2.7 ± 0.32 (2.25, 3.46)	2.3 ± 0.33 (1.82, 2.82)	2.6 ± 0.51 (1.91, 3.97)
Day 30	2.3 ± 0.33 (1.86, 2.87)	2.4 ± 0.31 (1.87, 2.87)	2.3 ± 0.20 (1.92, 2.75)	2.6 ± 0.35 (2.14, 3.70)	3.3 ± 0.76 (2.42, 5.57)	2.8 ± 0.45 (2.17, 4.19)	2.3 ± 0.28 (1.85, 2.77)	2.3 ± 0.32 (1.83, 2.88)	2.4 ± 0.25 (1.80, 2.85)	2.4 ± 0.31 (2.00, 3.14)	2.2 ± 0.25 (1.74, 2.71)	2.3 ± 0.37 (1.71, 2.94)
Day 70	2.6 ± 0.43 (2.04, 3.73)	2.3 ± 0.31 (1.85, 2.82)	2.3 ± 0.30 (1.81, 2.92)	2.7 ± 0.41 (2.26, 4.19)	2.3 ± 0.33 (1.82, 2.89)	2.3 ± 0.31 (1.82, 2.78)	2.3 ± 0.33 (1.82, 2.89)	2.3 ± 0.33 (1.92, 2.89)	2.2 ± 0.19 (1.94, 2.66)	2.2 ± 0.21 (1.78, 2.76)	2.2 ± 0.34 (1.84, 3.05)	2.3 ± 0.21 (2.04, 2.72)

5.5 Animal behaviour

5.5.1 Flight speed

Raw flight speed (m/s) is shown in Table 13. There were no differences in flight speed between shaded and unshaded cattle at any of the time points (induction, Day 30 or Day 70). The raw data for flight speed at days 0, 30 and 70 are shown in Table 13. Both shade and unshaded cattle demonstrated a reduction in flight speed over the duration of their time in the feedlot ($P < 0.01$). For both treatment groups, on average at the time of induction the flight speed was 2.54 m/sec ± 0.05 which reduced to 2.41 ± 0.05 at day 30 and then 2.17 ± 0.05 at day 70.

Table 13. Raw mean ± SD (minimum, maximum) for flight speed (m/s) on crush exit for Groups A-F of cattle that were housed in shaded and unshaded pens at day 0, day 30, day 70.

	Group A		Group B		Group C		Group D		Group E		Group F	
	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded
	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)	Mean ± SD (min, max)
Day 0 flight speed (m/s)	2.7 ± 0.75 (0.8, 4.33)	2.6 ± 0.77 (0.96, 4.33)	2.7 ± 0.66 (1.1, 4.06)	2.5 ± 0.67 (0.78, 4.06)	2.4 ± 0.72 (1.1, 4.33)	2.4 ± 0.62 (1.03, 3.82)	2.4 ± 0.62 (0.8, 4.06)	2.6 ± 0.61 (1.23, 3.61)	2.6 ± 0.80 (1.0, 4.06)	2.4 ± 0.66 (1.07, 4.06)	2.5 ± 0.78 (0.9, 4.33)	2.7 ± 0.90 (0.93, 4.64)
Day 30 flight speed (m/s)	2.5 ± 0.63 (0.92, 4.06)	2.4 ± 0.57 (1.23, 3.61)	2.5 ± 0.64 (0.96, 4.06)	2.6 ± 0.69 (1.20, 3.82)	2.4 ± 0.64 (0.93, 4.06)	2.3 ± 0.63 (1.20, 4.33)	2.4 ± 0.63 (1.20, 4.33)	2.1 ± 0.66 (0.75, 3.61)	-	-	2.5 ± 0.81 (0.69, 5.00)	2.5 ± 0.73 (1.02, 3.82)
Day 70 flight speed (m/s)	2.5 ± 0.68 (1.25, 4.06)	2.3 ± 0.75 (1.07, 4.06)	2.2 ± 0.64 (1.12, 4.06)	2.2 ± 0.69 (0.72, 4.06)	1.9 ± 0.62 (0.24, 3.61)	1.9 ± 0.48 (1.03, 3.42)	2.1 ± 0.70 (0.46, 3.42)	2.0 ± 0.58 (1.07, 3.82)	2.1 ± 0.72 (0.78, 4.06)	2.0 ± 0.62 (0.86, 3.82)	2.1 ± 0.70 (0.88, 4.06)	2.2 ± 0.74 (1.10, 4.33)

5.5.2 Panting score

Pen-average panting score (aPS) was variable over the whole study period (Table 14), with the unshaded animals in group blocks C, D and E having the highest aPS (P < 0.005). When the climatic conditions within the study blocks was taken into account it was found that aPS was influenced by shade treatment (P < 0.01), THI category (P < 0.005) and HLI category (P < 0.005), and the interaction between shade treatment and THI/HLI category (P < 0.001; Figure 9).

For the unshaded cattle, as THI increased from ‘no stress’ to ‘severe stress’ there was increase from 0.009 ± 0.015 to 0.400 ± 0.052 (P < 0.001) in aPS, and as THI increased from ‘no stress’ to ‘very severe stress’ aPS increased to 0.635 ± 0.121 (P < 0.001). For the shaded cattle, as THI increased from ‘no stress’ to ‘moderate stress’ and ‘severe stress’ there was no significant difference in aPS, but as THI increased from ‘no stress’ to ‘very severe stress’ aPS increased from 0.002 ± 0.007 to 0.250 ± 0.131 (P < 0.001). Within the ‘severe’ THI category, the aPS in the unshaded group was 6.7-fold higher than the shaded group (P < 0.001), and within the ‘very severe’ THI category the aPS un the unshaded group was 2.5-fold higher than the shaded group (P < 0.001).

For the unshaded cattle, as HLI increased from ‘cool’ to ‘moderate’ there was increase from 0.009 ± 0.015 to 0.150 ± 0.038 (P < 0.005) in aPS, and as HLI increased to ‘hot’ and ‘very hot’ aPS increased to 0.283 ± 0.151 (P < 0.05) and 0.635 ± 0.121 (P < 0.001), respectively. For the shaded cattle, as HLI increased from ‘cool’ to ‘moderate’ and ‘hot’ there was no significant difference in aPS, but as HLI increased from ‘cool’ to ‘very hot’ aPS increased from 0.003 ± 0.007 to 0.160 ± 0.131 (P < 0.05). Within the ‘hot’ HLI category, the aPS in the unshaded group was 23-fold higher than the shaded group (P < 0.001), and within the ‘very hot’ HLI category the aPS in the unshaded group was 4-fold higher than the shaded group (P < 0.005).

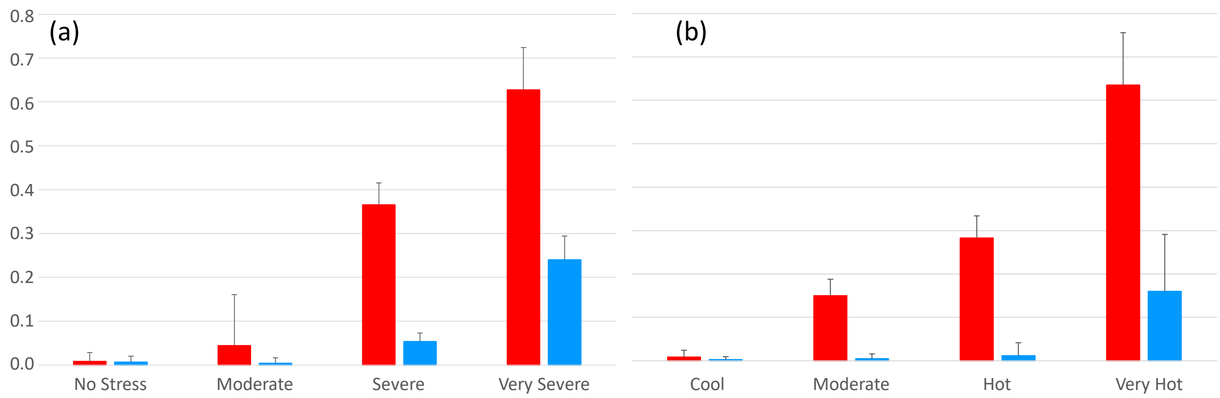

Figure 9. Mean (± SD) of the average panting score (aPS) collated by (a) temperature humidity index (THI) category and (b) heat load index (HLI) category. Blue (shaded) and red (unshaded) bars indicate treatment groups. The aPS was calculated based on the number of cows observed at each corresponding panting score. An aPS above 0.8 indicates cattle are experiencing a high heat load.

Table 14. Mean (± SD) pen average panting score (aPS). Mean (± SD) percentage of cattle per pen in the shade (if available), drinking, or eating. Mean (± SD) within-pen temperature humidity index (THI) category (1=no stress to 4=very severe stress) and heat load index (HLI) category (1=cool to 4=very hot).

Group	Shade	Period	aPS	%Shade	%Drinking	% Eating	Av. THI	Av. HLI
A	S	0-30	0.0 ± 0.00	63 ± 35.9	2.6 ± 0.77	2.1 ± 1.44	1.0 ± 0.00	1.0 ± 0.00
A	U	"	0.0 ± 0.02	-	5.3 ± 1.85	4.4 ± 2.89	1.0 ± 0.00	1.0 ± 0.00
A	S	31-70	0.0 ± 0.00	64 ± 39.4	2.9 ± 1.56	9.3 ± 2.42	2.3 ± 0.52	2.3 ± 0.82
A	U	"	0.0 ± 0.03	-	2.7 ± 1.12	9.9 ± 3.63	2.3 ± 0.52	2.3 ± 0.82
A	S	0-70	0.0 ± 0.00	64 ± 35.9	2.8 ± 1.25	6.5 ± 2.85	1.8 ± 0.79	1.8 ± 0.92
A	U	"	0.0 ± 0.03	-	3.7 ± 2.88	7.7 ± 2.24	1.8 ± 0.79	1.8 ± 0.92
B	S	0-30	0.0 ± 0.00	79 ± 32.6	4.3 ± 1.13	4.7 ± 2.65	1.8 ± 0.84	1.6 ± 0.89
B	U	"	0.0 ± 0.02	-	2.4 ± 1.79	11.0 ± 7.28	1.8 ± 0.84	1.6 ± 0.89
B	S	31-70	0.0 ± 0.01	90 ± 4.82	4.1 ± 0.97	3.5 ± 1.24	2.0 ± 0.82	2.3 ± 0.96
B	U	"	0.0 ± 0.02	-	7.8 ± 2.02	3.8 ± 1.79	2.0 ± 0.82	2.3 ± 0.96
B	S	0-70	0.0 ± 0.00	84 ± 24.0	4.2 ± 1.00	4.1 ± 1.14	1.9 ± 0.74	1.9 ± 0.88
B	U	"	0.0 ± 0.02	-	4.5 ± 2.29	8.9 ± 3.16	1.9 ± 0.74	1.9 ± 0.88
C	S	0-30	0.0 ± 0.02	89 ± 7.4	2.4 ± 0.61	4.8 ± 1.28	2.0 ± 0.89	2.0 ± 0.89
C	U	"	0.1 ± 0.20	-	8.4 ± 2.07	8.9 ± 3.52	2.0 ± 0.89	2.0 ± 0.89
C	S	31-70	0.0 ± 0.01	84 ± 23.9	2.6 ± 1.13	2.3 ± 1.62	1.8 ± 0.98	2.2 ± 0.98
C	U	"	0.3 ± 0.49	-	9.3 ± 4.68	5.3 ± 3.54	1.8 ± 0.98	2.2 ± 0.98
C	S	0-70	0.0 ± 0.01	87 ± 17.1	2.5 ± 0.87	3.5 ± 1.19	1.9 ± 0.90	2.1 ± 0.90
C	U	"	0.2 ± 0.37	-	8.9 ± 3.48	7.1 ± 3.35	1.9 ± 0.90	2.1 ± 0.90
D	S	0-30	0.0 ± 0.01	86 ± 5.2	2.1 ± 1.69	9.3 ± 3.07	2.3 ± 0.96	2.3 ± 0.96
D	U	"	0.2 ± 0.29	-	10.7 ± 3.22	11.3 ± 5.03	2.3 ± 0.96	2.3 ± 0.96
D	S	31-70	0.0 ± 0.01	93 ± 6.1	2.3 ± 0.53	2.2 ± 1.54	1.8 ± 0.98	2.2 ± 0.98
D	U	"	0.4 ± 0.77	-	9.1 ± 3.61	4.3 ± 1.51	1.8 ± 0.98	2.2 ± 0.98
D	S	0-70	0.0 ± 0.01	90 ± 6.6	2.2 ± 1.06	5.0 ± 2.48	2.0 ± 0.94	2.2 ± 0.92
D	U	"	0.4 ± 0.61	-	9.7 ± 3.38	7.1 ± 2.74	2.0 ± 0.94	2.2 ± 0.92
E	S	0-30	0.1 ± 0.11	92 ± 6.3	3.2 ± 1.52	4.3 ± 1.53	3.2 ± 0.45	3.2 ± 0.45
E	U	"	0.5 ± 0.66	-	10.6 ± 4.38	4.9 ± 3.42	3.2 ± 0.45	3.2 ± 0.45
E	S	31-70	0.0 ± 0.01	71 ± 28.0	3.4 ± 1.98	2.9 ± 1.18	2.3 ± 0.89	2.4 ± 0.74
E	U	"	0.1 ± 0.09	-	9.1 ± 3.07	3.9 ± 3.46	2.3 ± 0.89	2.4 ± 0.74
E	S	0-70	0.0 ± 0.08	79 ± 23.4	3.3 ± 1.75	3.5 ± 1.39	2.6 ± 0.87	2.7 ± 0.75
E	U	"	0.3 ± 0.49	-	9.8 ± 3.68	4.4 ± 3.35	2.6 ± 0.87	2.7 ± 0.75
F	S	0-30	0.0 ± 0.01	96 ± 1.6	1.8 ± 1.17	2.4 ± 1.92	3.0 ± 0.00	3.0 ± 0.00
F	U	"	0.0 ± 0.06	-	7.1 ± 5.73	2.0 ± 1.86	3.0 ± 0.00	3.0 ± 0.00
F	S	31-70	0.0 ± 0.00	30.4 ± 4.6	5.4 ± 1.26	6.9 ± 4.13	1.0 ± 0.00	1.2 ± 0.41
F	U	"	0.0 ± 0.01	-	6.9 ± 1.55	6.8 ± 4.56	1.0 ± 0.00	1.2 ± 0.41
F	S	0-70	0.0 ± 0.01	56 ± 33.8	3.9 ± 2.20	5.1 ± 4.00	1.8 ± 1.03	1.9 ± 0.99
F	U	"	0.0 ± 0.05	-	7.0 ± 3.89	4.4 ± 4.10	1.8 ± 1.03	1.9 ± 0.99

5.5.3 Pen position, posture and activity

Shade utilisation

Shade utilisation was variable over the whole study period (Table 14) with group blocks B, C and D having the highest usage (P < 0.05). When the climatic conditions within the study blocks was taken into account it was found that shade utilisation was influenced by THI category (P < 0.05) and HLI category (P < 0.05; Figure 10 a and Figure 10 b). Minimum shade utilisation was 56.2 ± 32.15 % and 58.5 ± 30.58 % for the THI 'no stress' and the HLI 'cool' categories, respectively. Shade utilisation in the 'moderate' categories for THI and HLI was not significantly different to the THI 'no stress' and the HLI 'cool' categories. As THI increased from 'no stress' to 'severe stress' and HLI increased from 'cool' to 'hot' there was a 30% (P < 0.005) and 58% (P < 0.001) increase, respectively, in shade utilisation. As THI increased from 'no stress' to 'very severe stress' and HLI increased from 'cool' to 'very hot' there was a 70% (P < 0.001) and 64% (P < 0.001) increase, respectively, in shade utilisation. Maximum shade utilisation was 95.8 ± 2.14 % for the THI 'very severe stress' and HLI 'very hot' categories.

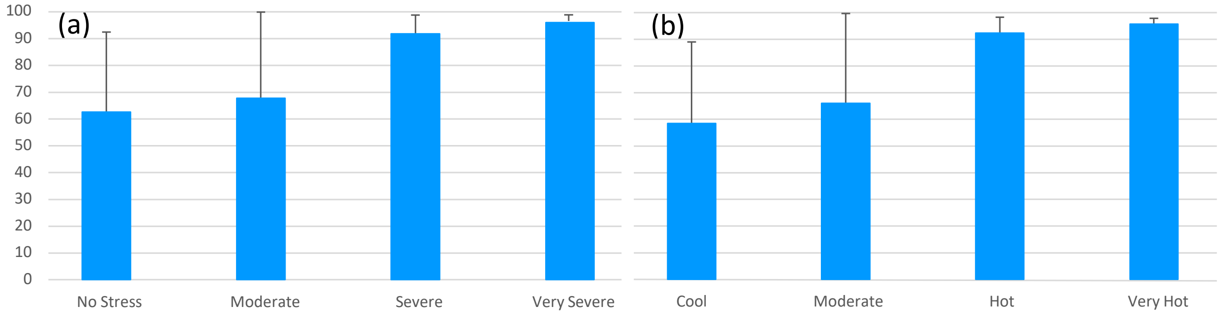

Figure 10. Mean (± SD) of shade utilisation collated by (a) temperature humidity index (THI) category and (b) heat load index (HLI) category.

Drinking and Eating Activity

The percentage of animals observed drinking or eating was variable over the whole study period (Table 14) with the unshaded animals in Groups C, D and E having the highest drinking occurrences (P < 0.05). There were no group differences in eating behaviour. When the climatic conditions within the study blocks was taken into account it was found that drinking was influenced by shade treatment (P < 0.01), THI category (P < 0.005) and HLI category (P < 0.005), and the interaction between shade treatment and THI/HLI category (P < 0.01; Figure 12).

For the unshaded cattle, as THI increased from 'no stress' to 'moderate stress' there was no significant difference in % drinking. As THI increased from 'no stress' to 'severe stress' and 'very severe stress' drinking increased from 6.8 ± 2.39 to 9.3 ± 4.77 (P < 0.05) and 11.4 ± 2.30 (P < 0.01), respectively. For the shaded cattle, as THI increased there was no significant difference in drinking. Within the 'severe stress' THI category, the % drinking in the unshaded group was 3.7-fold higher than the shaded group (P < 0.01), and within the 'very hot' THI category the % drinking in the unshaded group was 4.6-fold higher than the shaded group (P < 0.001).

For the unshaded cattle, as HLI increased from 'cool' to 'moderate' there was increase from 5.9 ± 2.85 to 7.1 ± 3.75 (P < 0.05) in % drinking, and as HLI increased to 'hot' and 'very hot' drinking increased to 9.0 ± 4.50 (P < 0.01) and 11.4 ± 2.30 (P < 0.005), respectively. For the shaded cattle, as HLI increased from 'cool' to 'moderate' and 'hot' there was no significant difference in drinking, but as HLI increased from 'cool' to 'very hot' drinking decreased from 3.7 ± 1.82 to 1.7 ± 0.72 (P < 0.05). Within the 'hot' HLI category, the % drinking in the unshaded group was 3.5-fold higher than the shaded group (P < 0.01), and within the 'very hot' HLI category the % drinking in the unshaded group was 6.7-fold higher than the shaded group (P < 0.005).

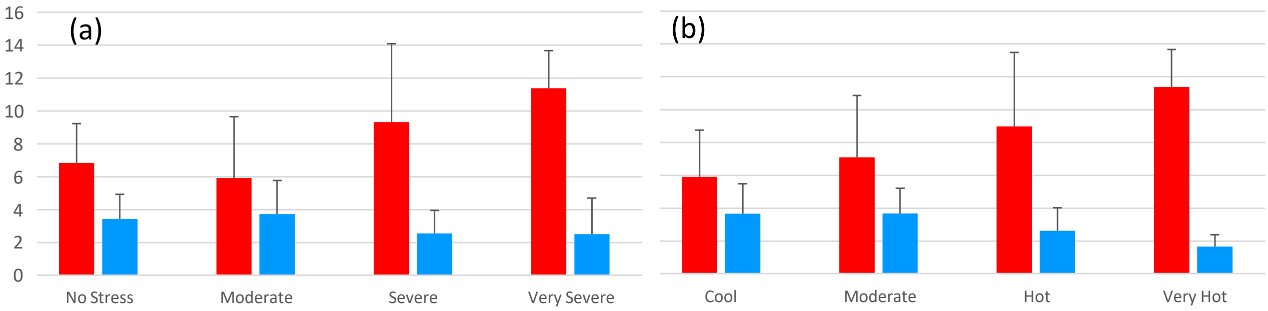

Figure 11. Mean (± SD) of total percentage of animals drinking collated by (a) temperature humidity index (THI) category and (b) heat load index (HLI) category. Blue (shaded) and red (unshaded) bars indicate treatment groups.

Posture

The percentage of animals observed lying was variable over the whole study period (Table 15), with group block D having the highest occurrence, both in the shade and in the sun ($P < 0.05$). However, when the climatic conditions within the study blocks was taken into account there was no significant difference between treatments or THI/HLI category (Figure 12).

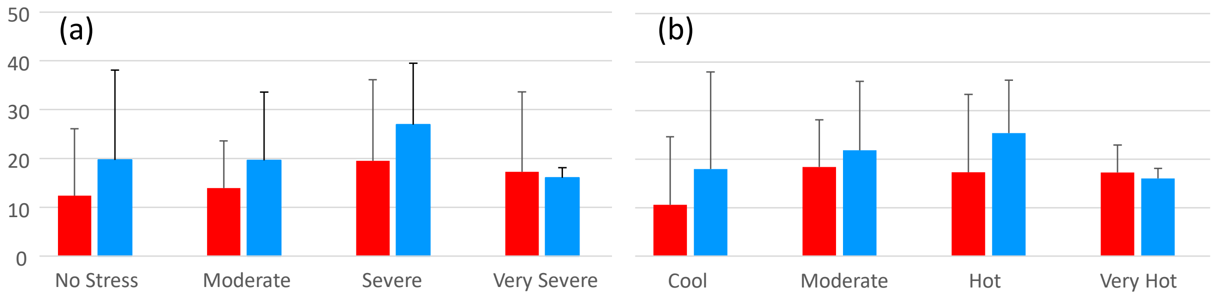

Figure 12. Mean (± SD) of total percentage of animals lying collated by (a) temperature humidity index (THI) category and (b) heat load index (HLI) category. Blue (shaded) and red (unshaded) bars indicate treatment groups.

Table 15. Mean (± SD) percentage of cattle per pen lying when in the sun or in the shade (if available). Mean (± SD) within-pen temperature humidity index (THI) category (1=no stress to 4=very severe stress) and heat load index (HLI) category (1=cool to 4=very hot).

Group	Shade	Period	% Lying in Sun	% Lying in Shade	% Total Lying	Av. THI	Av. HLI
A	S	0-30	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	1.0 ± 0.00	1.0 ± 0.00
A	U	"	0.0 ± 0.00	-	0.0 ± 0.00	1.0 ± 0.00	1.0 ± 0.00
A	S	31-70	2.6 ± 1.32	10.8 ± 4.09	18.7 ± 2.41	2.3 ± 0.52	2.3 ± 0.82
A	U	"	7.8 ± 3.52	-	7.8 ± 3.52	2.3 ± 0.52	2.3 ± 0.82
A	S	0-70	1.4 ± 0.71	6.0 ± 2.49	11.2 ± 1.64	1.8 ± 0.79	1.8 ± 0.92
A	U	"	4.7 ± 2.52	-	4.7 ± 2.52	1.8 ± 0.79	1.8 ± 0.92
B	S	0-30	5.2 ± 1.09	8.9 ± 1.82	8.7 ± 1.24	1.8 ± 0.84	1.6 ± 0.89
B	U	"	4.1 ± 1.90	-	4.1 ± 1.90	1.8 ± 0.84	1.6 ± 0.89
B	S	31-70	0.5 ± 0.30	31.9 ± 3.57	28.9 ± 2.41	2.0 ± 0.82	2.3 ± 0.96
B	U	"	5.3 ± 3.50	-	15.3 ± 3.50	2.0 ± 0.82	2.3 ± 0.96
B	S	0-70	3.0 ± 1.27	19.1 ± 6.14	17.7 ± 1.94	1.9 ± 0.74	1.9 ± 0.88
B	U	"	2.6 ± 1.19	-	8.6 ± 2.19	1.9 ± 0.74	1.9 ± 0.88
C	S	0-30	19.9 ± 8.14	28.8 ± 9.20	27.0 ± 8.65	2.0 ± 0.89	2.0 ± 0.89
C	U	"	16.1 ± 7.55	-	16.1 ± 7.55	2.0 ± 0.89	2.0 ± 0.89
C	S	31-70	0.0 ± 0.00	16.2 ± 5.46	16.2 ± 5.46	1.8 ± 0.98	2.2 ± 0.98
C	U	"	23.1 ± 7.57	-	23.1 ± 7.57	1.8 ± 0.98	2.2 ± 0.98
C	S	0-70	9.9 ± 7.62	22.5 ± 3.80	21.0 ± 6.42	1.9 ± 0.90	2.1 ± 0.90
C	U	"	19.6 ± 7.55	-	19.6 ± 7.55	1.9 ± 0.90	2.1 ± 0.90
D	S	0-30	14.8 ± 4.42	45.5 ± 14.64	41.2 ± 15.52	2.3 ± 0.96	2.3 ± 0.96
D	U	"	18.9 ± 6.46	-	18.9 ± 6.46	2.3 ± 0.96	2.3 ± 0.96
D	S	31-70	18.0 ± 7.94	34.2 ± 8.97	33.4 ± 18.63	1.8 ± 0.98	2.2 ± 0.98
D	U	"	20.2 ± 9.95	-	20.2 ± 9.95	1.8 ± 0.98	2.2 ± 0.98
D	S	0-70	16.7 ± 5.21	38.7 ± 10.48	36.5 ± 17.04	2.0 ± 0.94	2.2 ± 0.92
D	U	"	19.7 ± 7.35	-	19.7 ± 7.35	2.0 ± 0.94	2.2 ± 0.92
E	S	0-30	0.0 ± 0.00	19.3 ± 6.96	19.3 ± 6.96	3.2 ± 0.45	3.2 ± 0.45
E	U	"	8.5 ± 4.16	-	8.5 ± 4.16	3.2 ± 0.45	3.2 ± 0.45
E	S	31-70	21.6 ± 8.44	36.0 ± 15.65	26.5 ± 9.89	2.3 ± 0.89	2.4 ± 0.74
E	U	"	19.2 ± 10.04	-	19.2 ± 10.04	2.3 ± 0.89	2.4 ± 0.74
E	S	0-70	14.4 ± 12.91	28.4 ± 15.65	23.8 ± 7.24	2.6 ± 0.87	2.7 ± 0.75
E	U	"	15.1 ± 9.70	-	15.1 ± 9.70	2.6 ± 0.87	2.7 ± 0.75
F	S	0-30	2.9 ± 1.70	16.9 ± 8.61	16.4 ± 6.42	3.0 ± 0.00	3.0 ± 0.00
F	U	"	17.4 ± 10.59	-	17.4 ± 10.59	3.0 ± 0.00	3.0 ± 0.00
F	S	31-70	30.1 ± 3.16	18.5 ± 6.91	18.8 ± 9.85	1.0 ± 0.00	1.2 ± 0.41
F	U	"	27.1 ± 11.36	-	27.1 ± 11.36	1.0 ± 0.00	1.2 ± 0.41
F	S	0-70	20.6 ± 14.49	17.7 ± 8.34	17.7 ± 9.79	1.8 ± 1.03	1.9 ± 0.99
F	U	"	22.2 ± 11.41	-	22.2 ± 11.41	1.8 ± 1.03	1.9 ± 0.99

5.5.4 Qualitative behavioural assessment (QBA)

Video footage was collected from 30 animals in the shaded and 30 animals from the unshaded treatment groups, with a third collected on days classified as potential no heat stress (NS; THI ≥72), a third on days classified as potential moderate heat stress (MS; THI = 72-78), and a third on days classified as potential severe heat stress (SS; THI = 78-88). The videos were cropped and adjusted for brightness, such that the recordings excluded as much of the surrounding environment as possible in the footage, including indications of shade (shadows).

Fourteen volunteers, all with some experience with cattle, were recruited to perform QBA analysis. Observers were shown 2 video clips for instructional purposes and talked through the scoring system (see below). After this training, observers watched the 30 video clips in random order, without any identification of location or experimental design. After watching each video, observers scored it on the visual analogue scale (VAS) using the provided list of descriptive terms. After scoring, these values on the VAS were converted into measurements from 0-100, and subjected to Principal Component Analysis (PCA).

The general Procrustes analysis (GPA) consensus explained 62% of the variation between observer scores of steers and this differed significantly from the mean randomised profile (t_{99}=12.3, $P < 0.001$). GPA determined that the majority of the variation (75.2%) in VAS scores was explained by two main dimensions (Figure 13a), from now on denoted as Dimension 1 (47.4%) and Dimension 2 (27.8%). The two highest ranking terms, as ascertained by PCA analysis, for each dimension (1 and 2, +ve and -ve) are used as semantic tags on the axes.

QBA indicated that observers mainly saw differences in cattle demeanour related to the treatments when the terms they used were assigned to Dimension 2 in the PCA statistical analysis (Figure 13b and Figure 13c). This QBA dimension usually represents activity of the animals rather than valency of mood (*cf.* dimension 1). Closer inspection of the treatment averages from Dimension 2 (Figure 13c) indicates that there was no difference in Dimension 2 scores between the shaded and unshaded NS groups, or between the NS groups and the shaded MS group. The unshaded MS group had a Dimension 2 score which was nearly 3-fold lower than the unshaded NS group ($P < 0.05$), indicating that these animals were perceived as more 'agitated/anxious'. Both the shaded and unshaded SS groups had a Dimension 2 scores lower than the NS groups, with the shaded SS group about 2-fold lower than the shaded NS group ($P < 0.05$), the unshaded SS group about 7.5-fold lower than the unshaded NS group ($P < 0.01$), again indicating that these animals were perceived as more 'agitated/anxious'.

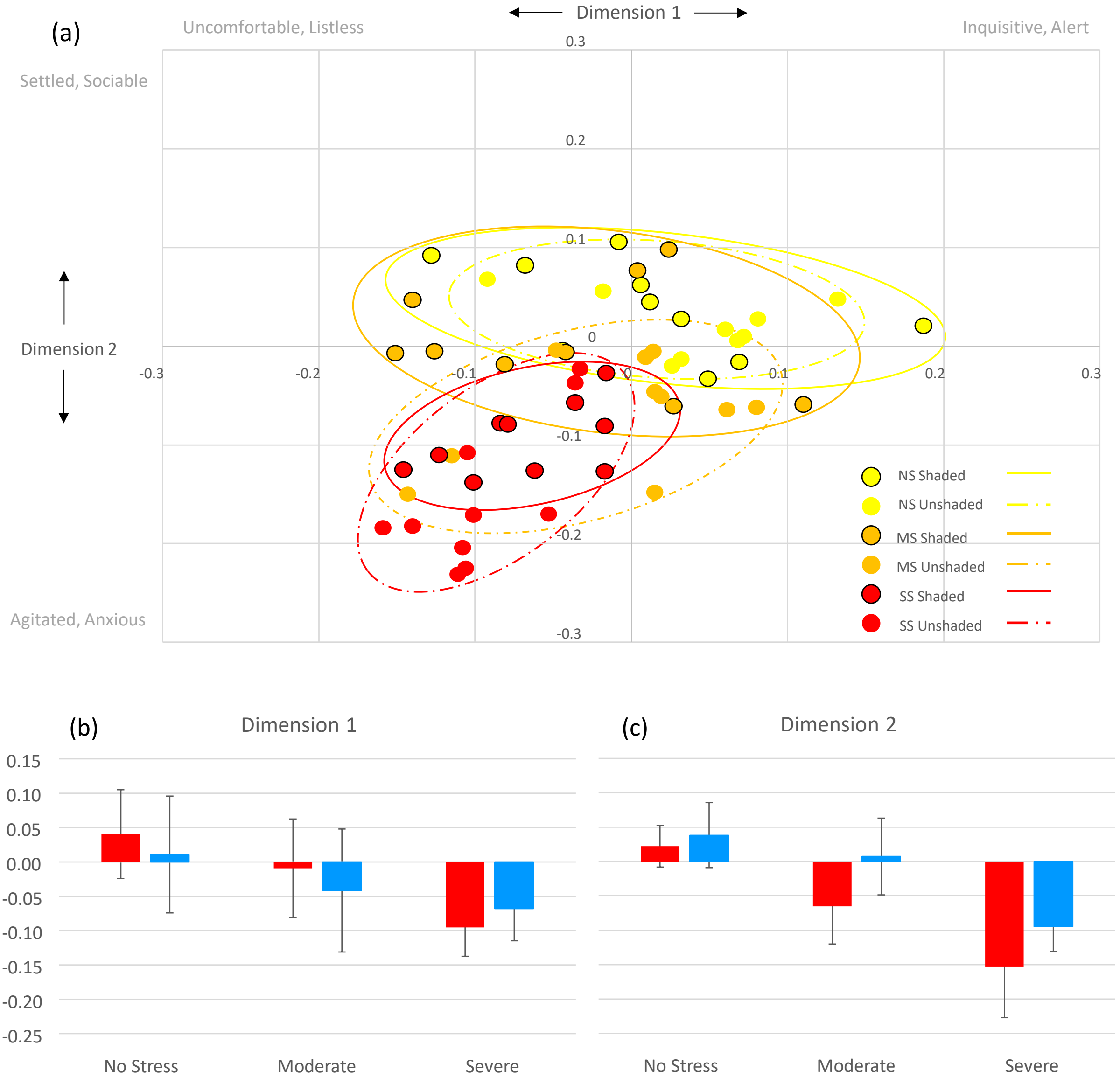

Figure 13. Position of (a) individual cattle from the shaded (black bordered circles) and unshaded (non-bordered circles) groups on the two main principal component analysis (PCA) dimensions characterised their temperature humidity index (THI) category as no stress (NS; yellow), moderate stress (MS; orange), and severe stress (red). The corresponding coloured elipses highlight the clustering of the cattle on the dimensions and the effect of THI level and shade provision. Graphical summary of treatment x THI effects for (b) PCA dimension 1 and (c) PCA dimension 2 scores for the shaded (blue) and unshaded (red) treatment groups. Values are means ± SD.

Panting scores for the unshaded cattle were correlated to the Dimension 2 PCA scores (R^2 = 0.43; $P < 0.001$)) indicating that as pant score increased, the cattle were described as more 'agitated/anxious' by the observers (Figure 14). There was no significant relationship between the panting scores for the shaded cattle and their Dimension 2 PCA scores.

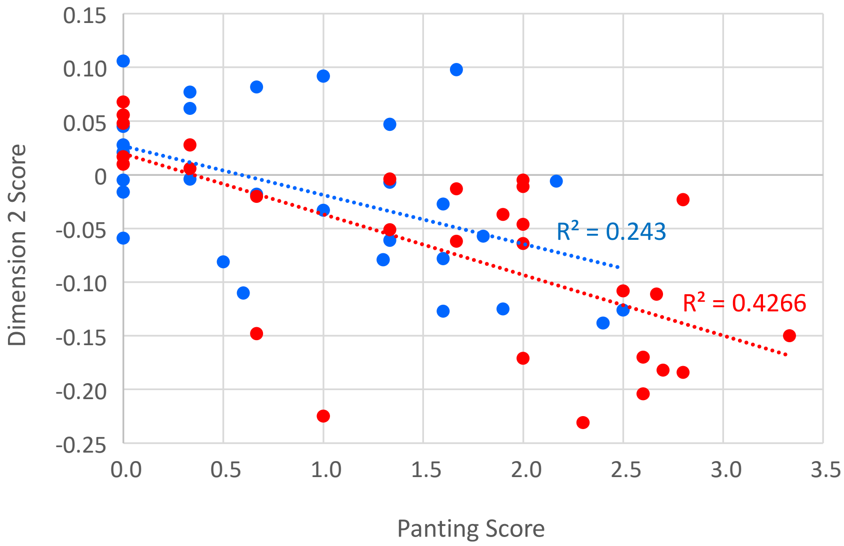

Figure 14. Relationships between the PCA Dimension 2 score and panting score for black Angus cattle under shade (blue), and with no shade (red).

6. Discussion

Predictions from climate change models are suggesting that there will be more extreme thermal events and that the duration of these events will be longer. While cattle losses due to extreme thermal events have been low in temperate regions of Australia, even in the Mediterranean-style central and northern agricultural regions of WA, the impact of production losses due to extreme heat in these regions is less certain. In 2006, Sackett et al. (2006) estimated that Australian feedlots lose $16.5 million (due to reductions in animal performance) over summer. There is little scientific research regarding the effects on feedlot cattle in temperate regions during, and following, prolonged exposure to high heat load, however, conditions in these regions can pose thermal challenges for cattle (eg. average Summer max/min =34°C/17°C; and reached 47°C on 4th Feb 2020). Research suggests that the effects of heat stress in cattle can be reduced by a number of strategies (eg. nutrition, genotype, shade, fans, sprinklers), with the provision of shade having the best direct application. Shade structures have the advantage of being passive i.e. there is no need to switch something on or off, and animals are able to choose shade as required, as long as the shade footprint is sufficient for the number of animals.

6.1 Climatic data

The weather conditions throughout the study were typical for the time of year, in terms of ambient temperatures and relative humidity, based on 30-year historical averages from 1991-2023 (BOM, 2023). The climate in the region is classified as a temperate Mediterranean climate (Csa: Köppen climate classification system) with a hot dry summer. The hottest (and driest) months in our study were December, January, February and the beginning of March which corresponded to the final 'finisher feeding' period (Day 31-7) of Group B, Group C, Group D and the beginning 'starter feeding' period (Day 0-30) of Groups E and F. It was also in these groups that there were generally more time-periods when the temperature humidity index (THI) values were in the 'severe' and 'very severe' heat stress categories and the heat load index (HLI) values were in the 'hot' and 'very hot' categories. The cooler months in our study were October, November, April and May which corresponded to Group A, the 'starter feeding' period of Group B, the 'finisher feeding' period of Groups E and F.

In this study, we have reported the results in comparison to both THI and HLI fluctuations. THI is calculated only based on ambient temperature and relative humidity. The benefit of THI it has been extensively applied in research and, if there is no dedicated on-site weather recording instrument, it can be calculated from local weather station recordings. The limitation of THI is that it does not take into account solar radiation or air flow, or accumulation effects. HLI is a more complete environmental index which includes ambient temperature, relative humidity, solar radiation, wind speed, and can calculate accumulation load. These parameters are derived from the black globe temperature (BGT), an advanced meteorological measurement which uses a heat-absorbing metal globe, which may not be available on traditional weather stations.

Pen microclimate and surface temperatures

Previous studies have shown that shade structures do not alter ambient temperature or relative humidity (Buffington et al., 1981; Buffington et al., 1983; Gaughan et al., 2004). What shade provides is an area of reduced direct exposure to direct solar radiation, reducing the radiant heat load by up to 30 % (Bond et al., 1967). This is reflected in the findings from our study where black globe temperatures (BGT), which incorporates solar radiation, showed a positive relationship with ground, water and animal skin temperature within the pens. Moreover, the provision of shade in the pens reduced ground surface temperature by nearly 50% and cattle skin temperatures by nearly 30% at the hottest BGT levels recorded. Solar radiation plays a significant role in the heat dissipation process of animals (Blackshaw and Blackshaw, 1994). When the BGT is high, heat accumulation may surpass the animal's ability to dissipate it effectively. Shade provides a location within pen to seek relief from solar radiation and a potential area where heat dissipation can occur.

6.2 Performance data

This experiment has demonstrated there is a modest production advantage to the provision of shade in a commercial feedlot in this geographical location. Across the 6 Groups used in this experiment, carried out between the months of October through to May, there was a modest overall effect of shade, whereby these cattle had an increased ADG of 0.13 kg. However, there was a considerable range in overall effect of shade on ADG, from -0.04 kg/d in Group D to 0.40 kg/d in Group E. Similar to our results, Mitlöhner, Morrow, Dailey et al. (2001) demonstrated shaded heifers to have an increase in ADG and final body weight compared to unshaded heifers. Blaine and Nsahlai (2011) showed a small increase in ADG and body weight in finisher cattle over 36 days in South Africa. An Australian study in a subtropical climate by Gaughan, Bonner, Loxton et al. (2010) showed that shaded Angus cattle had increased ADG, liveweight and gain per kg feed. It is difficult to compare the magnitude of results in other experiments with the current experiment as cattle are of different breed, genetics, sex and are managed under different environmental conditions. However, the results of the current study add to the literature that indicate production benefits of shade and importantly in this experiment it was under commercial conditions with 80 steers per pen, in Western Australia over typical summer conditions for the region. In contrast to our study, there are other studies that have not shown production advantages associated with shaded cattle (Brown-Brandl, Eigenberg and Nienaber 2013, DiGiacomo, Warner, Leury et al. 2014). However similarly, it is difficult to compare these results to our experiment due to the study designs, cattle breeds and environmental conditions of the experiments.

In our experiment there was on average no difference in DMI between shaded and unshaded treatment pens. It has been well recognised that DMI decreases as cattle become heat stressed in dairy (West 2003, Rhoads, Rhoads, VanBaale et al. 2009) and beef cattle (Gaughan et al. 2010). Increasing heat has been shown to decrease intake directly through inputs to the hypothalamus (Baile and Forbes 1974). Reduced DMI can result in reduced growth rates, with the magnitude and duration of high heat load periods and reduced DMI will influence the impact on cattle growth. Given this experiment was conducted under commercial conditions accurate information regarding individual DMI was not obtained which may have provided evidence of DMI differences between shaded and unshaded cattle. However, there are other factors that contribute to decreased growth under the influence of heat other than reduced DMI which could be attributed to the difference in weight gain such as insulin activity and glucose metabolism (Wheelock, Rhoads, VanBaale et al. 2010).

Cost benefit and payback period

Overall there was a trend for 0.13 kg/d higher ADG in shaded pens (*P* =0.13). The higher ADG in the shaded pens may offer an additional financial advantage with reduced time to reach market weight. To apply these advantages over time, eg. to calculate the payback period for cost of shade infrastructure, it must be emphasized that the magnitude of the financial benefits of shade will vary based on numerous factors such as the variability in summer weather conditions, growth potential of the cattle in the feedlot, health status of the cattle, cost of feed, and any marketing incentives. However, to give an approximation of the financial benefit of the findings from the current study we can perform a sensitivity analysis based on the following inputs (Table 16):

Table 16. Sensitivity analysis representing how the shade cost payback model will change with price per hot carcass weight (HCW, kg) and shade capital cost.

Item	Shade Effect
ADG benefit per year	0.13
Day benefit per year	91.25
Extra BW, kg	11.8625
Dressing %	52
Extra HCW, kg	6.2
$/kg HCW	**Extra Revenue, $/hd/yr**
5	30.84
6.5	40.10
8	49.35
9.5	58.60

Payback, yrs

Shade Capital Cost, $/hd	$5.00/kg HCW	$6.50/kg HCW	$8.00/kg HCW	$9.50/kg HCW
100	3.2	2.5	2.0	1.7
150	4.9	3.7	3.0	2.6
200	6.5	5.0	4.1	3.4
250	8.1	6.2	5.1	4.3
300	9.7	7.5	6.1	5.1

Footnote: Day benefit per year (days) calculated for 3 months of summer. Extra BW (body weight) = ADG/days. Extra HCW (hot carcass weight) = dressing%/100*extra BW. Extra revenue = $/kg HCW/extra HCW. Payback = shade capital cost/extra revenue.

Using an ADG benefit per year of 0.13, the shade capital cost payback period ranges from about 2 years ($100/hd shade cost and $9.50/kg HCW) to 10 years ($300/hd shade cost and $5.00/kg HCW) given variable shade capital costs and $/kg HCW. There may also be other further financial benefits of the shaded cattle reaching their market weights earlier, and possible incentives from the cattle qualifying for carbon reduction schemes like Coles Carbon-Neutral Beef.

6.3 Rumen logger data

Rumen temperature

There was little difference between treatment groups with respect to the rumen temperatures and when data from all cattle containing rumen loggers were analysed, there was no difference between the mean or maximum T_{RUM} of shaded and unshaded cattle. This is similar to some other studies that measured body temperature of shaded and unshaded Angus steers (Gaughan et al. 2010). However, in this same study, during a heat load event, shaded cattle have been demonstrated to have lower body temperature. In our experiment, cattle were not all managed in the same environmental conditions (time of summer) and therefore identifying a specific time period to analyse heat load events was not possible. However, to identify cattle that were considered to have experienced heat load events, their data was analysed separately if they had registered T_{RUM} > 41.5°C on one or more occasions. A T_{RUM} of 41.5°C was chosen as a minimum as it is likely to reflect a core temperature of approximately 40.5°C which is significantly elevated above the normal range for a cow in thermoneutral temperatures (38 to 38.5°C) (Sjaastad, Sand and Hove 2010) and a temperature above which the ruminal microflora are likely to be impacted (Yadav et al. 2013). In our experiment, the cattle which experienced these higher temperatures there continued to be no difference between the mean and maximum T_{RUM} of shaded and unshaded cattle. The reason for the lack of difference may be that environmental temperatures were not extreme enough to elicit a difference between treatments, with cattle compensating well for the heat load experienced in both shaded and unshaded pens.

This experiment demonstrated an increase in the average minimum rumen temperature on the shaded cattle. This result is difficult to interpret, although a similar result has been observed in other studies (Brown-Brandl, Jones and Woldt 2005). This result has previously been attributed to better dissipation of heat due to greater exposure to the night sky, however in the pens used in the current study this is unlikely to be an issue as the shade structures did not cover the entire pens. Cattle behaviour was not monitored over-night and future studies could assess the pen usage of the unshaded cattle to see if they maintained closer contact under the shade structures over-night, limiting heat dissipation.

Drinking events

Water consumption was unable to be directly measured, however the frequency of drinking events was able to be estimated using the rumen loggers data. From this data it was found that differences existed in drinking frequency, with drinking events increased in the shaded cattle. It has previously been demonstrated that drinking frequency increases with THI (Tsai, Hsu, Ding et al. 2020, Herbut, Hoffmann, Angrecka et al. 2021) , therefore it was unexpected that drinking frequency would be increased in the shaded cattle. Although, the drinking events may not equate to actual water consumption with the rumen loggers used in this experiment having not been specifically calibrated to determine volume (L) of drinking. The duration of a drinking event has been used to represent differences in volume of water consumed by the cattle, rather than litres consumed *per se*. Gaughan et al. (2010) have shown that despite measured water consumption being shown to increase in times of increased heat load, their experiment showed no overall increase in water consumption between shaded and unshaded cattle over a 120-day study period. The behaviour analysis in this current study did suggest that the unshaded cattle had higher incidences of drinking behaviour, however drinking was defined as the animal standing with their head near the water trough, and it could not be ascertained if they were actively drinking. Indeed, the observers commented that the cattle probably weren't drinking and may have been 'resource guarding'. Resource guarding has been seen in dairy cattle competing for feeding bunk access (Val-Laillet et al. 2008) where dominant cattle block access to the bunk even when they have finished eating, resulting in reduced intakes of the less dominant animals. Resource guarding for water access on hot days may have been occurring in our study, and this may have contributed to the relative decrease in drinking frequency of the unshaded cattle in these groups. Other studies have demonstrated that social hierarchy in cattle does influence drinking frequency and time spent drinking (Coimbra, Machado Filho and Hötzel 2012). Further data analysis of weather data, behaviour and drinking events in the current data may reveal the underlying reason for unshaded cattle drinking less in these groups. Future experiments could focus on the drinking behaviour of feedlot cattle in shaded and unshaded pens.

Additionally, there was no evidence of dehydration in either treatment group as measured by PCV and TPP and no difference between the shaded and unshaded cattle at any time point. This is not unexpected given blood samples were only collected in the mornings, prior to 10 am, therefore it would only be likely to a sick or severely heat stressed animal to have a persistently high PCV and TPP from the previous day.

Rumen Logger—based activity

Although there were not significant differences in activity between shaded and unshaded cattle, it was noted that the rumen loggers indicated the shaded cattle demonstrated less activity than the unshaded cattle at all time periods. This is in contrast to what was expected as it has been reported that as cattle become more heat stressed they decrease activity. One explanation is that in the feedlot where this experiment was conducted, shaded cattle had access to water near their shade structure and therefore during hot periods of time may have had little reason to move from shade. Interestingly, Kendall et al. (2006) showed that dairy cattle with access to shade in summer grazed less than cattle without access to shade, presumably preferring to limit their grazing to periods when climatic conditions were more favourable. The investigation into activity was not a specific aim of this experiment, however the activity output from the rumen bolus could be further analysed over time periods where the cattle were also being observed to better align cattle behaviour with the activity data being collected. Future experiments could specifically target cattle that are exposed to heat stress events to analyse the impact that panting behaviours have on the bolus activity data.

6.4 Behaviour data

Flight speed

There were no differences in flight speed between shaded and unshaded cattle at any of the time points (induction, Day 30 or day 70). Flight speed is used by researchers as a marker of cattle temperament and has been shown to associate with measures of stress in cattle (Randel & Vann, 2004; Curley et al. 2006; Burdick et al. 2011; Coombes et al. 2014). This is re-assuring for the study design as it indicates the cattle were managed equally in terms of potential handling stress, especially has temperament has been linked to differences in growth in cattle (Behrends et al., 2009). Both shaded and unshaded cattle demonstrated a reduction in flight speed over the duration of their time in the feedlot. This experiment indicates that repeated handling at the feedlot had a positive impact on cattle temperament, which agrees with one of our previous studies (Anderson and Miller, 2018).

Panting score

Mean panting score increased with increasing THI/HLI category level, agreeing with other studies (Gaughan et al. 2010; Lees et al. 2020), and shade provision, with the highest pen-average panting score (aPS = 0.635) observed in the unshaded groups when the conditions were very severe/very hot, compared to an aPS of about 0.2 in the shaded groups at these times. Average panting scores have been described by Gaughan et al. (2008) into categories based on the severity of the heat load status via four stress categories: (1) no stress, aPS = 0 ≤ 0.40; (2) mild stress, aPS = 0.41 ≤ 0.80; (3) high stress, aPS = 0.81 ≤ 1.20; and (4) severe stress, aPS ≥ 1.21. So even the high panting scores of 0.63 in the unshaded cattle during the high heat load events in the present study would only put these cattle in the 'mild stress' category, and the shaded cattle in the 'no stress' category. This seems to suggest that the black Angus cattle in the present study weren't particularly 'heat stressed' during the study period. The results of the panting scores in the shaded cattle of the present study provide evidence that shade provision for black Angus cattle in a temperate climatic region is an important thermoregulatory aid.

Shade utilisation

Shade utilisation increased with increasing THI/HLI category level, agreeing with other studies (Robertshaw 1985; Lees et al. 2020). Minimum shade utilisation was about 56% and 58% for the THI 'no stress' and the HLI 'cool' categories, respectively. Shade utilisation in the 'moderate' categories for THI and HLI was not significantly different to the THI 'no stress' and the HLI 'cool' categories. As THI increased from 'no stress' to 'severe stress' and HLI increased from 'cool' to 'hot' there was a 30% and 58% increase, respectively, in shade utilisation. As THI increased to 'very severe stress' and HLI increased to 'very hot' there was a 70% and 64% increase, respectively, in shade utilisation. Maximum shade utilisation was about 95% for the THI 'very severe stress' and HLI 'very hot' categories. Obviously, shade utilisation could only be determined for cattle within the shade pens, however observers noted shade-seeking behaviours by the cattle in the unshaded pens. 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. (2001), Castaneda et al. (2004), Gaughan and Mader (2014) and Lees et al. (2020), and provides further evidence of the importance of access to shade for feedlot cattle, regardless of regional climate classification.

Drinking and eating

Mean eating behaviour was not affected by THI/HLI category level or the provision of shade, which agrees with our pen DMI data. As mentioned previously, it has been shown by others that DMI decreases as cattle become heat stressed in dairy (West 2003, Rhoads, Rhoads, VanBaale et al. 2009) and beef cattle (Gaughan et al. 2010). Along with our previous comment that information regarding individual DMI was not available in this study, which may have provided evidence of DMI differences between shaded and unshaded cattle, the behavioural measure used here was based on location in the pen and therefore may not accurately describe feed intake. The eating measure used here was defined as the animal standing at the feed pad with their head in the feed bunk, so it could not be ascertained if they were actively eating. An alternative explanation is that the animals in the present study were not as 'heat stressed' as the animals in the previous studies where DMI was affected.

Mean drinking behaviour increased with increasing THI/HLI category level, agreeing with other studies (Tsai, Hsu, Ding et al. 2020, Herbut, Hoffmann, Angrecka et al. 2021), and shade provision. Minimum mean drinking behaviour was about 7% and 6% for the unshaded cattle and about 3% and 4% for the shaded cattle in the THI 'no stress' and the HLI 'cool' categories, respectively. Drinking behaviour was only modestly affected by increasing THI/HLI category level in the shaded cattle. For the unshaded cattle, as THI increased to 'very severe stress' and HLI increased to 'very hot' there was a 3.5-fold and 6.7-fold increase, respectively, in % drinking. As previously mentioned, Gaughan et al. (2010) similarly found that water consumption increased in times of increased heat load, but they found no overall increase in water consumption between shaded and unshaded cattle. Moreover, our drinking event data, based on acute rumen logger temperature declines, suggested that the shaded cattle had higher incidences of drinking events. Again, it must be stated that the behavioural measure used here was based on location in the pen and therefore may not accurately describe water intake. Drinking behaviour was defined as the animal standing with their head near the water trough, and it could not be ascertained if they were actively drinking. Indeed, the observers commented that many of the unshaded cattle probably weren't drinking and may have been 'resource guarding'.

Posture

Mean lying behaviour was not affected by THI/HLI category level or the provision of shade. This disagrees with Brown-Brandl et al. (2006b) who found that in feedlot heifers standing behaviour increased from 42% during thermoneutral conditions to 48% during periods of heat load. Similarly, Lees et al. (2020) proportion of cattle standing increased to approximate 49% from 41% when conditions changed from cool to very hot. Overall, in our study mean pen lying behaviour ranged from 10% to 25% (ie. 75% to 90% standing). The high level of standing in our study probably relates to the commercial nature of the facility where our cattle were located, as opposed to the research facilities where the other studies were undertaken. It is likely that the large-scale feeding, cleaning, monitoring and movement of animals in neighbouring pens in a commercial feedlot would have meant that our animals were more regularly disturbed from their lying positions.

Qualitative Behavioural Assessment (QBA)

Apart from performance indicators and physiological markers of health, such as temperature, heart rate and blood parameters, behavioural measures such as ethograms (quantitative descriptions of behaviour such as those described above) are useful to record and interpret reactions to a treatment. However, despite extensive research, the impact to which heat events impact the affective state of animal welfare remains unknown (Colditz et al., 2014). Qualitative behavioural assessment (QBA), where the affective state of animals can be evaluated, has been used by the Murdoch University team for a number of years to successfully assess the affective state of cattle under land transport (Stockman et al., 2011), and extensive and intensive farming systems (Anderson & Miller, 2018; Miller et al., 2018; Stockman et al., 2012).

In the current study, QBA indicated that the cattle in the 'no stress' THI category (shaded and unshaded), and the shaded cattle in the 'moderate stress' THI category displayed the most positive demeanour, being described as more 'settled and sociable'. The cattle in the 'severe stress' THI category (shaded and unshaded), and the unshaded cattle in the 'moderate stress' THI category displayed the most negative demeanour, being described as more 'agitated and anxious'. Ferro et al. (2016) found similar results in a study examining behaviour frequencies in steers in an intensive system, with steers provided with shade that blocked 80% of light displaying significantly more rest and 'play behaviours' than steers either without shade or with less effective shade. The authors concluded that this is due to the shaded environment leading to more favourable physiological conditions and thus better welfare. While we cannot directly observe or assess psychological welfare, it has been suggested that QBA offers insight into the emotional (psychological) state by summarizing how animal perceive and interact with their environment through assessment of body language and behavioural expression (Boissy et al. 2007; Rutherford et al. 2012).

6.5 Blood results

Blood samples collected at the time of induction in cattle administered rumen loggers in shaded and unshaded cattle for all groups demonstrated fibrinogen and complete blood count parameters that were within normal limits. The purpose of collecting fibrinogen and white cell parameters throughout the study was to enable identification of cattle with potentially high levels of inflammation or infection in the feedlot that could bias the analysis of production traits between treatment groups (shaded v unshaded). It also serves as an “on entry” assessment of health status or to feedlot entry and a baseline for comparison over time in the feedlot. Lack of difference in acute phase proteins such as fibrinogen over time are supportive of the concept that both shaded and unshaded cattle were not subject to inflammation or infection and therefore the differences in performance data such as ADG are unlikely due to disease. The raw mean of white cell parameters was within normal limits, indicating no group or pen demonstrated a complete blood count indicating large numbers of the pen showed evidence of infection or inflammation throughout the study.

Heat stress has been shown to impact on ruminant glucocorticoid concentrations (Elvinger, Natzke and Hansen 1992, Caroprese, Albenzio, Bruno et al. 2012), which has been shown to have a negative impact on the immune response (Abdelnour, Abd El-Hack, Khafaga et al. 2019) and stress can induce a neutrophilia and lymphopenia. In this experiment there were few differences between shaded and unshaded cattle in relation to neutrophil and lymphocyte counts and N:L ratio. At day 30 the unshaded cattle had an increased N:L ratio and increase in neutrophil numbers which may indicate a relative increase in stress response of these cattle at this time. Previous studies in cattle showing unshaded, heat stressed cattle to have increase neutrophil and lymphocyte counts and increased N:L (Mitlohner, Galyean and McGlone 2002). The relationship of heat stress with leucocytes is complex with studies in ruminants demonstrating at times contrasting results in relation to N:L and leukocytes numbers (Abdelnour et al. 2019). This is likely related to whether there is acute or chronic stress. Further evaluation of the complete blood count data in relation to the behavioural and temperature data may be able to explain these results more comprehensively.

There were no consistent differences in HSP between treatment groups. This may be attributed to the fact that the overall conditions during the trial were not extreme enough to evoke a differential response in the treatment groups. Rather than demonstrating no effect of the provision of shade, it may indicate cattle in both treatment groups were not under high enough levels of heat stress in the feedlot and maintained adequate thermoregulation during the trial. HSP is considered one of the first lines of defence against heat stress as it pre-exists in the cytoplasm. HSP are induced by a variety of stresses which include heat stress and helps to stabilise cells during hyperthermia and heat stress and will persist after the animal has returned to normal temperature. In animals it has been shown that HSP will have an initial rise in response to heat stress then again after approximately 16 days (Asea and Kaur 2017). The duration of time that the HSP are elevated post heat stress are not well defined, so it is also possible that if differences did exist between treatments, that the collection of the blood samples has not coincided with elevations in the HSP.

HSP 70 has previously been evaluated in shaded v non-shaded cattle in feedlot conditions (Gaughan, Bonner, Loxton et al. 2013) where similar to the results of this study there was no significant difference in concentrations of HSP70. The mean and range of HSP 70 in this study across all groups was lower than those reported in cattle from a study by Gaughan et al. (2013) (5.22 ± 0.62 ng/mL, range 0.54 to 19.75). Although the primary purpose for the analysis of HSP was to determine if differences in measures of heat stress existed between treatment groups, further evaluation of the data collected may better establish relationships between environmental conditions and HSP in commercial feedlot animals and prediction of production traits.

7. Conclusions

This experiment has demonstrated there may be modest production advantages to the provision of shade in a commercial feedlot in this geographical location. Across the 6 groups, spread across the months of October to May, used in this experiment there was an overall effect of shade, whereby the cattle had increased ADG and live weight at day 70. This ADG benefit in a sensitivity analysis model, equates to a shade capital cost payback period ranging from about 2 to 10 years given variable shade capital costs.

The physiological markers of health (rumen temperature and blood analysis) revealed that, even during to hottest times of the experiment, the cattle were quite able to thermoregulate to maintain physiological homeostasis. The thermoregulatory measures we observed that aided this were the increased heat loss via increased panting, and seeking shade (if available). In addition, we were also able to show the effect of heat stress and shade provision on the affective state of the cattle. Qualitative behavioural assessment was used to indicate that the cattle in the 'no stress' THI category (shaded and unshaded), and the shaded cattle in the 'moderate stress' THI category displayed the most positive demeanour, being described as more 'settled and sociable'. Whilst cattle in the 'severe stress' THI category (shaded and unshaded) and the unshaded cattle in the 'moderate stress' THI category displayed the most negative demeanour, being described as more 'agitated and anxious'.

Overall, the findings from the present study suggest that there are production and welfare benefits associated with providing feedlot cattle with shelter from summer conditions in the temperate climatic region of WA.

8. Project outcomes

The benefits shown in this study (performance and welfare) of shade provision for lot fed black Angus cattle in the temperate climatic region of WA sets a benchmark for feedlot producers in these types of climatic regions in Australia to assess the advantages of adopting a shade solution. Black Angus cattle not only represent the major genotype lot fed in this region, but they are also one of the higher risk genotypes in an extreme heat event, thus providing a highly relevant animal model. Better knowledge of the benefits of various shade designs to animal health and welfare may facilitate further adoption of shade in the Australian feedlot industry. This would provide the industry with powerful information for public education and greater product awareness.

9. Future research and recommendations

Cattle in this experiment were managed in shaded structures that provided 3.125 m^2 per head of shade. Future experiments could investigate different size of shade provision and construction materials to determine the minimum requirements of shade and potential benefits to use of other materials or shade design. Moreover, the benefits of shade to other cattle types and medium-fed and long-fed production systems, along with seasonal performance effects could also be investigated.

In this study, cattle were unable to be maintained in their separate treatment groups beyond 70 days to allow selected feeding of any lighter cattle to bring them up to target market specifications by 100 days. Future experiments where cattle were maintained in their treatments groups until slaughter would allow the collection of Meat Standard's Australia grading data. Additionally, meat quality samples such as glycogen, intramuscular fat % and shear force of cuts such as the *M.longissiums lumborum* would allow for further assessment of meat quality attributes.

Despite lack of difference between rumen temperature (maximum, average) in shaded and unshaded cattle, this data could be further analysed to investigate the association of rumen temperature with production indices in the sub-set of cattle that contain rumen loggers. Other approaches to the analysis of T_{RUM} could investigate not only the time above a threshold temperature, but also the magnitude of the increase, which may better explore differences in thermoregulation of the cattle and the association with provision of shade and production indices. The investigation into activity was not a specific aim of this experiment, however the activity output from the rumen bolus could be further analysed over time periods where the cattle were also being observed to better align cattle behaviour with the activity data being collected. Future experiments could specifically target cattle that are exposed to heat stress events to analyse the impact that panting behaviours have on the bolus activity data. Future research could also continue to investigate the relationship between provision of shade and drinking volume and behaviour. This could include better validation and use of rumen loggers to monitor heat, drinking events and activity levels and their relationships with shade and cattle behaviour.

10. References

Abdelnour, S.A., Abd El-Hack, M.E., Khafaga, A.F., Arif, M., Taha, A.E. and Noreldin, A.E. 2019. Stress biomarkers and proteomics alteration to thermal stress in ruminants: A review. Journal of Thermal Biology 79: 120-134.

Anderson, F., and Miller, D.W. 2018. MLA Final Report "The Impact of Handling Conditions and New Environments on the Stress of Cattle". P.PIP.0743.

Asea, A.A.A. and Kaur, P. 2017. Heat Shock Proteins in Veterinary Medicine and Sciences Published under the Sponsorship of the Association for Institutional Research (AIR) and the Association for the Study of Higher Education (ASHE). Cham, Springer International Publishing.

Baile, C.A. and Forbes, J.M. 1974. Control of feed intake and regulation of energy balance in ruminants. Physiological Reviews 54(1): 160-214.

Beatty, D. T., Barnes, A., Taylor, E., and Maloney, S. K. 2008. Do changes in feed intake or ambient temperature cause changes in cattle rumen temperature relative to core temperature?. Journal of Thermal Biology, 33(1), 12-19.

Behrends, S., Miller, R., Rouquette Jr, F., Randel, R., Warrington, B., Forbes, T., Welsh, T., Lippke, H., Behrends, J., & Carstens, G. (2009). Relationship of temperament, growth, carcass characteristics and tenderness in beef steers. Meat science, 81(3), 433-438.

Blackshaw, Judith K., and A. W. Blackshaw. 1994. Heat stress in cattle and the effect of shade on production and behaviour: a review. Australian Journal of Experimental Agriculture. 34: 285-295.

Blaine, K.L. and Nsahlai, I.V. 2011. The effects of shade on performance, carcass classes and behaviour of heat-stressed feedlot cattle at the finisher phase. Tropical Animal Health and Production 43(3): 609-615.

Boissy, A.; Manteuffel, G.; Jensen, M.B.; Moe, R.O.; Spruijt, B.; Keeling, L.J.; Winckler, C.; Forkman, B.; Dimitrov, I.; Langbein, J.; et al. Assessment of positive emotions in animals to improve their welfare. Physiol. Behav. 2007, 92, 375–397.

Bond, T. E., C. F. Kelly, S. R. Morrison, and N. Periera. 1967. Solar, Atmospheric, and Terrestrial Radiation Received by Shaded and Unshaded Animals. Transactions of the American Society of Agricultural Engineers 10:622-627.

Bond, T. E., and Laster, D. B. 1975. Influence of shading on production of Midwest feedlot cattle. Transactions of the ASAE, 18(5), 957-0959.

Brown-Brandl, T. M., Eigenberg, R. A., Hahn, G. L., and Nienaber, J. A. 2001. Correlations of respiration rate, core body temperature, and ambient temperatures for shaded and nonshaded cattle. Livestock Environment VI.

Brown-Brandl, T. M., R. A. Eigenberg, and J. A. Nienaber. 2006a. Heat stress risk factors of feedlot heifers. Livestock Science 105(1-3):57-68.

Brown-Brandl, T. M., J. A. Nienaber, R. A. Eigenberg, T. L. Mader, J. L. Morrow, and J. W. Dailey. 2006b. Comparison of heat tolerance of feedlot heifers of different breeds. Livestock Science 105(1-3):19-26.

Brown-Brandl, T., Jones, D.D. and Woldt, W. 2005. Evaluating modelling techniques for cattle heat stress prediction. Biosystems Engineering 91(4): 513-524.

Brown-Brandl, T.M., Eigenberg, R.A. and Nienaber, J.A. 2013. Benefits of providing shade to feedlot cattle of different breeds. Transactions of the ASABE 56(4): 1563-1570.

Buffington, D., A. Collazo-Arocho, G. Canton, D. Pitt, W. Thatcher, and R. Collier. 1981. Black Globe-Humidity Index (BGHI) as a Comfort Equation for Dairy Cows. Transactions of the American Society of Agricultural Engineers 27:711-714.

Buffington, D., R. Collier, and G. Canton. 1983. Shade management systems to reduce heat stress for dairy cows in hot, humid climates. Transactions of the American Society of Agricultural Engineers 26(6):1798-1802.

Burdick, N., Randel, R., Carroll, J., & Welsh, T. 2011. Interactions between temperament, stress, and immune function in cattle. International Journal of Zoology, 2011.

Bureau of Meteorology (BOM). 2023. Climatic conditions for Cunderdin, WA 1991-20. http://www.bom.gov.au/jsp/ncc/cdio/cvg/av?p_stn_num=010035&p_prim_element_index=0&p_comp_element_index=0&redraw=null&p_display_type=statistics_summary&normals_years=1991-2020&tablesizebutt=normal (Accessed April 22, 2023).

Caroprese, M., Albenzio, M., Bruno, A., Annicchiarico, G., Marino, R. and Sevi, A. 2012. Effects of shade and flaxseed supplementation on the welfare of lactating ewes under high ambient temperatures. Small Ruminant Research 102(2-3): 177-185.

Castaneda, C. A., J. B. Gaughan, and Y. Sakaguchi. 2004. Relationships between climatic conditions and the behaviour of feedlot cattle. Animal Production in Australia 25:33-36.

Coimbra, P.A.D., Machado Filho, L.C.P. and Hötzel, M.J. 2012. Effects of social dominance, water trough location and shade availability on drinking behaviour of cows on pasture. Applied Animal Behaviour Science 139(3-4): 175-182.

Colditz, I. G., Ferguson, D. M., Collins, T., Matthews, L., & Hemsworth, P. H. 2014. A prototype tool to enable farmers to measure and improve the welfare performance of the farm animal enterprise: The unified field index. Animals, 4(3), 446-462.

Coombes, S. V., Gardner, G. E., Pethick, D. W., & McGilchrist, P. (2014). The impact of beef cattle temperament assessed using flight speed on muscle glycogen, muscle lactate and plasma lactate concentrations at slaughter. *Meat Science, 98*(4), 815-821.

Curley, K. O., Paschal, J. C., Welsh, T. H., and Randel, R. D. 2006. Technical note: Exit velocity as a measure of cattle temperament is repeatable and associated with serum concentration of cortisol in Brahman bulls1. Journal of Animal Science, 84(11), 3100-3103.

DiGiacomo, K., Warner, R.D., Leury, B.J., Gaughan, J.B. and Dunshea, F.R. 2014. Dietary betaine supplementation has energy-sparing effects in feedlot cattle during summer, particularly in those without access to shade. Animal Production Science 54(4): 450-458.

Eigenberg, R. A., Hahn, G. L., Nienaber, J. A., Brown-Brandl, T. M., & Spiers, D. E. (2000). Development of a new respiration rate monitor for cattle. Transactions of the ASAE, 43(3), 723.

Elvinger, F., Natzke, R.P. and Hansen, P.J. 1992. Interactions of heat stress and bovine somatotropin affecting physiology and immunology of lactating cows. Journal of Dairy Science 75(2): 449-462.

Entwistle, K., M. Rose, and B. McKiernan. 2000. Mortalities in Feedlot Cattle at Prime City Feedlot, Tabbita, NSW, 2000: A Report to the Director General. New South Wales Agriculture, New South Wales Government, New South Wales, Australia.

Ferro DC, Arnhold E, Bueno CP, Miyagi ES, Ferro RC, Santos AP, et al. Physiological and behavioral responses of Nellore steers to artificial shading in an intensive production system. Semina: Ciencias Agrarias (Londrina). 2016;37(4 Suppl. 1):2785-92.

Gaughan, J. B., Holt, S., Hahn, G. L., Mader, T. L., and Eigenberg, R. 2000. Respiration rate: Is it a good measure of heat stress in cattle?. Asian-Australasian Journal of Animal Sciences, 13(Supplement Vol C), 329-332.

Gaughan, J. B., and T. L. Mader. 2014. Body temperature and respiratory dynamics in un-shaded beef cattle. International Journal of Biometeorology 58:1443-1450.

Gaughan, J. B., L. A. Tait, R. Eigenberg, and W. L. Bryden. 2004. Effect of shade on respiration rate and rectal temperature of Angus heifers. Animal Production in Australia 25:69 - 72.

Gaughan, J. B., T. L. Mader, S. M. Holt, and A. Lisle. 2008. A new heat load index for feedlot cattle. Journal of Animal Science 86(1):226-234.

Gaughan, J.B., Bonner, S., Loxton, I., Mader, T.L., Lisle, A. and Lawrence, R. 2010. Effect of shade on body temperature and performance of feedlot steers. Journal of Animal Science 88(12): 4056-4067.

Gaughan, J.B., Bonner, S.L., Loxton, I. and Mader, T.L. 2013. Effects of chronic heat stress on plasma concentration of secreted heat shock protein 70 in growing feedlot cattle. Journal of Animal Science 91(1): 120-129.

Hahn, G. L. 1999. Dynamic Responses of Cattle to Thermal Heat Loads. Journal of Animal Science 77 (Suppl. 2):10-20.

Hahn, G. L., and Mader, T. L. 1997. Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. In Proceedings, Fifth International Livestock Environment Symposium.

Herbut, P., Hoffmann, G., Angrecka, S., Godyń, D., Vieira, F.M.C., Adamczyk, K. and Kupczyński, R. 2021. The effects of heat stress on the behaviour of dairy cows–a review. Annals of Animal Science 21(2): 385-402.

Ingram, D. L., and Mount, L. E. 2012. Man and animals in hot environments. Springer Science & Business Media.

Kendall, P. E., P. P. Nielsen, J. R. Webster, G. A. Verkerk, R. P. Littlejohn, and L. R. Matthews. 2006. The effects of providing shade to lactating dairy cows in a temperate climate. Livestock Science 103(1- 2):148-157.

Kibler, H. H., and Brody, S. 1949. Environmental physiology with special reference to domestic animals. VII, Influence of temperature, 50 degrees to 5 degrees F and 50 degrees to 95 degrees F, on heat production and cardiorespiratory activities of dairy cattle. University of Missouri, College of Agriculture, Agricultural Experiment Station.

Lees, A. M. 2016. Biological responses of feedlot cattle to heat load (PhD Thesis). The University of Queensland, School of Agriculture and Food Sciences.

Lees, A. M., J. C. Lees, A. T. Lisle, M. L. Sullivan, and J. B. Gaughan. 2018. Effect of heat stress on rumen temperature of three breeds of cattle. International Journal of Biometeorology 62(2):207-215.

Lees, A. M., J. C. Lees, V. Sejian, M. L. Sullivan, and J. B. Gaughan. 2020. Influence of shade on panting score and behavioural responses of *Bos taurus* and *Bos indicus* feedlot cattle to heat load. Animal Production Science 60(2):305-315.

Lees, A.M., Standfield, B., Pryor, P., Shankar, R., Cowley, F.C., Wilkes, J., McGilchrist, P. and Tarr, G. 2022. MLA Final Report "Evaluation of shade and shelter solutions in a southern Australia feedlot". B.FLT.4009.

Lefcourt, A. M., and Adams, W. R. 1996. Radiotelemetry measurement of body temperatures of feedlot steers during summer. Journal of animal science, 74(11), 2633-2640.

Mader, T. L. 2003. Environmental stress in confined beef cattle. Journal of Animal Science 81(14 suppl 2):E110-E119.

Mader, T. L., Dahlquist, J. M., Hahn, G. L., and Gaughan, J. B. 1999. Shade and wind barrier effects on summertime feedlot cattle performance. Journal of Animal Science, 77(8), 2065-2072.

McLean, A. S. 1973. Early adverse effects of radiation. British Medical Bulletin, 29(1), 69-73.

Meat and Livestock Australia (MLA). 2023. Veterinary handbook contents: Temperature humidity index (THI). http://www.veterinaryhandbook.com.au/ContentSection.aspx?id=51. (Accessed April 22, 2023).

Miller, D. W., Fleming, P. A., Barnes, A. L., Wickham, S. L., Collins, T., & Stockman, C. A. 2018. Behavioural assessment of the habituation of feral rangeland goats to an intensive farming system. Applied Animal Behaviour Science, 199, 1-8.

Mitlöhner, F.M., Morrow, J.L., Dailey, J.W., Wilson, S.C., Galyean, M.L., Miller, M.F. and McGlone, J.J. 2001. Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. Journal of Animal Science 79(9): 2327-2335.

Mitlohner, F.M., Galyean, M.L. and McGlone, J.J. 2002. Shade effects on performance, carcass traits, physiology, and behavior of heat-stressed feedlot heifers. Journal of Animal Science 80(8): 2043-2050.

Nienaber, J. A., G. L. Hahn, T. M. Brown-Brandl, and R. A. Eigenberg. 2003. Heat stress climatic conditions and the physiological responses of cattle. Pages 255–262 in 5th Int. Dairy Hous. Proc. Soc. Eng. Agric., Food and Biol. Syst., Fort Worth, TX.

Paul, R.M., Turner, L.W., Larson, B.T. 2000. Effects of shade on production and body temperatures of grazing beef cows. In: Kentucky beef cattle report. Lexington, KY: University of Kentucky. Publication PR117. p. 24–28.

Randel, R. D., and Vann, R. C. 2004. Relationships between temperament and growth performance in beef cattle. Proceedings Journal Dairy Science.

Rhoads, M., Rhoads, R., VanBaale, M., Collier, R., Sanders, S., Weber, W., Crooker, B. and

Baumgard, L. 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. Journal of Dairy Science 92(5): 1986-1997.

Robertshaw, D. 1985. Heat loss in cattle. Page 55–66 in Stress Physiology in Livestock. Vol. 1. M. K. Yousef, ed. CRC Press Inc., Boca, Raton, Florida, USA.

Rutherford, K.M.; Donald, R.D.; Lawrence, A.B.; Wemelsfelder, F. Qualitative Behavioural Assessment of emotionality in pigs. Appl. Anim. Behav. Sci. 2012, 139, 218–224.

Sackett, D., Holmes, P., Abbott, K., Jephcott, S. and Barber, B. 2006. Assessing the economic cost of endemic disease on the profitability of Australian beef cattle and sheep producers – MLA Final Report AHW.087.

Sjaastad, O.V., Sand, O. and Hove, K. 2010. Physiology of Domestic Animals, Scan. Vet. Press.

Spain, J. N., and Spiers, D. E. 1996. Effects of supplemental shade on thermoregulatory response of calves to heat challenge in a hutch environment. Journal of Dairy Science, 79(4), 639-646.

Stockman, C., Collins, T., Barnes, A., Miller, D., Wickham, S., Beatty, D., Blache, D., Wemelsfelder, F., & Fleming, P. (2011). Qualitative behavioural assessment and quantitative physiological measurement of cattle naïve and habituated to road transport. Animal Production Science, 51(3), 240-249.

Stockman, C.A., McGilchrist P., Collins T., Barnes A.L., Miller D., Wickham S.L., Greenwood P.L., Cafe L.M., Blache D., Wemelsfelder F., Fleming P.A. 2012. Qualitative behavioural assessment of angus steers during pre-slaughter handling and relationship with temperament and physiological responses. Applied Animal Behaviour Science. 142(3-4): 125-133.

Sullivan, M. L., A. J. Cawdell-Smith, T. L. Mader, and J. B. Gaughan. 2011. Effect of shade area on performance and welfare of short-fed feedlot cattle. Journal of Animal Science 89(9):2911-2925.

Thom, E. C. 1959. The Discomfort Index Weatherwise 12:57-61.

Tsai, Y.-C., Hsu, J.-T., Ding, S.-T., Rustia, D.J.A. and Lin, T.-T. 2020. Assessment of dairy cow heat stress by monitoring drinking behaviour using an embedded imaging system. Biosystems Engineering 199: 97-108.

West, J.W. 2003. Effects of heat-stress on production in dairy cattle. Journal of Dairy Science 86(6): 2131-2144.

Wheelock, J., Rhoads, R., VanBaale, M., Sanders, S. and Baumgard, L. 2010. Effects of heat stress on energetic metabolism in lactating Holstein cows. Journal of Dairy Science 93(2): 644-655.

Yadav, B., Singh, G., Verma, A. K., Dutta, N., & Sejian, V. 2013. Impact of heat stress on rumen functions. Veterinary World. 6:992-996.

11. Appendix

11.1 Animal Ethics Certificate

Murdoch UNIVERSITY

Research and Innovation
Research Ethics and Integrity Office

Animal Ethics
Room 1.006, Chancellery, South Street
MURDOCH WA 6150
Telephone: 08 9360 7366
Facsimile: 08 9360 6686
animal.ethics@murdoch.edu.au
www.murdoch.edu.au

A/Prof David Miller
College of Science, Health, Engineering and Education
Murdoch University

Thursday, 24 September 2020

Dear David,

ANIMAL ETHICS

Protocol ID.	777
Permit No.	R3277/20
Protocol Title	Evaluation of the benefits of shade for feedlot cattle

Thank you for your reply to the letter dated 15 September 2020 regarding the AEC response to the above Protocol. The committee's concerns have all been addressed and the permit now has **OUTRIGHT** approval.

The standard conditions for the research are listed on the reverse of this page.

Location	Impact	Species Code	Animal Species	Number Requested	Number Approved
WA	3. Minor conscious intervention	11	Black Angus cattle	**1,700**	**1,700**

The Research Ethics and Integrity Office wish you every success for your research.

MSeneque

Dr Margot Seneque
Animal Welfare Officer
On behalf of the Animal Ethics Committee

cc: Dr Joshua Aleri; Dr Fiona Anderson; A/Prof Anne Barnes; A/Prof Teresa Collins; Dr Kate Loudon; Dr Liselotte Pannier;

11.2 Health management: diagnosis and treatment record

VID	EID	Date	Shade?	Diagnosis	Treatment	Notes
57853	982 123759768785	01-Feb-22	NS	Pink eye	Orbenin	Left in trial
58504	951 000319375083	02-Mar-22	NS	Minor leg wound	Propercillin	Left in trial
58416	951 000319358816	02-Mar-22	NS	Pink eye	Orbenin	Left in trial
64774	951 000318065468	09-Nov-22	NS	Pink eye	Orbenin	Left in trial
64943	964 001035346470	09-Nov-22	S	Pink eye	Orbenin	Left in trial
64890	982 123779791762	09-Nov-22	S	Febrile	Flunixil	Left in trial
64778	982 123769627266	09-Nov-22	NS	Pink eye	Orbenin	Left in trial
64797	982 123769955025	09-Nov-22	NS	Pink eye	Orbenin	Left in trial
64880	964 001027523362	09-Nov-22	NS	Febrile	Flunixil	Left in trial
64902	951 010002168057	09-Nov-22	S	Pink eye	Orbenin	Left in trial
70309	982 123747434583	11-Jan-23	S	Pink eye	Terramycin	Left in trial
70309	982 123747434583	11-Jan-23	S	Pink eye	Orbenin	Left in trial
70321	982 123747434540	11-Jan-23	S	Pink eye	Orbenin	Left in trial
64996	937 000002961323	19-Jan-23	NS	Pink eye	Orbenin	Left in trial
70475	937 000002961067	19-Jan-23	NS	Bloat	Trocar / Penecillin	Left in trial

11.3 Posture, Location and Activity Recording Sheet

DATE: ______ PEN NUMBER: ______ STARTING TIME: _____

1st Interval: _________

Drinking ___%

Shade ___%

Standing ___% Lying ___%

Sun ___%

Standing ___% Lying ___%

Eating ___%

2nd Interval: _________

Drinking ___%

Shade ___%

Standing ___% Lying ___%

Sun ___%

Standing ___% Lying ___%

Eating ___%

3rd Interval: _________

Drinking ___%

Shade ___%

Standing ___% Lying ___%

Sun ___%

Standing ___% Lying ___%

Eating ___%

4th Interval: _________

Drinking ___%

Shade ___%

Standing ___% Lying ___%

Sun ___%

Standing ___% Lying ___%

Eating ___%

11.4 Panting Recording Sheet

DATE: _____ PEN NUMBER: _____					
Time: _____	Panting Score (Pen %)	1st Interval	2nd Interval	3rd Interval	4th Interval
0	No panting				
1	Slight panting				
2	Fast panting, drool/foam present				
2.5	2 + some open mouth				
3	Open mouth, some drooling, neck extended, head up				
3.5	3 + tongue out slightly				
4	Open mouth, tongue out, drooling, neck extended, head up				
4.5	4 + head held down				

DATE: _____ PEN NUMBER: _____					
Time: _____	Panting Score (Pen %)	1st Interval	2nd Interval	3rd Interval	4th Interval
0	No panting				
1	Slight panting				
2	Fast panting, drool/foam present				
2.5	2 + some open mouth				
3	Open mouth, some drooling, neck extended, head up				
3.5	3 + tongue out slightly				
4	Open mouth, tongue out, drooling, neck extended, head up				
4.5	4 + head held down				

DATE: _____ PEN NUMBER: _____					
Time: _____	Panting Score (Pen %)	1st Interval	2nd Interval	3rd Interval	4th Interval
0	No panting				
1	Slight panting				
2	Fast panting, drool/foam present				
2.5	2 + some open mouth				
3	Open mouth, some drooling, neck extended, head up				
3.5	3 + tongue out slightly				
4	Open mouth, tongue out, drooling, neck extended, head up				
4.5	4 + head held down				

DATE: _____ PEN NUMBER: _____					
Time: _____	Panting Score (Pen %)	1st Interval	2nd Interval	3rd Interval	4th Interval
0	No panting				
1	Slight panting				
2	Fast panting, drool/foam present				
2.5	2 + some open mouth				
3	Open mouth, some drooling, neck extended, head up				
3.5	3 + tongue out slightly				
4	Open mouth, tongue out, drooling, neck extended, head up				
4.5	4 + head held down				

11.5 QBA Scoring Sheet

Definitions

Sociable	Engaging in social activities, affiliative and playful social interactions
Uncomfortable	Troubled, showing signs of physical discomfort, irritation
Listless	Lacking energy, uneasy and not engaging with surrounding environment
Active	Engaged in a task, eating, walking, social interaction
Agitated	Restless, fidgety, worried, or upset
Alert	Fully aware, attentive, vigilant, ready to act
Settled	Quiet, relaxed, calm, not tense
Inquisitive	Positively interested, curious, showing active investigation
Frustrated	Annoyed, impatient, prevented from achieving something
Anxious	Worried, nervous

Clip 1

Place a mark (X) on the line to indicate the level of expression that this animal is displaying for each term below.

Sociable Min. |————————————| Max.

Uncomfortable Min. |————————————| Max.

Listless Min. |————————————| Max.

Active Min. |————————————| Max.

Agitated Min. |————————————| Max.

Alert Min. |————————————| Max.

Settled Min. |————————————| Max.

Inquisitive Min. |————————————| Max.

Frustrated Min. |————————————| Max.

Anxious Min. |————————————| Max.