final report

Project code: B.FLT.4006

Prepared by: J. Gaughan, M. Sullivan, S. Woldeyohannes. N. Perkins
The University of Queensland

Date published: 17-Feb-2020

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Evaluation of feedlot heat load model adjustments

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

Executive summary

The Heat Load Index (HLI) model and the Accumulated Heat Load Unit (AHLU) were developed by monitoring panting scores of commercial feedlot cattle across a range of sites in Australia and the United States (Gaughan et al. 2008). When the HLI and AHLU models were first published in 2008 it was the intention that at some point the models would need to be reviewed. MLA Project B.FLT.0387 conducted during the summer of 2017/2018 evaluated the model across six Australian feedlots. Accumulated heat load was a significant variable in explaining heat load response of feedlot cattle, however improvements in prediction confidence intervals of panting scores ≥ 2 is required across feedlot sites and breed types. Potential adjustments to improve heat load model adequacy were recommended. This project was set up to evaluate the robustness of the panting score model developed from B.FLT.0387 by evaluating cattle responses to heat load on two independent feedlots (i.e. not used in the 2017/18 study) during the summer of 2019.

Primary Objective: Determine adequacy of model adjustments proposed in MLA Project B.FLT.0387 to explain the proportion of cattle of different breed types with a panting score ≥ 2.

Materials & Methods

Two commercial feedlots (Feedlot A and Feedlot B) located in South East Queensland were used in a 77-day study. One had shade in each pen and the other had no shaded pens. At feedlot A (shaded pens; approximately 2.5 m^2) 16 pens were monitored, and at Feedlot B, 16 un-shaded pens were monitored. The feedlots varied by SCU, pen size, pen dimensions, pen orientation, shade type, breed types, days on feed, market focus and feedlot terrain – which ranged from flat (Feedlot A) to hilly (Feedlot B). Feedlot A's market focus was primarily mid to long feed export, whereas Feedlot B was focused on the domestic market. Both feedlots were monitored daily over 77 days, from 14 January 2019 until 31 March 2019. No HGPs were used.

Feedlot A: Two breed types were evaluated: Breed Type 1 (100% *Bos taurus* – Angus; BT1), and Breed Type 6 (100% *Bos taurus* – Wagyu; BT6). There were 9 pens of Angus and 7 pens of Wagyu that where monitored over the duration of the study. Wagyu were fed up to 450 days, and the Angus up to 200 days. The pens used were clustered by breed type: cluster 1 (BT6) consisted of pens 1 to 7 (inclusive), with all pens within 80 m of each other; cluster 2 (BT1) consisted of pens 13 to 21 (inclusive), with all pens within 60 m of each other. There was approximately 80 m between the clusters.

Feedlot B: Two breed types were evaluated: Breed Type 3 (25% *Bos indicus*; BT3) and Breed Type 4 (50% *Bos indicus*; BT4). Thirteen pens (three pens were used twice as new cattle back filled pens following the sale of a pen) were used over the duration of the study, and there was a mixture of BT3 and BT4 within each pen. Seven pens were single sex pens (heifers only) and six pens were mixed sex pens (steers + heifers). Within a pen breed types were identified, and during evaluation of panting scores (PS) (see below) individuals within a specific breed type were identified and PS for the individual recorded. Sixteen cohorts of cattle were observed. The cattle observed range in DOF from 3 to 145 days.

Cattle & Management Information: Origin of cattle, sex, age (teeth), breed type and live weight were recorded at induction. A head count for each breed type was obtained; HGP status; Days on feed at time of monitoring; Morbidity to date at time of monitoring; Mortality to date at time of monitoring; Daily pen as-fed deliveries and ration fed; Daily pen head counts; Times of the day that cattle were fed. A composite sample of each ration used in the observation pens was obtained each week, and frozen for later analysis.

Visual Assessment of Cattle: Visual assessment of cattle in the enrolled pens occurred three times each day (at approximately 0800, 1200 and 1600 h). The visual assessment data collected was: (i) Panting scores (PS) by BT within a pen, and (ii) Behavioural observations: Number of cattle (by BT) standing or lying; location in pen (shade, feed bunk, water trough, in sun); activity (eating, drinking), and disposition (agitated, milling around, depressed).

Weather Stations: Two weather stations (Weather Maestro 10 Channel Weather Station, Environdata Weather Stations Pty. Ltd., Warwick Qld.) were set up calibrated by Environdata at Feedlot A prior to the commencement of the study. The weather stations were located centrally to observation pens. Five weather stations (Weather Maestro 10 Channel Weather Station, Environdata Weather Stations Pty. Ltd., Warwick Qld.) were set up calibrated by Environdata at Feedlot B prior to the commencement of the study. The five weather stations were located centrally to all of the observation pens.

Weather data: Dry bulb temperature, relative humidity, solar radiation, black globe temperature, wind speed {2 m height} and wind direction were collected at 10-minute intervals over the duration of the study at each feedlot. These data were then used to calculate HLI and AHLU. Rainfall was collected on site on a daily basis at 0900 h. A web-based service WeatherMation LIVE (Environdata Weather Stations Pty Ltd., Warwick Qld) provided real time weather data as well as real time HLI and AHLU values for each weather station.

Main Outcomes

Panting Score evaluation: There was good agreement in terms of the predictive probability of panting score for BT relative to AHL between the current study and B.FLT.0387. The magnitude of the change in panting score varied more than the direction of change.

The outcomes from the current study show that there is a time of day effect on panting score response to AHL, with a greater panting score response in late morning to mid-afternoon (T2) compared with other times of the day give the same AHL. Panting score was lower during T3 and this is a reflection of reduced heat load during the latter part of the day. It should be noted that PS can be elevated in the early morning (T1) if there has been carry-over heat from the previous day and night.

Scanning across the predictive plots in the current study shows that the predicted probability of having elevated panting score for a given AHL_{ADJ} is lower for BT6 relative to the other breed types. Anecdotal evidence has suggested the Wagyu cattle (BT6) have a higher heat tolerance than Angus (BT1), however DMI and MEI were lower in the BT6 group compared with all other breed types. So, it is not clear if the lower panting score is due to heat tolerance, lower MEI or a combination of both.

Dry matter intake and MEI: There was little DMI or MEI responses to the climatic conditions to which cattle were exposed for BT3, BT4 and BT6 cattle. Although DMI and MEI reduced as heat load increased for all BTs the differences were not statistically significant. For BT1 (Angus) significant reductions in DMI and MEI occurred when conditions were Hot to Extreme, and Minor to High respectively for HLI and Accumulated Heat Load.

The following recommendations have arisen from this study.

1. Accumulated heat load is a significant variable in explaining heat load response of feedlot cattle, however improvement in prediction confidence intervals of panting

scores ≥ 2 is required across feedlot sites and breed types. It is recommended that collection of continuous panting score data (i.e. daily over summer) for various breed types be undertaken. Preferably from sites where it is more likely that very hot to extreme conditions (for BT1 cattle) are likely. This may involve the movement of susceptible cattle to feedlot where they would not normally be fed over summer.

2. Data for the current heat load model development were collected based on subjective observation of panting score (pens and breed types) within pens. Technologies that objectively measure respiration rate (and panting score) on a continuous individual basis may result in more accurate data collection and hence an improved model. Additionally, further investigation of feedlot level factors determining variation in panting score is required.
3. The current heat load model is somewhat difficult to evaluate. Consideration for a revised model using logistic regressions to predict the probability of elevated panting scores or mortality across breed types is warranted. Data collected as part of Recommendation 1 and Recommendation 2 could be to evaluate the logistic regression model adequacy developed in this project.

Table of contents

1 Background

The Heat Load Index (HLI) model (Gaughan et al. 2008) was developed by monitoring panting scores of commercial feedlot cattle across a range of sites in Australia and the United States. When the HLI and Accumulated Heat Load Unit (AHLU) models were first published in 2008 it was the intention that at some point the models would need to be reviewed. MLA Project B.FLT.0387 conducted during the summer of 2017/2018 evaluated the model across 6 Australian feedlots. Accumulated heat load was a significant variable in explaining heat load response of feedlot cattle, however improvements in prediction confidence intervals of panting scores ≥ 2 is required across feedlot sites and breed types. Potential adjustments to improve heat load model adequacy were recommended. This project was set up to evaluate the robustness of the panting score model developed from B.FLT.0387 by evaluating cattle responses to heat load on two independent feedlots (i.e. not used in the 2017/18 study) summer of 2019.

2 Project Objectives

2.1 Primary Objective

Determine adequacy of model adjustments proposed in MLA Project B.FLT.0387 to explain the proportion of cattle of different breed types with a panting score ≥ 2.

3 Methodology

3.1 Feedlots

Two commercial feedlots (Feedlot A and Feedlot B) located in South East Queensland were used in a 77-day study. One had shade in each pen and the other had no shaded pens. At feedlot A (shaded pens; approximately 2.5 m^2/animal) 16 pens were monitored, and at Feedlot B, 16 un-shaded pens were monitored. The feedlots varied by SCU, pen size, pen dimensions, pen orientation, shade availability, breed types, days on feed, market focus and feedlot terrain – which ranged from flat (Feedlot A) to slightly undulating (Feedlot B). Feedlot A's market focus was primarily mid to long fed export, whereas Feedlot B was focused on the domestic market. Both feedlots were monitored daily over the 77 days, from 14 January 2019 until 31 March 2019. No HGPs were used.

For each feedlot the following data was obtained:

Pen Information: A pen description for each pen used in the study was obtained before experimental data was collected. This included pen dimensions (L x W x D), orientation, pen slope, distance from weather station, shade type and area (if shade was available), shade orientation (if shade was available), feed bunk and water trough dimensions (L x W x D) and shade properties (height, location in pen, material, and coverage).

3.2 Breed Type and Market Categories Monitored at Each Feedlot

3.3 Feedlot A

Two breed types were evaluated: Breed Type 1 (100% *Bos taurus* – Angus; BT1), and Breed Type 6 (100% *Bos taurus* – Wagyu; BT6) (See Animal Data below). There were 9 pens of Angus and 7 pens of Wagyu that where monitored over the duration of the study. The Angus pens ranged in days on feed (DOF) over the duration of the study as follows: 1 to 73, 8 to 80, 31 to 103, 95 to 167, 110 to 182, 113 to 185, 125 to 197, 131 to 293 and 147 to 215 days. The Wagyu pens days on feed ranged as follows: 53 to 125, 92 to 164, 181 to 253, 182 to 254, 271 to 343, 321 to 393 and 322 to 394 days. Wagyu were fed up to 450 days, and the Angus up to 200 days. The pens used where clustered by breed type: *cluster 1* (BT6) consisted of pens 1 to 7 (inclusive), with all pens within 80 m of each other; *cluster* 2 (BT1) consisted of pens 13 to 21 (inclusive), with all pens within 60 m of each other. There was approximately 80 m between the clusters.

3.4 Feedlot B

Two breed types were evaluated: Breed Type 3 (25% *Bos indicus*; BT3) and Breed Type 4 (50*% Bos indicus*; BT4). Thirteen pens (three pens were used twice as new cattle back filled pens following the sale of cattle) were used over the duration of the study, and there was a mixture of BT3 and BT4 within each pen. Within a pen breed types were identified, and during evaluation of panting scores (PS) (see below) individuals within a specific breed type were identified and PS for the individual recorded. Sixteen cohorts of cattle were observed. The cattle observed range in DOF as follows: 3 to 55, 6 to 60, 7 to 39, 12 to 33, 15 to 42, 15 to 60, 20 to 49, 22 to 35, 22 to 39, 22 to 83, 40 to 78, 43 to 75, 45 to 70, 60 to 80, 66 to 77, and 127 to 145 days. The pens used where located in three rows: pens 1, 2, 3, 4 and 5 in *row 1*; pens 7, 9, 10 and 11 in *row 2*; pens 19, 20, 21 and 22 in *row* 3. Seven pens were single sex pens (heifers only) and six pens were mixed sex pens (steers + heifers)

3.5 Animal data – both feedlots

The following data were obtained for each pen at the commencement of the study, when new pens were enrolled after the commencement of the study.

- Origin of cattle, sex, age (teeth), breed type (see next dot point) and live weight at induction.
- Breed type (BT): four breed types were identified – BT1: 100 % *Bos taurus* (English), BT3: 25% *Bos indicus*; BT4: 50% *Bos indicus* and BT6: Wagyu. A head count for each breed type was obtained for each pen.
- HGP status.

Once pens were enrolled in the study the following was obtained.

- Days on feed at time of monitoring.
- Morbidity to date at time of monitoring (including diagnosis) (individual cattle identified).
- Mortality to date at time of monitoring (including necropsy reports) (individual cattle identified).
- Daily pen as-fed deliveries (kg/pen).
- Daily pen head counts for pens.
- Times of the day that cattle were fed.
- Visual assessment of cattle in the enrolled pens occurred three times each day (at approximately 0800, 1200 and 1600 h). The visual assessment data collected was:
- Panting scores (PS) by BT within a pen. The PS system used was as per: Recognising Excessive Heat Load in Feedlot Cattle – In Tips and Tools "Heat Load in Feedlot Cattle".
- Behavioural observations: Number of cattle (by BT) standing or lying; location in pen (shade, feed bunk, water trough, in sun); activity (eating, drinking), and disposition (agitated, milling around, depressed).

3.6 Feed Nutrient Analysis

A composite sample of each ration used in the observation pens, at both feedlots, was obtained each week and frozen for later analysis. The samples were analysed for Dry Matter, Crude Protein, Neutral Detergent Fibre, Fat, Ash, and Metabolisable Energy was calculated (Symbio Laboratories Pty. Ltd. Brisbane).

3.7 Weather Data

Feedlot A: Two weather stations (Weather Maestro 10 Channel Weather Station, Environdata Weather Stations Pty. Ltd., Warwick Qld.) were calibrated by Environdata prior to the commencement of the study. One weather station was located centrally to cluster 1 and the other centrally to cluster 2. No pen was further than 80 m from a weather station.

Feedlot B: Five weather stations (Weather Maestro 10 Channel Weather Station, Environdata Weather Stations Pty. Ltd., Warwick Qld.) were calibrated by Environdata prior to the commencement of the study. In *row 1* a weather station was located 50 m from the rear of pen 5 and another 50 m from the rear of pen 3. In *row 2* a weather station was located 3 m from pen 10, and another was located 20 m from the rear of pen 7. In *row 3* a weather station was located 3 m from the rear of pens 21 and 22, and another was located 18 m from the side of pen 22.

Weather data: dry bulb temperature, relative humidity, solar radiation, black globe temperature, wind speed {2 m height} and wind direction were collected at 10-minute intervals over the duration of the study at each feedlot. These data were then used to calculate HLI and AHLU. Rainfall was collected on site on a daily basis at 0900 h. A web-based service WeatherMation LIVE (Environdata Weather Stations Pty Ltd., Warwick Qld): provided real time weather data as well as real time HLI and AHLU values for each weather station. In addition, the service provided 3 hourly, 12 hourly and 30-day graphical representation of the data. The quality and integrity of data streams was assessed each day.

3.7.1 Calculation of the heat load index and accumulated heat load units

Heat load index thresholds and the consequent accumulated heat load units were calculated for each breed type were as per 'Recognising Excessive Heat Load in Feedlot Cattle – In Tips and Tools "Heat Load in Feedlot Cattle"'.

3.7.1.1 Heat Load Index Calculation

Calculation of the Heat Load Index (HLI) requires ambient temperature (T_A; °C), relative humidity (RH; %), wind speed (WS; m/s) and black globe temperature (BGT; °C). Of these, T_A, RH and WS are routinely measured by the majority of weather stations. Although sensors for measuring BGT exist, these are not normally included as part of the standard weather station (however theses were included on the weather stations used in this study) and must be ordered from a suitable supplier. In the absence of a BGT sensor, the BGT can be inferred from measurements of T_A and solar radiation (SR; W/m^2).

The equation for calculating BGT from T_A and SR is:

$BGT = 1.33 \times T_A - 2.65 \times Sqrt(T_A) + 3.21 \times \log(SR + 1) + 3.5$, where: log is the logarithm (base 10) function and Sqrt is the square root function.

HLI_{LO} = 1.3 × BGT + 0.28 × RH – WS + 10.66, and HLI_{HI}= 1.55 × BGT + 0.38 × RH – 0.5 × WS + exp (2.4 – WS) + 8.62: where: *exp* is the exponentiation function and the HLI value was taken as either HLI_{HI} or HLI_{LO} depending on the BGT value (LO refers to a BGT<25 ^{o}C, and HI refers to a BGT>25 ^{o}C.

A blending function (S(BGT)) – was used to produce a smooth transition in HLI values calculated using the two different equations. The blending function is: SBGT = 1 / (1 + exp (-(BGT – 25) / 2.25)). Using this blending function, a value of the HLI is calculated as follows:

HLI = SBGT × HLI_{HI} + (1 – S(BGT)) × HLI_{LO}

3.7.1.2 Accumulated Heat Load Unit Calculation

The Accumulated Heat Load Unit (AHLU) represents the amount of heat accumulated in cattle over a period of time. For this study AHLUs were calculated from mid-January 2019 to end-April 2019 (the actual end date varied slightly between the two feedlots). The rate of accumulation depends on the current HLI value and the thresholds used. Large HLI values result in a more rapid increase in AHLU, conversely, low HLI values result in a decrease of the AHLU (i.e. the cattle cool down and recover). The thresholds are determined based on breed type, access to shade, and days on feed (see Gaughan et al. 2008 for details). Whether cattle recover or become heat stressed depends on the value of the thresholds. Weather station data (per feedlot) were pooled for the calculations.

The ***base threshold*** occurs at a HLI value of 86 (base AHL). This threshold is based on a healthy Black Angus steer, 80 days on feed without access to shade. For each breed type used in the study a different threshold was used to calculate the AHLU for any given period of time. Firstly, a threshold value of +5 was added to each breed type for having access to shade (86 from the base threshold + 5) (Feedlot A only), and then the breed type (BT) adjuster (see Gaughan et al 2008) was added. Thus, for BT1 (Feedlot A) the threshold was 91 (+5 for shade and 0 for BT1) and for BT6 the upper threshold was 95 (+5 for shade and +4 for BT6). For Feedlot B (no shade) the threshold for BT3 was 90 (0 for shade and + 4 for BT3) and for BT4 the threshold was 93 (0 for shade + 7 for BT4). The lower threshold remained at 77 for all breed types. The subsequent AHLUs were then used to evaluate the efficacy of the AHLU adjusted for breed type to predict PS.

3.8 Statistical Analysis

Weather data was categorized for statistical analysis based on maximum daily HLI (HLI_{CAT}) and maximum daily Accumulated Heat Load adjusted for breed type (AHL_{ADJ}). The following five categories of HLI_{CAT} were used: Cool <70, Moderate >70<77, Hot >77<85, Very Hot >85<95, and Extreme >95. For the AHL_{ADJ} five categories were used: No heat load < 0, Minor >0<10, Moderate >10 <20, High >20 <40, and Very High >40. Days on feed were also categorised as: DOF <20, DOF >20<40, DOF >40<60, and DOF >60.

3.8.1 Statistical Models:

Dry Matter Intake (DMI): The effects of heat load index and accumulated heat load units on DMI were examined using PROC GLIMMEX (SAS Inst. Inc., Cary, NC, USA). The random effect was feedlot. BT was a fixed effect. Pen was the experimental unit for DMI. Days on feed was used a co-variant in the model. PROC Mixed Model (SAS Inst. Inc., Cary, NC, USA) for a randomised block design using REML estimation was further used to determine interactions. In addition, the effects of the categorized weather parameters HLI_{CAT} and AHL_{ADJ} on DMI were examined as single parameter effects and as two and three way interactions e.g. BT, HLI_{CAT} Categories, AHL_{ADJ} Categories, Days on Feed, BT × HLI_{CAT}, BT x AHL_{ADJ}, Treatment × DOF, Treatment × HLI_{CAT} × AHL_{ADJ}. Where there were no treatment effects on the measured variables, the variable data were combined and the impact of HLI_{CAT} and AHL_{ADJ} investigated. All data is presented as mean DMI at the pen level (kg/pen/day). Data are presented as least square means ± SE. When significance was indicated (P<0.05), means were separated using Tukey's Studentized range test.

Panting Score (PS): Panting score data consists of date (dd/mm/yyyy) and time (hours: minutes: seconds) of observation, pens (29 pens: 16 from feedlot 1 and 13 from feedlot 2), breed type (BT1, BT3, BT4, and BT6), sex (mixed, steers and heifers), relative humidity, temperature, black globe temperature, solar radiation, and wind speed, Heat Load Index (HLI), Accumulated Heat Load adjusted for breed type 1, Accumulated Heat Load adjusted for breed type 3, Accumulated Heat Load adjusted for breed type 4, Accumulated Heat Load adjusted for breed type 6, total number of cattle per pen, number of cattle showing each of the panting score (PS) categories (PS 01, PS 2, PS 2.5, PS 3, PS 3.5, PS 4, PS 4.5). A total of 59 rows with zero counts of cattle were excluded.

Panting Score Data Analysis:

Descriptive statistics: Descriptive summary measures were used to quantify the proportion of cattle showing each of the panting score categories. Sub analysis based on feedlot, breed types and pen categories are performed. Panting scores were reclassified into two binary (PS 01, PS 2 – 4.5) and three multinomial outcomes (PS 01, PS 2, PS 2.5 – 4.5). The corresponding number of cattle showing each of the panting scores were added to get the total counts in each of the reclassified panting score categories.

Logistic regression: The choice of logistic regression was based on the coding of the outcome variable of interest – elevated panting score. The decision to use logistic regression was also informed by similar models used for statistical analyses in the MLA Cash Cow project (B.NBP.0382), and also B.FLT. 0387. Panting score is an arbitrary score from 0 to 4.5. The goal for the analysis is to understand causal factors that may be associated with an elevation in panting score.

Animals with panting scores of 0 or 1 may be considered to be normal i.e. not suffering from any level of discomfort or distress. Panting scores above 3 are definitely associated with distress.

For the purposes of these analyses we have assigned a cut-point between panting score 1 and panting score 2 such that animals with a raw panting score of 0 or 1 are considered normal and animals with a raw panting score of 2 or above, are considered to have an elevated panting score.

A binary outcome variable representing panting score was then developed and coded as follows:

- Outcome = 0 (Normal animal, raw panting score = 0 or 1)
- Outcome = 1 (Elevated panting score, raw panting score = 2 or higher)

The data can then be represented as counts of animals in each pen based on whether they have binary panting score outcomes equal to either 0 or 1. When the outcome variable is binary, logistic regression is the most commonly performed analytical approach. Whereas linear regression gives the predicted mean value of a continuous outcome variable at a particular value for one or more predictor variables, logistic regression gives the conditional probability that an outcome variable equals one at a particular value of the predictor variable(s).

Logistic regressions produce coefficients on the logit scale. The exponential of a coefficient for a predictor variable in a logistic regression (equation 1) produces an odds ratio estimate. Models may also be used to generate predicted probability estimates for a given combination of explanatory variable input values – providing an estimate of the predicted probability of the outcome variable being equal to 1, given assumed values of the input or explanatory variables.

Clustering: The term clustering is used to describe datasets where observations are clustered into groups such that observations within one cluster or group may be more similar than observations that are in different clusters or groups. Data containing multiple levels of clustering may be described as hierarchical or multi-level or nested data. In these data, animals were clustered in pens and then observations on animal-pens may be considered to be clustered within days. For analyses a two level clustering approach was used:

- Level 1 represents an observation on an animal.
- Level 2 represents the combination of pen and day.

It is important to account appropriately for clustering when conducting multivariable analyses. The main approach to adjust for clustering was to incorporate a random effect coding for the pen-day combination. This approach was taken to ensure that statistical output was adjusted for the possible effects of clustering at the pen-day level.

Where data were provided for multiple feedlots, feedlot was coded as either a level 3 random effect (pen clustered within feedlot) or as a fixed effect. This ensured multivariable results were adjusted for effects at the feedlot level.

Variance: Model outputs were used to estimate the amount of variance in the outcome that is explained by the model. These measures are generally expressed as the proportion of total variance in the outcome that may be explained by the model.

There are particular challenges in generating variance estimates for multilevel logistic regression and in generating estimates of the amount of variance in the outcome variable explained by the model. In a multi-level logistic regression model, the level one variance is defined as equal to pi-squared divided by 3. The explanation for this is based on the fact that the modelling approach uses the logit transformation of an underlying binary response variable (coded as 0 or 1), to represent a threshold continuous variable where the outcome is 0 below the threshold and 1 above the threshold. It can then be shown mathematically that the level-1 residual has a logistic distribution and furthermore that this distribution has a mean of zero (0) and a variance equal to π2/3 (Snijders and Bosker, 1999).

Higher level variance estimates (level 2 or level 3) are estimated directly and reported by the multilevel model. The sum of all variance components in the full model (variance explained by the fixed effects, random variance at level 1 and random variance at any higher levels) provides an estimate of the total variance.

The model outputs can also be used to estimate the level of clustering at each higher-order random effect (level 2 or level 3 etc.) through the residual intra-class correlation (ICC). In a model with two levels of random effect, the ICC is estimated as the pen-day level variance from the full model divided by the sum of the level-1 variance and the pen-day level variance (the sum of these two is the total variance that is not explained by the fixed effects in the model).

The ICC estimate represents the correlation between values of two randomly drawn observations from the same level of pen-day. It can also be interpreted as the proportion of the overall variation in the outcome (in this case elevated panting score) that is attributable to pen-day level effects. In the full model it is the proportion of the overall residual variation in the outcome – that is not explained by the fixed effects in the model – that is attributable to pen-day level effects. The measure of this in the full model (when developed) will indicate the amount of variance in panting score that is at the pen-day level and that is due to un-measured explanatory factors (factors other than those that are included in the model).

Caterpillar plots: Caterpillar plots are derived from multilevel models and represent an ordered plot of the random effects or level-2 residuals (at the pen-day level). The residuals are by definition deviances (or differences) from the overall mean probability of elevated panting score (represented by the horizontal line at zero). See Figure 1 as an example.

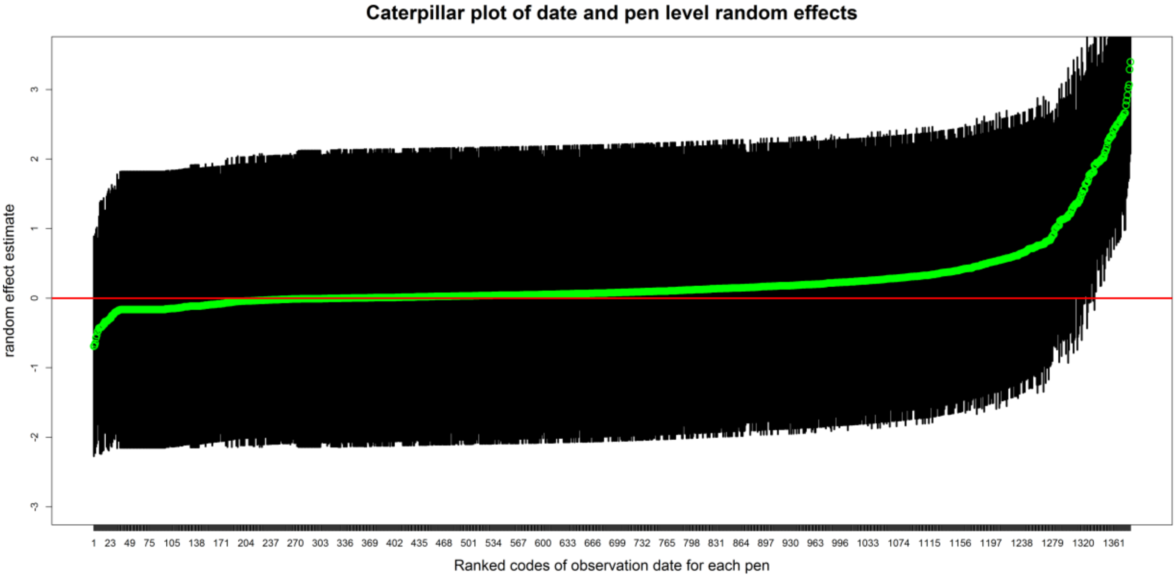

Figure 1. Caterpillar plot of the day and pen level random effects. It represents the unobserved variance that could be attributed to variation between day and time.

Each point is the residual for one combination of pen and day. The bars represent the width of the 95% confidence interval for each point. The values are ordered from smallest to largest i.e. by rank of the estimated residual. The horizontal line at zero represents the average performance for the outcome across all pen-day levels (in this study performance will be % of cattle with elevated panting score). Those points where the 95% CI (the vertical bars surrounding each point), crosses the zero-line, identifies pen-day combinations that are not different to the average performance.

Those values that are above the line (where the entire confidence interval range for the estimate is above the average line at zero), identify combinations of pen and day that are performing better than average and those pen-day combinations that are below the line are performing worse than average. The scale of the y-axis does not have a great deal of relevance.

The usefulness of the plot is in providing a simple graphical representation of the variability in performance between pen-day combinations. Most pen-day combinations are performing around the average line or just under or above it. However, there are some that are performing way above the average line and there are others that are performing way below the average line. It is a visual way of rapidly appreciating the level of variability in pen-day performance due to random effects i.e. unexplained variation.

Bivariate association between binary panting score and accumulated heat load adjusted for breed type (AHL_{ADJ}): Two separate multivariable random effect models were run using data from the two feedlots used in the current study. The first model was run using breed type adjusted AHL (AHL_{ADJ}) as fixed predictors in the model, and the second mixed effects model used AHL_{ADJ} and breed type. In these particular models, two random intercepts were considered. The first was yard and the second represents pens nested within yards. In addition, two random effect models were fitted for the data from the six feedlots from B.FLT.0387. In this case, only one random intercept representing the yard, pen and day as random effects was used.

In addition, another bivariate model using Yard, Pen and Time of Day as random intercepts and with AHL_{ADJ} as fixed effect was used to assess its association with the binary elevated panting score outcome variable for the data from the two feedlots used in the current study. A comparison with B.FLT.0387 data could not be made due to a lack of continuous day data with this data set.

3.9 Breed Type and Sex

There were differences between feedlots in regard to the number of heifers and steers and breed types. At Feedlot A there were 1856 BT1 and 1423 BT6 animals. The sex ratio was 2869 steers and 410 heifers. At Feedlot B there were 822 BT3 and 982 BT4 animals. The sex ratio was 552 steers and 1252 heifers.

3.10 Weather

3.10.1 Mean weather conditions, HLI and AHLU for Feedlot A and Feedlot B

Ambient temperature (TA) was greater than average for both sites. At Feedlot A mean daily maximum TA was +1.6, +2.3 and +1.4 ^{o}C respectively compared with the long-term averages for January, February and March. Minimum TA was equal to long term averages for each month. At Feedlot B mean daily maximum TA was +3.6, +3.3 and +3.1 ^{o}C respectively compared with the long-term averages for January, February and March. Minimum TA was equal to long term averages for each month. However, there were very few days where HLI or AHLU were classified as Very High or Extreme.

The mean (±SE) for the main weather parameters (relative humidity, ambient temperature, black globe temperature and wind speed), heat load index (mean, maximum and minimum) and accumulated heat load units (mean for each breed type, and the maximum for each breed type) over the duration of the study for each feedlot are presented in Table 1. The relative humidity was higher ($P<0.05$) and wind speed was lower ($P<0.05$) at Feedlot B. No other parameters were significantly different between the two sites.

3.10.2 Feedlot A

The maximum ambient temperature (TA) recorded was 40.3 ^{o}C, maximum black globe temperature (BG) was 51.1 ^{o}C, maximum HLI was 105.48 units, maximum AHLU for BT1 was 38.08 units, and for BT6 it was 13.88 units. There were 20 days when TA<30 ^{o}C and 57 days when TA>30 ^{o}C. Of the days exceeding 30 ^{o}C, 22 days had a TA>35 ^{o}C and 40 ^{o}C was exceeded on 1 day.

The maximum daily HLI is thought to be a better indicator of the heat load on cattle than TA alone. The maximum HLI was ≥86 on 66 days, of these 66 days the HLI≥ 90 on 42 days, was greater than 95 on 25 days, and ≥100 on 4 days (Figure 2). These data suggest that the BT1 cattle would have been under high heat load for at least some part of the 42 days when HLI≥90.

Accumulated Heat Load was determined for both breed types. In summary the AHLU for BT1 was 0 on 41 days (i.e. No heat load), >0 <10 (Minor) on 17 days, >10 <20 (Moderate) on 14 days, >20<40

(Hot) on 4 days, and >30 (Very Hot) on 1 day. For the BT6 cattle the AHL was 58 days (No heat load), 15 days at Minor heat load and 4 days of Moderate heat load (Figure 3).

Table 1. Mean (± SE) for relative humidity (RH, %), ambient temperature (TA, °C), black globe temperature (BG, °C), wind speed (WS, m/s), heat load index (HLI, units), accumulated heat load (AHL, units) for Feedlot A and Feedlot B.

Item	Feedlot A	Feedlot B
RH, %	59.80 ± 0.18[a]	67.74 ± 0.15[b]
TA, °C	25.54 ± 0.05	24.59 ± 0.04
TA_{MAX}, °C	40.30	40.40
TA_{MIN}, °C	8.90	9.50
BG, °C	28.36 ± 0.08	27.40 ± 0.07
WS, m/s	2.55 ± 0.01[a]	1.38 ± 0.01[b]
HLI, units	69.16 ± 0.12	72.17 ± 0.10
HLI_{MAX}, units	105.48	109.86
HLI_{MIN}, units	41.47	41.98
AHL1, units	1.60 ± 0.08	-
AHL6, units	0.45 ± 0.08	-
$AHL1_{MAX}$, units	38.08	-
$AHL6_{MAX}$, units	13.88	-
AHL3, units	-	1.90 ± 0.05
AHL4, units	-	0.64 ± 0.02
$AHL3_{MAX}$, units	-	42.48
$AHL4_{MAX}$, units	-	24.80

AHL1 = Accumulated heat load units for breed type 1 (100% *Bos taurus*); AHL6 = Accumulated heat load units for breed type 6 (Wagyu); AHL3 = Accumulated heat load units for breed type 3 (25% *Bos indicus*); AHL4 = Accumulated heat load units for breed type 4 (50% *Bos indicus*). Means in a row with different superscripts are significantly different (P<0.05).

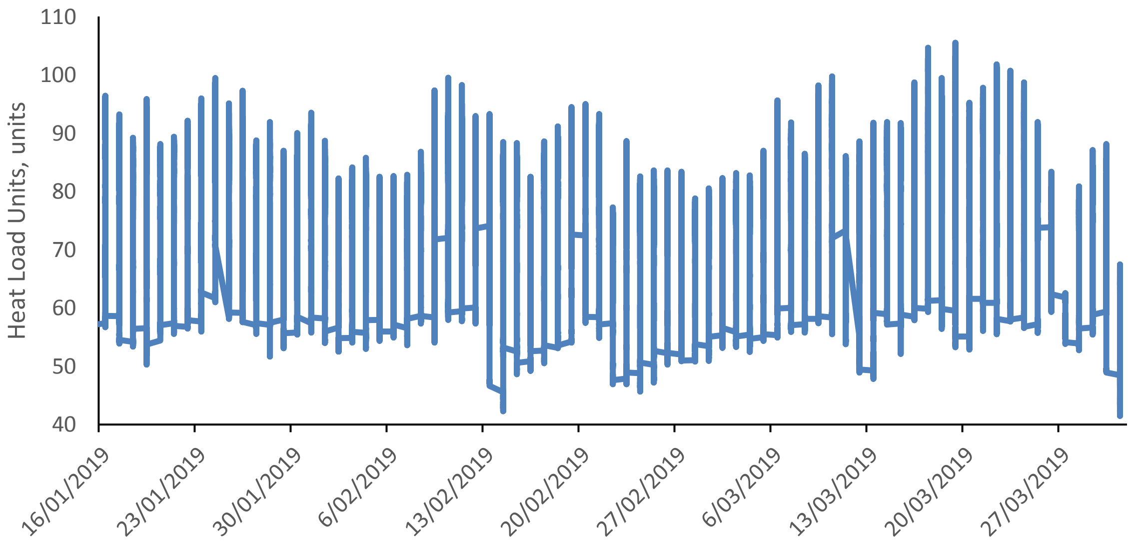

Figure 2. Heat load index (HLI, units) for Feedlot A, from 16 January 2019 to 31 March 2019.

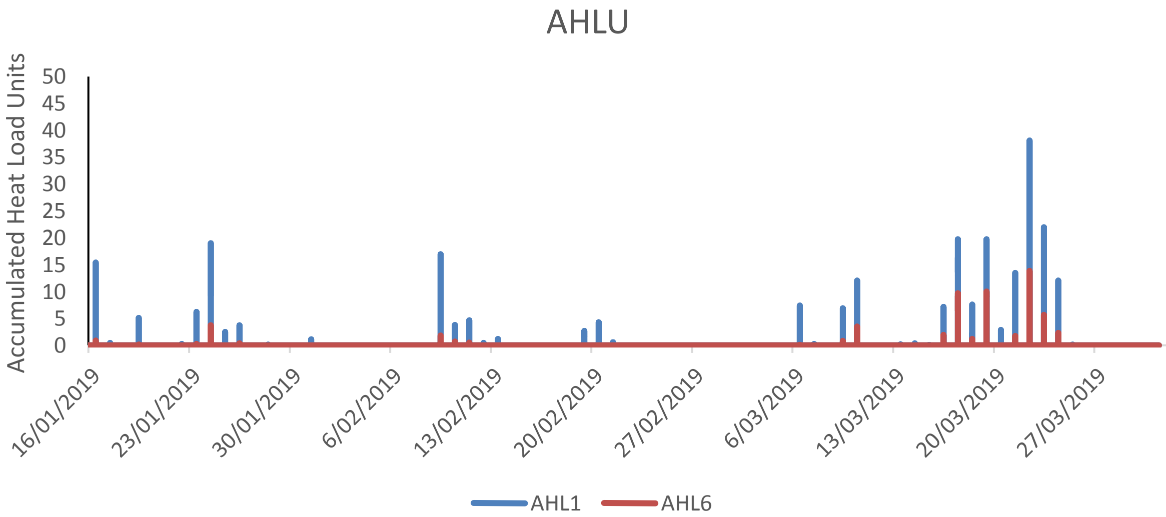

Figure 3. The accumulated heat load at Feedlot A adjusted for breed type 1 (AHL1) and breed type 6 (AHL6) over the duration of the study.

3.10.3 Feedlot B

The maximum ambient temperature (TA) recorded was 40.4 ^oC, maximum black globe temperature (BG) was 51.8 ^oC, maximum HLI was 109.85 units, maximum Accumulated Heat Load for BT3 was 42.49 units, and for BT4 it was 24.80 units. There were 22 days when TA ≤ 30 ^oC and 68 days when TA ≥ 30 ^oC. Of the days exceeding 30 ^oC, 13 days had a TA≥35 ^oC and 40 ^oC was exceeded on 1 day.

The maximum HLI was ≥86 on 66 days, ≥ 90.0 on 58 days, ≥ 95 on 43 days, and ≥100 on 9 days (Figure 4). These data suggest that the cattle would have been under high heat load for at least some part of the 43 days when HLI≥95.

Accumulated Heat Load was determined for both breed types. In summary the AHL for BT3 was 0 on 29 days (i.e. No heat load), >0 <10 (Minor) on 28 days, >10 <20 (Moderate) on 8 days, >20<40 (Hot) on 10 days, and >40 (Very Hot) on 2 days. For the BT4 cattle the AHL was 34 days (No heat load), 30 days at Minor heat load, 7 days of Moderate heat load and 1 day was classified as Hot (Figure 5).

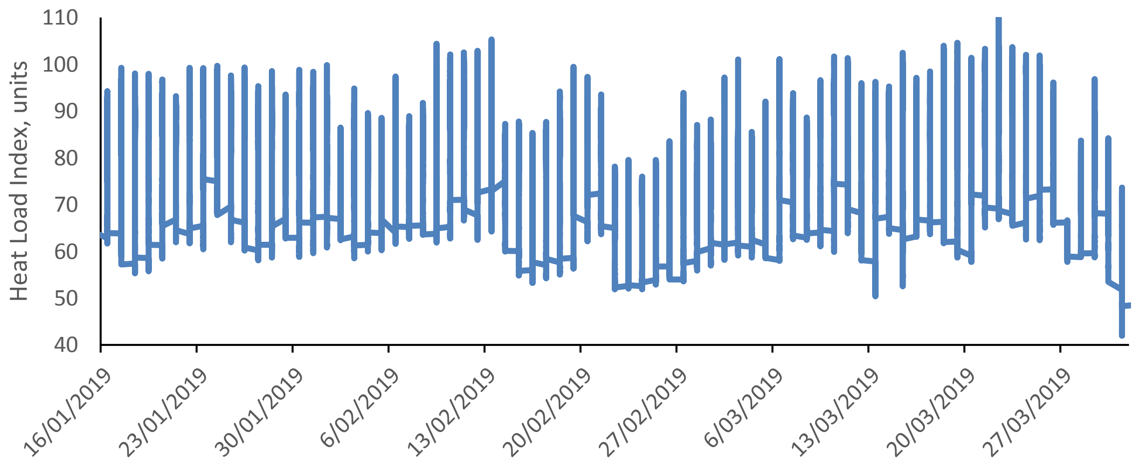

Figure 4. Heat load index (HLI, units) for Feedlot B, from 16 January 2019 to 31 March 2019

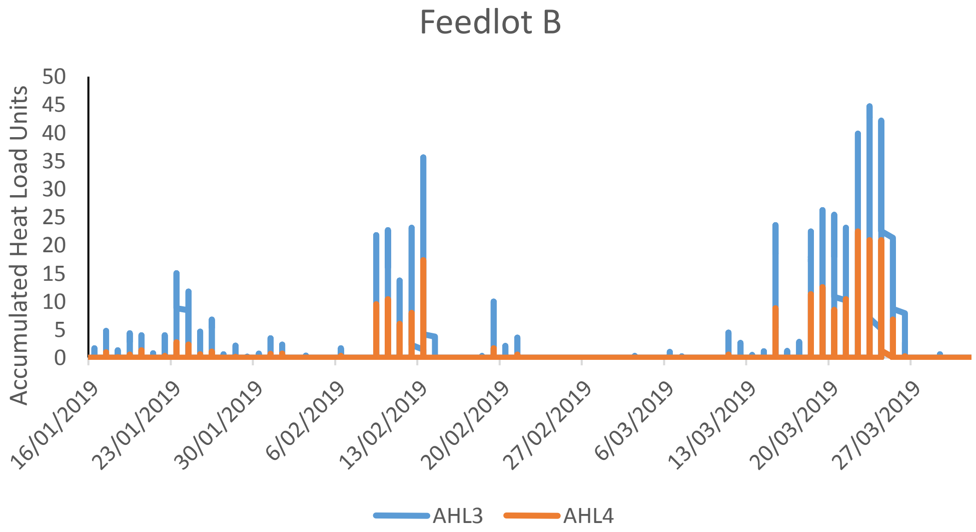

Figure 5. The accumulated heat load at Feedlot B adjusted for breed type 3 (AHL3) and breed type 4 (AHL4) over the duration of the study.

4 Feed Analysis

The nutrient analysis for the rations used at Feedlot B during the study are presented in Table 2 (for BT1) and Table 3 (For BT6). There was not a specific heat load ration for this feedlot. During the late March heat event one pen of heat affected BT6 cattle were transitioned from BT6 finisher to starter 1, and then transitioned for starter 2 before returning to BT6 finisher. The whole transition period from finisher back to finisher was 10 days.

Table 2. Nutrient composition of the starter, finisher and heat load rations used at Feedlot A for BT1 during the study.

Item	Starter 1	Starter 2	Intermediate	Finisher Jan[B]	Finisher Feb	Finisher Mar
Nutrient Composition (DM Basis)						
DM, %	76.0	75.3	72.6	69.7	71.2	70.6
NDF, %	25.9	23.9	22.4	19.4	20.7	20.6
Fat, %	2.6	2.6	4.9	6.0	5.6	5.6
Protein, %	15.3	15.1	14.4	15.5	14.3	15.2
Crude Fibre, %	9.0	9.6	7.5	5.8	5.2	6.1
Ash, %	7.2	6.6	6.5	4.8	4.8	6.1
Moisture (air), %	24.0	24.7	27.4	30.3	28.8	29.3
Nitrogen Free Extract, %	65.9	66	66.7	67.9	70.0	67.0
ME, MJ/kg[A]	12.3	12.4	13	13.5	13.5	13.2

[A]ME (MJ/kg, DM) = 0.12 x Crude Protein + 0.31 × Ether Extract + 0.005 × Crude Fibre + 0.14 × Nitrogen Free Extract.
[B]Jan = January, Feb= February, Mar = March.

Table 3. Nutrient composition of the starter, finisher and heat load rations used at Feedlot A for BT6 during the study.

Item	Finisher 1 Jan	Finisher 1 Feb	Finisher 1 Mar	Finisher 2 Jan	Finisher 2 Feb	Finisher 2 Mar
Nutrient Composition (DM Basis)						
DM, %	69.8	70.7	70.2	71.9	72.7	70.0
NDF, %	27.8	25.8	25.6	22.5	22.9	27.3
Fat, %	4.2	4.3	4.3	3.8	3.8	5.8
Protein, %	14.4	14.2	14.7	14.7	13.7	14.2
Crude Fibre, %	9.7	9.3	9.0	7.2	8.7	9.4
Ash, %	6.3	5.9	5.9	5.1	5.4	5.8
Moisture (air), %	30.2	29.3	29.8	28.0	27.2	30.0
Nitrogen Free Extract, %	65.4	66.4	65.9	69.2	68.3	64.8
ME, MJ/kg[A]	12.7	12.8	12.8	13.0	12.8	13.0

[A]ME (MJ/kg, DM) = 0.12 x Crude Protein + 0.31 × Ether Extract + 0.005 × Crude Fibre + 0.14 × Nitrogen Free Extract.
[B]Jan = January, Feb= February, Mar = March.

The nutrient analysis for the rations used at Feedlot B during the study are presented in Table 4. There is a large difference in percentage NDF between the heat load ration used in February (45.4%) and the heat load ration used in March (20.6%). This was due to a ration ingredient change where a large amount of biscuit meal was used in the March ration compared with the February ration.

Table 4. Nutrient composition of the starter, finisher and heat load rations used at Feedlot B during the study.

Item	Starter	Finisher (Jan/Feb[B])	Heat Load (Feb)	Finisher (Mar)	Heat Load (Mar)	Finisher (Mar)
Nutrient Composition (DM Basis)						
DM, %	66.9	74.5	74.8	72.5	72.3	73.0
NDF, %	64.9	22.0	45.4	22.3	20.6	24.9
Fat, %	1.9	6.6	7.0	5.6	6.5	6.6
Protein, %	10.2	11.9	12.2	13.1	12.9	13.2
Crude Fibre, %	35.8	8.6	7.4	8.0	6.4	5.8
Ash, %	8.7	7.3	10.5	8.3	9.1	10.6
Moisture (air), %	33.1	25.5	25.2	27.5	27.7	27.0
Nitrogen Free Extract, %	43.4	65.6	62.9	64.9	65	63.7
ME, MJ/kg[A]	9.7	13.1	12.8	12.8	13.0	12.9

[A]ME (MJ/kg, DM) = 0.12 x Crude Protein + 0.31 × Ether Extract + 0.005 × Crude Fibre + 0.14 × Nitrogen Free Extract.
[B]Jan = January, Feb= February, Mar = March.

5 DMI and ME Intake

Dry matter intake, and consequently ME intake (MEI), was a function of BT (Table 5). Dry matter intakes were similar for BT1 and BT3 (P=0.9632). However, the MEI of BT3 was lower (P=0.0252) compared with BT1. The BT6 cattle had the lowest DMI (P<0.0001) and MEI (P<0.0001) compared with the other BTs.

Table 5. Mean DMI (±SE) and MEI (±SE) for each breed type (BT) at Feedlot A and Feedlot B over the duration of the study (77 d).

Feedlot	BT	DMI, kg/head^{-1}	MEI, MJ ME/d
A	1	10.52 ± 0.06^{a}	13.99 ± 0.08^{a}
	6	8.76 ± 0.07^{b}	11.21 ± 0.09^{b}
B	3	10.53 ± 0.11^{a}	13.63 ± 0.14^{c}
	4	10.25 ± 0.07^{c}	13.24 ± 0.10^{d}

Means within a column with different superscripts are significantly different (P<0.05).

5.1 Effect of climatic conditions on DMI and MEI

5.1.1 Daily Maximum Heat Load Index

The maximum HLI (HLI_{MAX}) categories encountered at Feedlot A were: Cool (HLI_{MAX}<70 units), Hot (HLI_{MAX} >77 to 85 units), Very Hot (HLI_{MAX} >85 to 95 units) and Extreme (HLI_{MAX} >95 units). No Moderate days (HLI_{MAX} >70 to 77 units) were encountered at Feedlot A (Table 6). All conditions were encountered at Feedlot B.

Dry Matter Intake: Dry matter intake was numerically but not significantly lower for each BT as HLI_{MAX} increased from Hot to Extreme, apart from BT1, where DMI significantly decreased (P=0.0109) as HLI_{MAX} increased from Hot to Extreme.

Metabolisable Energy Intake: Metabolisable energy intake was numerically but not significantly lower for each BT as HLI_{MAX} increased from Hot to Extreme, apart from BT1, where MEI was significantly lower (P<0.0001) as HLI_{MAX} increased from Hot to Extreme.

5.1.2 Daily Maximum AHLU

The maximum AHLU (AHL_{MAX}) categories used were: Not Heat Load (AHL_{MAX} < 0 units), Minor (AHL_{MAX} >0 to 10 units), Moderate (AHL_{MAX} >10 to 20 units), High (AHL_{MAX} >20 to 40 units) and Very High (AHL_{MAX} >40 units). The calculation of AHL_{MAX} is breed type dependent and is based on the BT thresholds as previously discussed. At Feedlot A: Minor, Moderate and High heat load conditions were encountered for BT1, and Minor and Moderate conditions for BT6 (Table 6). At Feedlot B: Minor, Moderate, High and Very High heat loads were encountered for BT3, and Minor, Moderate and High heat loads were encountered for BT6.

Dry Matter Intake: Dry matter intake was numerically but not significantly lower for each BT3, BT4 and BT6 as AHL_{MAX} increased from Minor to High or Very High (Table 7). The DMI of BT1 significantly decreased (P=0.0001) as AHL_{MAX} increased from Minor to Moderate, and from Minor to High (P=0.0014). There was a trend for lower DMI in the BT1 group as conditions changed from Moderate to High (P=0.0649).

Metabolisable Energy Intake: Metabolisable energy intake was numerically but not significantly lower for each BT3, BT4 and BT6 as AHL_{MAX} increased from Minor to High or Very High (Table 7). The MEI of BT1 significantly decreased (P=0.0011) as AHL_{MAX} increased from Minor to Moderate, and from Minor to High (P<0.0001). There was a trend for lower MEI in the BT1 group as conditions changed from Moderate to High (P=0.0537).

Table 6. Impact of HLI category (HLI_{MAX}) on dry matter intake (DMI) by Breed Type (BT).

Feedlot	HLI_{MAX} category	BT	DMI kg/head.day^{-1}	MEI MJ/kgDMI.day-1
A	Cool	1	9.48 ± 0.50^{a}	12.51 ± 0.67^{a}
	Hot	1	10.78 ± 0.13^{b}	14.40 ± 0.16^{b}
	Very Hot	1	10.62 ± 0.10^{b}	14.13 ± 0.12^{b}
	Extreme	1	10.17 ± 0.12^{a}	13.47 ± 0.15^{a}
	Cool	6	7.24 ± 0.56^{a}	9.28 ± 0.77^{a}
	Hot	6	8.80 ± 0.13^{b}	11.25 ± 0.18^{b}
	Very Hot	6	8.83 ± 0.01^{b}	11.29 ± 0.13^{b}
	Extreme	6	8.70 ± 0.13^{b}	11.13 ± 0.17^{b}
B	Cool	3	10.20 ± 0.86^{a}	13.01 ± 1.17^{a}
	Moderate	3	11.22 ± 0.69^{a}	14.50 ± 0.91^{a}
	Hot	3	11.25 ± 0.53^{a}	14.72 ± 0.72^{a}
	Very Hot	3	10.42 ± 0.20^{a}	13.40 ± 0.28^{a}
	Extreme	3	10.39 ± 0.15^{a}	13.51 ± 0.20^{a}
	Cool	4	9.78 ± 0.61^{a}	12.56 ± 0.82^{a}
	Moderate	4	10.58 ± 0.43^{a}	13.56 ± 0.58^{a}
	Hot	4	10.22 ± 0.31^{a}	13.25 ± 0.41^{a}
	Very Hot	4	10.11 ± 0.14^{a}	13.08 ± 0.19^{a}
	Extreme	4	10.08 ± 0.11^{a}	13.02 ± 0.14^{a}

Means within a breed type with different superscripts are significantly different (P<0.05).

Table 7. Impact of AHLU category (AHL_{MAX}) on dry matter intake (DMI) by Breed Type (BT).

Feedlot	AHL_{MAX} category	BT	DMI kg/head.day^{-1}	MEI MJ/kgDMI.day^{-1}
A	Minor	1	10.51 ± 0.09^{a}	13.95 ± 0.13^{a}
	Moderate	1	9.84 ± 0.19^{b}	13.02 ± 0.25^{b}
	High	1	9.11 ± 0.35^{b}	11.99 ± 0.47^{b}
	Minor	6	8.77 ± 0.73^{a}	11.23 ± 0.18^{a}
	Moderate	6	8.21 ± 0.73^{a}	10.50 ± 0.44^{a}
B	Minor	3	10.30 ± 0.17^{a}	13.38 ± 0.23^{a}
	Moderate	3	10.89 ± 0.36^{a}	14.17 ± 0.49^{a}
	High	3	10.49 ± 0.37^{a}	13.63 ± 0.50^{a}
	Very High	3	9.95 ± 0.73^{a}	12.95 ± 0.10^{a}
	Minor	4	10.16 ± 0.73^{a}	13.11 ± 0.16^{a}
	Moderate	4	9.79 ± 0.73^{a}	12.71 ± 0.33^{a}
	High	4	9.16 ± 0.73^{a}	11.86 ± 0.90^{a}

Means within a breed type with different superscripts are significantly different (P<0.05).

6 Panting Scores

Data from 13 (44.83%) pens and 16 (55.17%) pens, respectively, from Feedlot A and Feedlot B were collected. During study period, approximately 64.36% and 27.16% of the cattle, respectively, from Feedlot A and Feedlot B showed panting score 0 or 1. Only 5.13% and 3.18% of the cattle, respectively, from Feedlot A and Feedlot B showed panting score 2. Approximately 574 (0.08%) and 295 (0.02%) of cattle showed panting score 2.5 from Feedlot A and Feedlot B. A greater number of animals in Feedlot B had elevated panting scores compared to Feedlot A (Table 8). Panting score details by pen are presented in Table 9.

Table 8. Distribution of panting score counts by feedlot.

		Counts (%) of cattle observations with panting scores 0 to 4.5 by feedlot						
Feedlot	Observations	01	2	2.5	3	3.5	4	4.5
A	520,885	481,797(64.36)	38,380(5.13)	574(0.08)	117(0.02)	11(0)	3(0)	3(0)
B	227,686	203,276(27.16)	23,785(3.18)	295(0.04)	135(0.02)	96(0.01)	71(0.01)	28(0)

Table 9. Panting score (PS) counts (%) by pens.

			Counts (%) of cattle showing panting scores by yard and pens						
Feedlot	Pen	Total Observations	01	2	2.5	3	3.5	4	4.5
B	**1**	**46,625**	**41,742(18.33)**	**4,774(2.10)**	**47(0.02)**	**22(0.01)**	**23(0.01)**	**14(0.01)**	**3(0)**
B	**2**	**15,642**	**13,642(5.99)**	**1,936(0.85)**	**32(0.01)**	**21(0.01)**	**4(0)**	**4(0)**	**3(0)**
B	**3**	**22,338**	**19,556(8.59)**	**2,712(1.19)**	**42(0.02)**	**15(0.01)**	**8(0)**	**2(0)**	**3(0)**
B	**4**	**28,391**	**24,835(10.91)**	**3,473(1.53)**	**37(0.02)**	**19(0.01)**	**12(0.01)**	**12(0.01)**	**3(0)**
B	5	13,600	12,675(5.57)	9,20(0.40)	3(0)	2(0)	0(0)	0(0)	0(0)
B	6	20,355	19,295(8.47)	1,056(0.46)	4(0)	0(0)	0(0)	0(0)	0(0)
B	**7**	**20,440**	**18,253(8.02)**	**2,121(0.93)**	**36(0.02)**	**18(0.01)**	**5(0)**	**5(0)**	**2(0)**
B	8	13,416	12,266(5.39)	1,125(0.49)	17(0.01)	5(0)	3(0)	0(0)	0(0)
B	**9**	**7,208**	**5,937(2.61)**	**1,218(0.53)**	**13(0.01)**	**7(0)**	**17(0.01)**	**13(0.01)**	**3(0)**
B	10	19,451	18,531(8.14)	916(0.40)	4(0)	0(0)	0(0)	0(0)	0(0)
B	11	10,780	9,490(4.17)	1,280(0.56)	10(0)	0(0)	0(0)	0(0)	0(0)
B	**12**	**3,200**	**1,849(0.81)**	**1,238(0.54)**	**39(0.02)**	**22(0.01)**	**21(0.01)**	**20(0.01)**	**11(0)**
B	13	6,240	5,205(2.29)	1,016(0.45)	11(0)	4(0)	3(0)	1(0)	0(0)
A	1	33,417	32,284(6.20)	1,130(0.22)	1(0)	2(0)	0(0)	0(0)	0(0)
A	2	32,891	32,156(6.17)	735(0.14)	0(0)	0(0)	0(0)	0(0)	0(0)
A	3	33,600	32,325(6.21)	1,251(0.24)	24(0)	0(0)	0(0)	0(0)	0(0)
A	4	33,210	32,181(6.18)	1,029(0.20)	0(0)	0(0)	0(0)	0(0)	0(0)
A	5	31,909	31,175(5.99)	732(0.14)	1(0)	1(0)	0(0)	0(0)	0(0)
A	6	33,241	32,164(6.17)	1,075(0.21)	2(0)	0(0)	0(0)	0(0)	0(0)
A	7	33,844	32,904(6.32)	940(0.18)	0(0)	0(0)	0(0)	0(0)	0(0)
A	8	32,570	28,589(5.49)	3,883(0.75)	84(0.02)	13(0)	0(0)	1(0)	0(0)
A	9	31,407	28,459(5.46)	2,922(0.56)	22(0)	4(0)	0(0)	0(0)	0(0)
A	**10**	**32,451**	**26,703(5.13)**	**5,572(1.07)**	**160(0.03)**	**15(0)**	**1(0)**	**0(0)**	**0(0)**
A	**11**	**32,209**	**28619(5.49)**	**3536(0.68)**	**36(0.01)**	**14(0)**	**3(0)**	**0(0)**	**1(0)**
A	12	32,321	29819(5.72)	2490(0.48)	11(0)	1(0)	0(0)	0(0)	0(0)

			Counts (%) of cattle showing panting scores by yard and pens						
Feedlot	Pen	Total Observations	01	2	2.5	3	3.5	4	4.5
A	13	32,113	29898(5.74)	2201(0.42)	14(0)	0(0)	0(0)	0(0)	0(0)
A	**14**	**32,251**	**28175(5.41)**	**3913(0.75)**	**108(0.02)**	**47(0.01)**	**4(0)**	**2(0)**	**2(0)**
A	15	31,673	27924(5.36)	3674(0.71)	63(0.01)	10(0)	2(0)	0(0)	0(0)
A	16	31,778	28422(5.46)	3297(0.63)	48(0.01)	10(0)	1(0)	0(0)	0(0)

7 Model evaluation

7.1 Model for the two feedlots: yard and pen as random effects

With Yard and Pen as random intercepts, an initial bivariate model with AHL_{ADJ} as fixed effect was used to assess its association with the binary elevated panting score outcome variable for the data from the two feedlots (Feedlots A & B). The model output showed that breed type adjusted AHL ($P < 0.001$), was significantly associated with elevated panting score (panting score ≥ 2). A one-unit increase in the AHL_{ADJ} was accompanied by a 10% (OR = 1.10, 95% CI: 1.08 – 1.11) increase in the odds of elevated panting score (Table 10). Evaluation of the variance components of the random effects showed that random effect variances (variance due to pens nested within yards and variance between the two yards) could not be computed as some variance components were equal to zero. A further consequence of this was that the model was unable to proceed to produce the intraclass correlation coefficient (ICC) (Table 10).

Table 10. Bivariate model results for breed type adjusted AHL as fixed predictor of binary elevated panting score outcome.

	Elevated panting score (≥2)		
Predictors	Odds Ratios	CI	P
(Intercept)	0.03	0.03 – 0.04	<0.001
AHLBT	1.10	1.08 – 1.11	<0.001
Random Effects			
σ^2	3.29		
$\tau_{00\ PenID:Yard}$	0.00		
$\tau_{00\ Yard}$	0.00		
N_{PenID}	29		
N_{Yard}	2		
Observations	10,960		
Marginal R^2 / Conditional R^2	0.085 / NA		

Predicted probability plots of elevated panting scores showed that increase in breed type adjusted AHL followed by increases in likelihood of elevated panting scores (Figure 6).

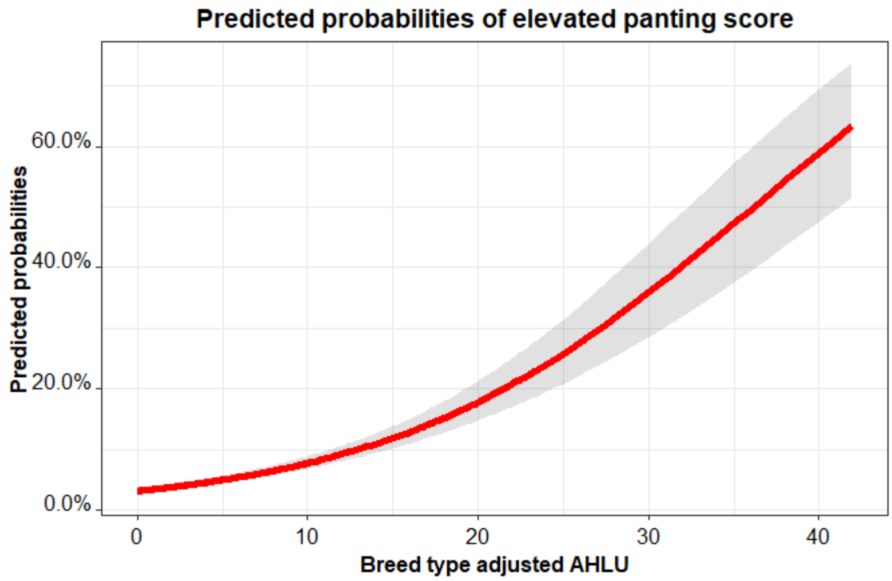

Figure 6. Predicted probability of elevated panting score (PS ≥2) for AHL_{ADJ} levels. The shaded bands represent 95% confidence intervals. Predicted probabilities derived from a multivariable mixed effects logistic regression model.

The random effects (Yard and Pen as random intercepts) model (Table 11) with AHL_{ADJ} as fixed effects was extended by adding breed type into the model as a fixed effect (Table 11). From the multivariable model output, AHL_{ADJ} (P < 0.001), 25% to 50% *Bos indicus* (BT3) (P = 0.003) and Wagyu (BT6) (P < 0.001) were significantly associated with the binned elevated panting score (PS ≥ 2) (Table 11).

A one-unit increase in the breed type AHL_{ADJ} was accompanied by 8% (OR = 1.08, 95% CI:1.06 – 1.09) increase in the odds of elevated panting score. In addition, compared to the reference group (100% *Bos taurus*: BT1), BT3 had 1.71 (OR = 1.71, 95% CI: 1.20 – 2.46) times increased risk of elevated panting score and BT6 had 86% (OR = 0.14, 95% CI: 0.05 – 0.33) lower chance of elevated panting score. Again, evaluation of the variance components of the random effects showed that random effect variances (variance due to pens nested within yards and variance between the two yards) couldn't be computed as some variance components were equal to zero. A further consequence of this was that the model was unable to proceed to produce the intraclass correlation coefficient (ICC) (Table 11).

Table 11. Model results for breed type adjusted AHL and breed type as fixed predictors.

		Elevated panting score (≥2)		
Predictors	Category	Odds Ratios	CI	P
(Intercept)		0.03	0.03 – 0.05	<0.001
AHL_{ADJ}		1.08	1.06 – 1.09	<0.001
Breed type	BT3	1.71	1.20 – 2.46	0.003
	BT4	1.08	0.73 – 1.58	0.708
	BT6	0.14	0.05 – 0.33	<0.001

Random Effects		
	$Var_{animals}$	3.29
	$Var_{PenID:Yard}$	0.00
	Var_{Yard}	0.00
	N_{PenID}	29
	N_{Yard}	2
	Observations	10,960
	Marginal R^2/Conditional R^2	0.270 / NA

Predicted probability plots of elevated panting scores showed that the highest was observed for BT3 (25 to 50% *Bos indicus*) followed by BT1 (100% *Bos taurus*) with the lowest predicted probability of elevated panting score being for BT6 (Wagyu). This predicted probability plot is similar to the plot obtained from B.FLT.0387 (apart from BT6, which were not observed in that study) (Figure 6). Biologically the predicted probability plots are not what would be expected. The slight deviation away from the expected i.e. BT3 having a greater probability of elevated panting score is most likely due to these animals not having access to shade.

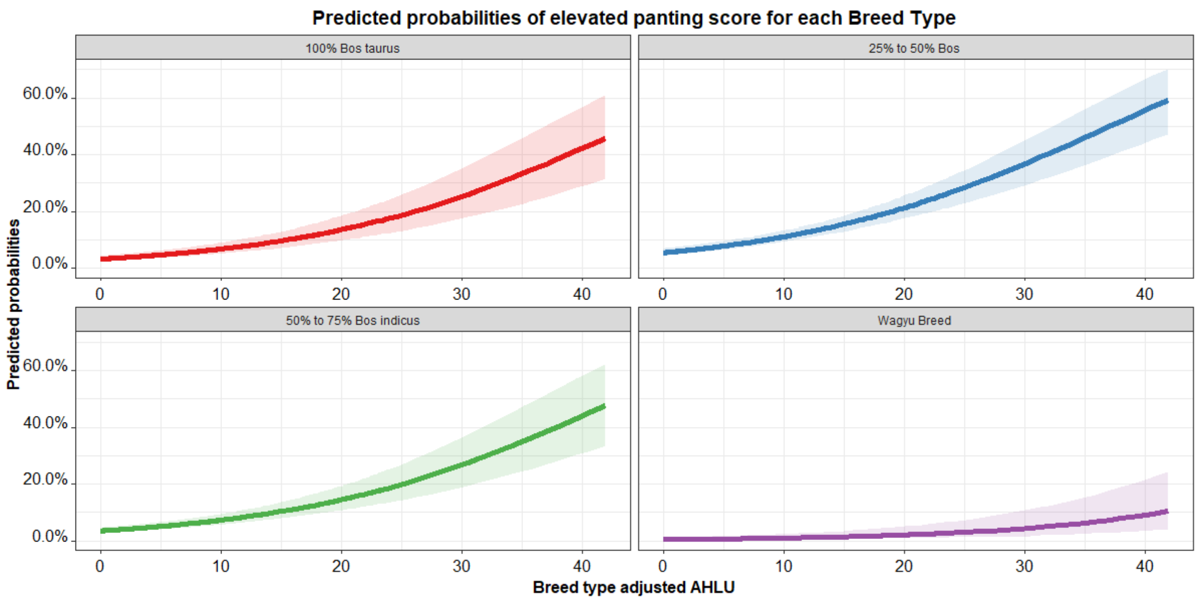

Figure 6. Predicted probability of elevated panting score (PS ≥2) for AHL_{ADJ}. The shaded bands represent 95% confidence intervals. Predicted probabilities derived from a multivariable mixed effects logistic regression model. BT1 = 100% *Bos taurus*; BT3 = 25 to 50% *Bos indicus*; BT4 = 50 to 75% *Bos indicus*; BT6 = Wagyu.

Model Assessment: Model choice summary statistics using Akaike's information criteria (AIC) and Bayesian Information Criteria (BIC) for comparing the random effects models with and without breed types, respectively, showed that the random effects model with breed types included (AIC=1692.212) is the preferred model than model without breed types (AIC=1748.267) (Table 12).

Table 12. Model choice summary statistics using Akaike's information criteria (AIC) and Bayesian Information Criteria (BIC) .

	Model Choice		
Model	DF	AIC	BIC
Random effects without breed types	4	1748.267	1777.475
Random effects with breed types	7	1692.212	1743.326

DF = degrees of freedom, AIC = Akaike's Information Criteria (AIC), BIC = Bayesian Information Criteria (AIC)

7.2 Model for the two feedlots: yard, pen and day as random effects

With Yard, Pen and Day as random intercepts, an initial bivariate model with AHL_{ADJ} as a fixed effect was used to assess its association with the binary elevated panting score outcome variable for the data from the two feedlots. The model output showed that AHL_{ADJ} ($P < 0.001$), was significantly associated with elevated panting score ($PS \geq 2$). A one-unit increase in the AHL_{ADJ} was accompanied by 11% (OR = 1.11, 95% CI: 1.09 – 1.13) increase in the odds of elevated panting score (Table 13). Which was similar to the effect when only pen and yard were used as random effects.

Evaluation of the variance components of the random effect showed that up to 28% (intraclass correlation coefficient = 0.28) of the variability in the binary elevated panting scores was due to Yard, Pen and Day effect (Table 13).

Table 13. Bivariate random effects model results with breed type adjusted AHL as fixed predictor of binary elevated panting score outcome.

	Elevated PS (≥2)		
Predictors	Odds Ratios	CI	P
(Intercept)	0.02	0.01 – 0.02	<0.001
AHL_{ADJ}	1.11	1.09 – 1.13	<0.001
Random Effects			
$Var_{animals}$	3.29		
$Var_{YardPenDay}$	1.27		
ICC	0.28		
$N_{YardPenDay}$	1,383		
Observations	10,960		
Marginal R^2 / Conditional R^2	0.079 / 0.336		

Predicted probability plots of elevated panting scores showed that increase in AHL_{ADJ} followed by increases in likelihood of elevated panting scores (Figure 7). This predicted probability plot is similar to the plot obtained from the model using just Yard and Pen.

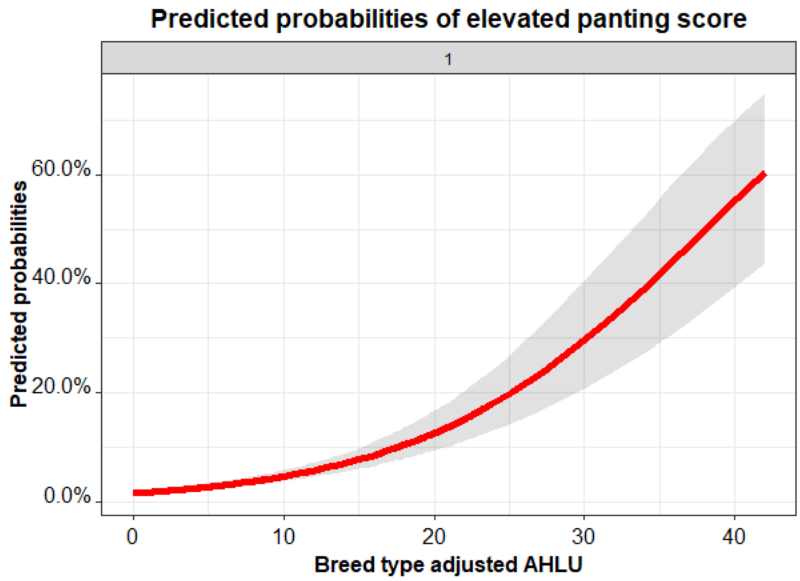

Figure 7. Predicted probability of elevated panting score (PS ≥2) for AHL_{ADJ}. The shaded bands represent 95% confidence intervals. Predicted probabilities derived from a multivariable mixed effects logistic regression model.

A random effects (Yard, Pen and Time of Day as random intercepts) model was fitted for the data from the two feedlots. The fixed effects consisted of breed types, AHL_{ADJ} and time of day when cattle observations were done (1 < 1000 h, 2 = 1000 to 1500 h, 3 = > 1500 h) and an additional interaction term between AHL_{ADJ} and time of day was also used. The model converged and from the multivariable model output, AHL_{ADJ} (P < 0.001), BT3 (P = 0.002) and BT6 (P < 0.001) were significantly associated with panting score (PS ≥ 2) (Table 14).

Compared to the reference group (BT1), BT3 had a 2.02 (OR = 2.02, 95% CI: 1.28 – 3.18) times increased risk of elevated panting score and BT6 had an 86% (OR = 0.14, 95% CI: 0.06 – 0.36) lower chance of elevated panting score. Although it would be unexpected that BT3 would have a greater risk of elevated PS compared with BT1 it needs to be remembered that the BT3 cattle did not have access to shade. In addition, a one-unit increase in AHL_{ADJ} was accompanied a 9% (OR = 1.09, 95% CI: 1.07 – 1.11) greater odds of elevated panting score. There was a time of day effect on PS. The risk of increase panting score was greater (P = 0.058) for the second observations (time of day = 2) compared the earlier observations. For the third time of day observation, a one-unit increase in AHL_{ADJ} was accompanied 15% (OR = 0.85, 95% CI: 0.77 – 0.94) lower odds of elevated panting score (Table 14).

Table 14. Multivariable random effects model output for assessing the association of breed type adjusted AHLBT, breed types and time of day.

Predictors		Elevated panting score (≥2) Odds Ratios	CI	P
(Intercept)		0.02	0.01 – 0.03	<0.001
Breed types	BT1			
	BT3	2.02	1.28 – 3.18	0.002
	BT4	1.10	0.68 – 1.76	0.697
	BT6	0.14	0.06 – 0.36	<0.001
AHL_{ADJ}		1.09	1.07 – 1.11	<0.001
Time of Day:	1			
	2	1.73	0.98 – 3.07	0.058
	3	0.72	0.40 – 1.31	0.283
	Random Effects			
	σ^2	3.29		
	$\tau_{00\ wave2}$	1.24		
	ICC	0.27		
	N_{wave2}	1,383		
	Observations	10,960		
	Marginal R^2 / Conditional R^2	0.238 / 0.446		

Predicted probability plots of elevated panting scores showed that the highest was observed for BT3 followed by BT1 with the lowest predicted probability of elevated panting score being for BT6. When observing the effect of AHL_{ADJ} based on the time of day, the highest predicted probability of elevated panting scores were observed in the time of day category 2 (1000 to 1500 h), followed by time of day category 1 (Figure 8).

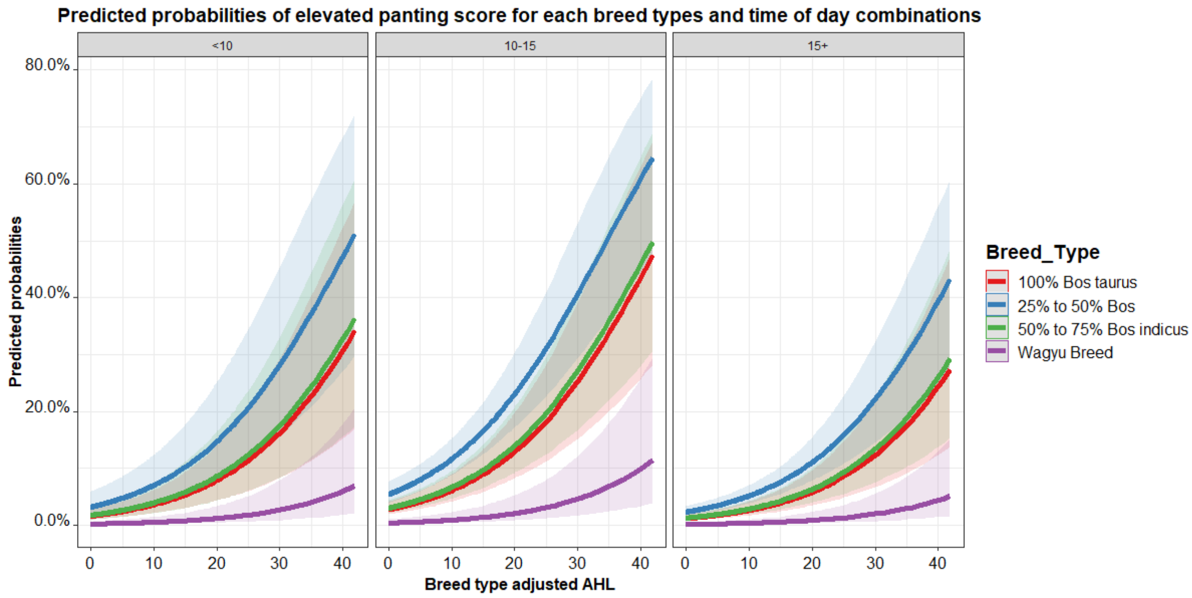

Figure 8. Predicted probability of elevated panting score (PS ≥2) for AHL_{ADJ}. The shaded bands represent 95% confidence intervals. Predicted probabilities derived from a multivariable mixed effects logistic regression model.

As seen in Figure 8 the probability of elevated panting score in BT1 was lower than for BT3 and BT4. AS previously stated, this is most likely due to the effect of shade. All BT1 cattle had access to shade whereas BT3 and BT4 did not.

Model Assessment: Model choice summary statistics showed that the random effects model with AHL_{ADJ}, breed types and time of day in the model (AIC=1562.326) is the preferred model for the data from the two feedlots (Table 15).

Table 15. Model choice summary statistics using Akaike's information criteria (AIC) and Bayesian Info rmation Criteria (BIC).

	Model Choice		
Model	DF	AIC	BIC
Random effects: AHL_{ADJ} without breed types	3	1633.569	1655.475
Random effects: AHL_{ADJ} with breed types and time of day interaction	8	1562.326	1620.743

DF = degrees of freedom, AIC = Akaike's Information Criteria (AIC), BIC = Bayesian Information Criteria (AIC)

7.3 Model for data from B.FLT.0387 applying the methods used for modelling the two feedlots: pen and date as random effects

With yard, pen and day representing the random intercepts, an initial bivariate model using AHL_{ADJ} as a fixed effect was used to assess its association with the binary elevated panting score outcome variable for the data from the six feedlots reported in B.FLT. 0387. The model output showed that AHL_{ADJ} ($P < 0.001$), was significantly associated with elevated panting score (PS ≥ 2). A one-unit increase in the AHL_{ADJ} was accompanied by an 8% (OR = 1.08, 95% CI: 1.07 – 1.09) increase in the odds of elevated panting score (Table 16). Evaluation of the variance components of the random effects showed that random effect variances (variance due to pens nested within yards and variance between the two yards) couldn't be computed as some variance components were equal to zero. A further consequence of this was that the model was unable to proceed to produce the intraclass correlation coefficient (ICC) (Table 16).

Table 16. Bivariate model results for AHL_{ADJ} as fixed predictor of binary elevated panting score outcome.

	Elevated panting score (≥2)		
Predictors	Odds Ratios	CI	P
(Intercept)	0.03	0.02 – 0.03	<0.001
AHL_{ADJ}	1.08	1.07 – 1.09	<0.001
Random Effects			
σ^2	3.29		
$\tau_{00\ wave2}$	0.00		
$N_{\ wave2}$	1425		
Observations	91,552		
Marginal R^2 / Conditional R^2	0.062 / NA		

Predicted probability plots of elevated panting scores showed that increase in breed type adjusted AHL followed by increases in likelihood of elevated panting scores. This predicted probability plot is similar to the plot obtained for B.FLT.0387 (Figure 9).

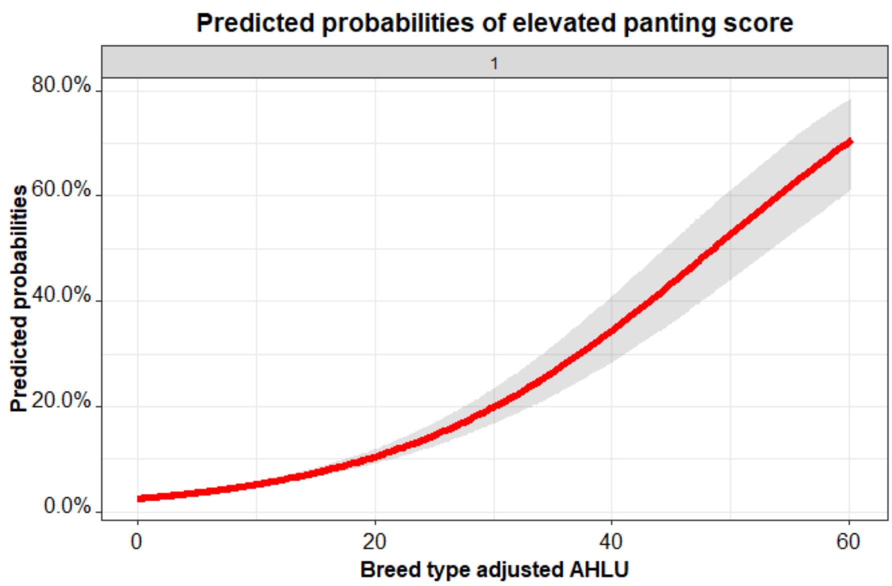

Figure 9. Predicted probability of elevated panting score (PS ≥2) for AHL_{ADJ}. The shaded bands represent 95% confidence intervals. Predicted probabilities derived from a multivariable mixed effects logistic regression model.

From the multivariable random effects model output, breed type AHL_{ADJ} ($P < 0.001$), BT5 ($P < 0.001$), BT2 ($P < 0.001$), BT3 ($P < 0.001$) and BT4 ($P < 0.001$) were significantly associated with elevated panting score ($PS \geq 2$) (Table 17).

A one unit increase in AHL_{ADJ} was accompanied by 6% (OR = 1.06, 95% CI: 1.05 – 1.06) increase in the risk of elevated panting score. In addition, compared to the reference group (BT1), respectively, BT2, BT3 and BT4 had a 79% (OR = 0.21, 95% CI: 0.15 – 0.29), 88% (OR = 0.12, 95% CI: 0.07 – 0.21), and 99% (OR = 0.01, 95% CI: 0.00 – 0.05) lower odds of elevated panting score (Table 5). Again, evaluation of the variance components of the random effects showed that random effect variances (variance due to pens nested within yards and variance between the two yards) couldn't be computed as some variance components were equal to zero. Hence, the model was unable to continue to produce the intraclass correlation coefficient (ICC) (Table 17). The lower odds of elevated panting score in this model for BT3 and BT4 relative to BT1 is in contrast to the two-pen model described above. However, it should be noted that all cattle in B.FLT.0387 had access to shade. The differences may be useful to further understand the impact of shade on BT3 and BT4 cattle.

Table 17. Multivariable random effects logistic regression model using pen and date as random effects.

		Elevated panting score (≥2)		
Predictors	Category	Odds Ratios	CI	P
(Intercept)		0.06	0.05 – 0.07	<0.001
Breed type	BT1 (Ref)			
	BT2	0.21	0.15 – 0.29	<0.001
	BT3	0.12	0.07 – 0.21	<0.001
	BT4	0.01	0.00 – 0.05	<0.001
	BT5	0.00	0.00 – Inf	1.000
	AHL_{ADJ}	1.06	1.05 – 1.06	<0.001
	Random Effects			
	σ^2	3.29		
	$\tau_{00\ wave}$	0.00		
	N_{wave}	1425		
	Observations	91,552		
	Marginal R^2 / Conditional R^2	0.993 / NA		

Ref=Reference category

Model Assessment: Model choice summary statistics showed that the random effects model with both AHL_{ADJ} and breed types in the model for both B.FLT.0387 and the current study were the best in predicting the probability of elevated panting score (Table 18).

Table 18. Model choice summary statistics using Akaike's Information Criteria (AIC) and Bayesian Information Criteria (BIC)

		Model Choice		
Source of Data	Model	DF	AIC	BIC
B.FLT.0387	Random effects: AHL_{ADJ} only	3	3223.442	3251.716
	Random effects: Both AHL_{ADJ} and Breed types	7	2885.636	2951.609
Current Study	Random effects: AHL_{ADJ} only	4	1748.267	1777.475
	Random effects: Both AHL_{ADJ} and Breed types	7	1692.212	1743.326

DF = degrees of freedom, AIC = Akaike's Information Criteria (AIC), BIC = Bayesian Information Criteria (AIC)

8 Discussion

8.1 Weather conditions

Ambient temperature (TA) was greater than average for both sites. At both feedlots mean daily maximum temperature were above long-term averages for January to March. Minimum TA was equal to long term averages for each month. There was a general belief over the study period that relative humidity was lower than normal at both sites. However, there is no long term Bureau of Meteorology data available to support this statement.

There were very few days at either feedlot where HLI or AHLU were classified as Very High or Extreme. The weather data suggest that the BT1 cattle would have been under high heat load for at least some part of the 42 days when HLI≥90. For the BT6 cattle there 15 days at Minor heat load and 4 days of Moderate heat load. At Feedlot B the maximum HLI was ≥85 on 66 days, ≥ 90.0 on 58 days, ≥ 95 on 43 days, and ≥100 on 9 days. These data suggest that the BT3 and BT4 cattle would have been under high heat load for at least some part of the 43 days when HLI≥95.

8.2 Predicting Panting Score

There was good agreement in terms of the predictive probability of panting score for BT relative to AHL between the current study and B.FLT.0387. The magnitude of the change in panting score varied more than the direction of change.

The outcomes from the current study show that there is a time of day effect on panting score response to AHL, with a greater panting score response in late morning to mid-afternoon (T2) compared with other times of the day give the same AHL. Panting score was lower during T3 and this is a reflection of reduced heat load during the latter part of the day. It should be noted that PS can be elevated in the early morning (T1) if there has been carry-over heat from the previous day and night.

Scanning across the predictive plots in the current study (Figure 6) shows that the predicted probability of having elevated panting score for a given AHL_{ADJ} is lower for BT6 relative to the other breed types. Anecdotal evidence has suggested the Wagyu cattle (BT6) have a higher heat tolerance than Angus (BT1), however DMI and MEI were lower in the BT6 group compared with all other breed types. So, it is not clear if the lower panting score is due to heat tolerance, lower MEI or a combination of both.

It is worth noting that BT3 and BT4 have an elevated probability of panting relative to BT1. This does not infer that BT1 has a higher heat tolerance but is a reflection of the lack of shade at Feedlot B. This suggests that the response is not just a breed type response it is also a location response. These data suggest that shade should be considered for BT3 and BT4 cattle.

The influence of feedlot, pen and time of day on the measured outcomes is an important consideration when attempting to predict an occurrence of elevated panting. The model used in the current study which included yard, pen and a day composite variable could explain up to 28% of the random variation in panting score outcomes.

It is unlikely that any model will give 100% agreement between feedlots given all of the subtle variations between yards. The current model could be used as the foundation for models that are individually developed for each yard.

8.3 Dry matter intake and metabolisable energy intake

There was little DMI or MEI responses to the climatic conditions to which cattle were exposed for BT3, BT4 and BT6 cattle. Although DMI and MEI reduced as heat load increased the differences were not significantly different. For BT1 (Angus) significant reductions in DMI and MEI occurred when HLI_{MAX} category and AHL_{MAX} categories moved from Hot to Extreme, and Minor to High respectively.

As previously mentioned, there were only a few heat load periods over the duration of the study. Further to this, management practices in regard to heat load-feeding strategies have most likely affected the DMI and MEI results. Changes in the amount of feed offered prior to, during and following a heat event, and because it takes some time for cattle to recover DMI following the heat event when AHLU may actually be decreasing may have biased DMI and MEI responses.

8.4 Meeting Project Objectives

Determine adequacy of model adjustments proposed in MLA Project B.FLT.0387 to explain the proportion of cattle of different breed types with a panting score ≥ 2.

The comparison of the predictive probability of elevated panting scores for B.FLT.0387 and the current study showed good agreement for the breed types used. However, there is still a degree of divergence, which highlights feedlot specific issues. A lack of very hot to extreme conditions during the study period limited panting score >2.5 data across all breed types used. Given that there was sufficient data to determine that increasing AHLU resulted in an increased probability of PS>2, a time of day effect was detected, and the impact of shade was seen. The unpredictability of weather conditions impacts on the ability to obtain sufficient animal data to test the model under extreme conditions.

9 Recommendations

The following recommendations have arisen from this study.

1. Accumulated heat load adjusted for breed type is a significant variable in explaining heat load response of feedlot cattle, however improvement in prediction confidence intervals of

panting scores ≥ 2 is required across feedlot sites and breed types. It is recommended that collection of continuous panting score data (i.e. daily over summer) for various breed types be undertaken. Preferably from sites where it is more likely that very hot to extreme conditions (for BT1 cattle) are likely. This may involve the movement of susceptible cattle to feedlot where they would not normally be fed over summer.

2. Data for the current heat load model development were collected based on subjective observation of panting score (pens and breed types) within pens. Technologies that objectively measure respiration rate (and panting score) on a continuous individual may result in more accurate data collection and hence an improved model. Additionally, further investigation of feedlot level factors determining variation in panting score is required.
3. The current heat load model in its current form is somewhat difficult to evaluate. Consideration for a revised model using logistic regressions to predict the probability of elevated panting scores or mortality across breed types is warranted. Data collected as part of Recommendation 1 and Recommendation 2 could be used to evaluate the logistic regression model adequacy developed in this project.

10 Bibliography

Gaughan et al. 2008. A new heat load index for feedlot cattle. Journal of Animal Science 86:226 – 234.

Gaughan et al. 2018. Evaluation of a heat load model for feedlot cattle. B.FLT. 0387. Meat and Livestock Australia Limited, Locked Bag 1961, North Sydney NSW 2059

Snijders, T. A. B., & Bosker, R. J. (1999). Multilevel analysis: An introduction to basic and advanced multilevel modeling. Thousand Oaks: Sage Publications.