doi:10.14720/aas.2023.119.1.2259 Original research article / izvirni znanstveni članek

Heat tolerance in Mashona beef cows in semi-arid rangelands: does conformation matter?

Alphonce MATOPE [1], Titus Jairus ZINDOVE [2, 3], Marshall DHLIWAYO [1], Michael CHIMONYO [4], Musavenga TIVAPASI [5]

Received June 23, 2021; accepted Avgust 23, 2022.
Delo je prispelo 23. junija 2021, sprejeto 23. avgusta 2022.

Heat tolerance in Mashona beef cows in semi-arid rangelands: does conformation matter?

Abstract: High temperatures and frequent heat waves raise concerns about heat stress in cattle in grass-based systems, especially in arid and semiarid areas. This study analysed the relationship between conformation traits and physiological parameters associated with heat stress in Mashona cattle. A total of 200 records from fifty cows were used to study the relationships between seven conformation traits and physiological parameters associated with heat stress. Body conformation traits were categorised into three principal components related to body capacity (body depth, flank circumference, chest girth), frame size (stature and body length), and loose skin fold (navel height and dewlap size). As the size of abdominopelvic and thoracic cavities increased, respiratory rate, heart rate, and rectal temperature decreased significantly, while blood triiodothyronine concentration increased. Cattle with deeper bodies, larger flanks, and larger chest girths had significantly lower heart rate, respiratory rate, and rectal temperature but higher blood triiodothyronine concentration than cattle with shallower bodies, smaller flanks, and smaller chest girths. Respiratory rate increased with increasing frame size. Large-framed cattle had significantly higher respiratory rate and lower blood thyroxine concentration. Small-framed cattle with larger chest girth, larger dewlap, and navel farther from the ground surface are better adapted to higher ambient temperatures.

Key words: beef cattle; breeds; Mashona; grazing; heat stress; physiological parameters; conformation traits; body frame; arid rangelands; semi-arid rangelands

Vpliv telesnih lastnosti na dovzetnost za vročinski stres pri kravah mesne pasme mashona v polsušnih pašnih pogojih

Izvleček: Visoke temperature in pogosti vročinski valovi povečujejo nevarnost vročinskega stresa pri govedu na paši, zlasti v sušnih in polsušnih okoljih. Raziskava je analizirala povezave med telesnimi lastnostmi goveda pasme mashona in fiziološkimi parametri, povezanimi z vročinskim stresom. Skupno 200 meritev, pridobljenih na petdesetih kravah, je bilo uporabljenih za preučevanje povezave med sedmimi telesnimi lastnostmi in različnimi fiziološkimi parametri, povezanimi z vročinskim stresom. Telesne lastnosti so bile razvrščene v tri kategorije, ki se nanašajo na obseg telesa (globina telesa, obseg trebuha, prsni obseg), velikost okvira (višina križa in dolžina telesa) in viseči kožni gubi (višina popka in velikost podgrline). S povečevanjem velikosti prsne in trebušne votline se je zmanjševala frekvenca dihanja, srčni utrip in rektalna temperatura, koncentracija trijodtironina v krvi pa se je povečevala. Govedo z večjo globino telesa, in večjim obsegom trebuha ter prsnega koša je imelo nižji srčni utrip, frekvenco dihanja in rektalno temperaturo, vendar višjo koncentracijo trijodotironina v krvi kot govedo s plitvejšim telesom, in manjšim obsegom trebuha ter prsnega koša. S povečevanjem velikosti okvira se je povečevala frekvenca dihanja. Živali z velikim okvirom so imele znatno manjšo frekvenco dihanja in nižjo koncentracijo tiroksina v krvi. Živali manjšega okvira z večjim prsnim obsegom, večjo podgrlino in popkom, bolj oddaljenim od površine tal, so bolje prilagojene na višje temperature okolja.

Ključne besede: govedo; mesne pasme; mashona; paša; vročinski stres; fiziološki parametri; telesne lastnosti; okvir; sušno okolje; polsušno okolje

1 Bindura University of Science Education, Faculty of Agriculture and Environmental Science, Department of Animal Science, Bindura, Zimbabwe
2 Lincoln University, Faculty of Agriculture and Life Sciences, Christchurch, New Zealand
3 Corresponding author, e-mail: zindovetj@gmail.com
4 University of KwaZulu-Natal, School of Agriculture, Earth and Environmental Science, Animal and Poultry Science, Pietermaritzburg, South Africa
5 University of Zimbabwe, Department of Veterinary Science, Mount Pleasant, Harare, Zimbabwe

1 INTRODUCTION

The effects of global warming on cattle are well-documented (Rust and Rust, 2013). Cattle are vulnerable to high temperatures due to fermentation in the rumen, which generates additional heat and low surface to body mass ratio (Alfonzo et al., 2016). Furthermore, cattle do not sweat effectively and mostly rely on respiration to cool themselves (Baumgard and Rhoads, 2012). The sub-Saharan region has been subjected to extremely hot and dry conditions in the past decade (Descheemaeker et al., 2018). This has resulted in low productivity, poor growth performance and increased mortality of cattle (Dzavo et al., 2019). As a result, there has been wide exploration on management and genetic strategies to address the effects of heat stress in dairy cattle because the effects of heat stress are more pronounced in highly productive cattle due to the close relationship between metabolic heat production and production levels (Bernabucci and Mele, 2014). Little, if any, has been done on countering heat stress in beef cattle.

Beef cattle grazing on natural rangelands are more susceptible to heat stress than confined cattle because most natural rangelands do not have confinement resources (Scasta et al., 2016). Due to physiological differences, beef cows are reportedly more vulnerable to heat stress than steers, heifers and bulls (Brown-Brandl, 2018). Heat stress can have a tremendous impact on the profitability of grassland-based beef farms as their productivity largely depends on female performance (Mulliniks et al., 2020). Managing heat stress of beef cattle in grass-based beef farms is, therefore, very important. While strategies like providing shade and spraying animals with water to reduce excessive heat loads are used in dairy production (Marcillac-Embertson et al., 2009), it is difficult to provide such measures in extensive production systems. Although cattle grazing on natural rangelands have the ability to seek natural shade, water and air movement to cool down, natural rangelands in semiarid regions lose their natural shade during dry periods (Scasta et al., 2016). Animals are therefore exposed to warm air and direct radiant heat during grazing.

The use of more robust cattle that can thrive in hot climates is a possible solution to counteract the effects of heat stress in semi-arid regions. Some beef breeds, usually *Bos indicus,* have thermoregulatory ability as an adaptation to harsh environmental conditions (Mwai et al., 2015). One of such breeds is the Mashona breed, a popular Sanga type beef breed in the sub-Sahara, which is native to Zimbabwe. Dilution of the adaptation genes through crossbreeding has, however, reduced their tolerance to heat stress (Scholtz and Theunissen, 2010). Thus, there is a need to improve the heat tolerance of the increasingly popular crossbred or nondescript beef populations in semi-arid areas. Traits such as sweating rate, heart rate, rectal temperature, thyroxine (T4) and triiodothyronine (T3) concentration in blood have been suggested as indicators of heat stress in dairy cows (De Rensis and Scaramuzzi, 2003; Levente et al., 2012; Alfonzo et al., 2016). However, the use of these indicator traits is limited because their measuring is expensive and time consuming. Considering that thermoregulation in cows is also determined by anatomical factors (McManus et al., 2009a), use of conformation traits as indirect indicators of heat stress susceptibility in cows may be an option.

Conformation traits, described by measurements of a range of visual characteristics are related to cattle anatomical and skeletal appearance (Zindove et al., 2015). Phenotypic and genetic relationships between the conformation traits such as body depth, body length, stature, flank circumference, and chest girth and reproductive performance of cows under harsh environmental conditions have been reported (Zindove et al., 2015). There is limited data on the relationship between conformation traits with heat tolerance and/or heat stress in cows. Katiyatiya et al. (2017) suggested that dark pigmentation in Nguni cows results in absorption of solar radiation resulting in high rectal temperature and breathing rate. There are suggestions that dewlap size is associated with heat tolerance in cattle (Hansen, 2004), but there is no empirical data to support these suggestions. There is need to ascertain the relationships between conformation traits and heat tolerance before using conformation traits as indicators of heat tolerance in beef cows. This will help cattle producers to understand and improve the conformation traits that have a significant impact on beef cattle tolerance to extreme temperatures. Conformation traits can be observed and recorded at an early stage and, thus, heat tolerant animals can be identified early in their lifetime. Farmers who do not keep records can also identify heat tolerant cows using conformation traits through visual appraisal (Zindove et al., 2015). Even communal farmers, who do not keep records, can use mere inspection to identify cows that are more heat tolerant.

There is a wide range of conformation traits which could be used to identify heat tolerant cows and most of the traits are highly correlated (Zindove et al., 2015). If conformation traits are to be used as indicators of heat tolerance, there is a need to combine them into a small number of variables or constructs to reduce redundancy and collinearity. The objectives of this study were to assess the reduction in dimensionality of seven conformation traits and to determine the relationships between extracted constructs and physiological parameters associated with heat stress traits in beef cattle.

2 MATERIALS AND METHODS

Animal handling adhered to guidelines by the Zimbabwe Scientific Animal Act, 1963, subsection 2 of section 4, License Number L624.

2.1 STUDY SITE

The study was conducted in Muzarabani district which is located in Zimbabwe's Mashonaland Central province. The district is in agro-ecological region IV. Zimbabwe's agro ecological region IV is a semi-arid region characterised by erratic rainfall of 600 mm per annum, highest mean monthly temperature of 37 °C in February and a mean annual temperature of 23 °C (Mugandani et al., 2012). The area is usually hit by frequent droughts and is characterised by mopane woodlands and vast grasslands of the *Eragrostis* species (Mugandani et al., 2012).

2.2 CONFORMATION TRAITS

Ten farmers with at least 20 multiparous Mashona cows grazing on communal rangelands were selected using the snow-ball technique. Breed score for each of the cows in the selected herds was determined by trained personnel using a 1–9 scale score based on nine physical characteristics of Mashona cows as described by Dzavo et al. (2020). A cow was considered to be a Mashona breed only if it met at least five of the nine characteristics. Rectal palpation was performed by an experienced veterinarian to determine the pregnancy status of the cows. Pregnant cows were excluded from the study. For each of the ten herds, a sampling frame was created by entering the identification numbers of the cattle in an excel sheet. Five cows were then selected from each of the ten sampling frames using Microsoft excel random function. The cows were then ear tagged for identification. Measurements were taken during November 2017 and June 2018, once in the cold-dry season (June 2018) and once in the hot-wet season (November 2017) by trained personnel. The cows were held in a race for measurement and before taking the measurements each farmer was interviewed on a number of calvings (parity) of each cow. Measurements for conformation traits were taken by the same individual throughout the trial between 8:00 am and 10:00 am. The five-point European system was used to determine the body condition score (BCS) of the cows, where a score of 1 is emaciated and a score of 5 is very fat (Edmonson et al., 1989). Coat colour for each cow used in the experiment was recorded.

The stature, body depth, chest girth, flank circumference, navel height and body length were measured using a plastic tape measure. Stature was measured from top of the spine in between hips to the ground. Body depth was measured as distance between the top of spine and bottom of barrel at last rib measured from the left side of the cow. Chest girth was defined as circumference of the body taken just behind the shoulders. Flank circumference was defined as circumference of the body taken just in front of the hook bones. Navel height was measured as the distance from the ground to the navel. Body length was measured as the horizontal distance from withers to pin bone (Zindove et al., 2015). Dewlap size was measured as the maximum width of skin folds in the ventral neck region (Khan et al., 2018). Dentition was used to determine the age of each cow. Cows with visible incisors were categorised as young whilst those with broken or gummy mouth were categorised as old (Raines et al., 2008).

2.3 PHYSIOLOGICAL PARAMETERS AND BLOOD COLLECTION

Heart rate, respiratory rate and rectal temperature were measured on a single day during the hot-wet and cold-dry season by a veterinarian. For each cow, the parameters were measured in the morning around 8:00 am and the measurements repeated in the afternoon around 2:00 pm. The animals were kept in an open paddock without shade for three hours before measurement of physiological parameters (Brown-Brandl, 2018). Heart rate was determined using a stethoscope. Respiratory rates were determined by observing and counting the number of flank movements per minute (da Costa et al., 2015). A digital thermometer with a sensitivity of 0.1 °C was used to determine rectal temperature. The thermometer was inserted into the rectum at a depth of about 10 cm. After every measurement, the thermometer was washed in cold water, cleaned with cotton wool soaked in alcohol, and then rinsed to remove the alcohol. After collecting the physiological parameters, 10 ml of blood were taken from the jugular vein of each of the cows using EDTA coated vacutainer tubes and temporarily stored in chilled cooler boxes before the analyses.

2.4 BLOOD SAMPLE ANALYSES

Blood T3 and T4 concentrations were determined using an automated MAGLUMI 800 chemiluminescence immunoassay system (Snibe Co. Ltd, Shenzhen 518000, China) at Diagnopath Medical Laboratories, Harare, Zimbabwe. Competitive immunoluminometric assay was performed to determine T3 and T4. Serum, ABEI labeled anti-T4 monoclonal antibody and T4 antigen coated magnetic microbeads were added to microwells. Unbound liquid fractions were then aspirated from the immune complex formed with the labeled antibody and precipitation in the magnetic field. Signal reagents were added to the wells to initiate a light which was then measured as relative light unit (RLU) by a photomultiplier. The RLU was proportional to T4 concentration in the samples. For T3 concentration, the same process was repeated using serum, ABEI labeled anti-T3 monoclonal antibody and T3 antigen coated magnetic microbeads.

2.5 STATISTICAL ANALYSES

All data were analysed using SAS 9.4 (SAS, 2012). The effects of parity, season, coat colour, age, time of the day, BCS on respiratory rate, heart rate, and T3 and T4 concentration in blood were determined using PROC GLM for repeated measures assuming fixed models with all possible first-order interactions. First-order autoregressive correlation (AR (1)) was fitted to the model. The model for the final analysis was obtained after eliminating interactions that were not significant ($p > 0.05$). Preliminary analyses showed that BCS, the age and parity of cows had no effect on any of the response variables and were, thus, excluded from the final models.

Principal component analysis (PCA) was used to organise conformation traits into more homogeneous groups called principal components. The matrix of partial correlations, Kaiser Statistic for sampling adequacy (MSA) was used to determine the degree of interrelations between variables and adequacy for use in principal component analyses. Principal components were chosen based on Kaiser's eigenvalue rule which states that only principal components with eigenvalues greater than one should be considered (Kong et al., 2017). The principal components were rotated using varimax rotation. Principal components weights greater than 0.55 were considered to indicate a significant correlation between traits and principal components (Kong et al., 2017). The PROC REG (SAS, 2012) was then used to test whether the relationships between physiological characteristics and principal components extracted from conformation traits were linear, quadratic or exponential.

3 RESULTS

Table 1 shows summary statistics for the traits analyzed. Amongst the linear measurements, flank circumference showed the largest variation while dewlap size showed the least variation. The standard deviation for the physiological traits ranged from 0.51 for rectal tempertaure to 7.7 for heart rate. Heart and respiratory rate had more variability as compared to rectal temperature and concentarion of thyroid hormones. There was little variation in body fat of the animals as indicated by low standard deviation for BCS.

Breed score and BCS had no significant effect on

Table 1: Summary statistics for conformation traits, breed score, body condition score (BCS), respiratory rate, heart rate, rectal temperature, blood thyroxine (T4) and triiodothyronine (T3) concentration of Mashona cows used in the study

Variable	N	Mean	SD	Minimum	Maximum
Body depth (cm)	100	101.9	6.91	83	119
Body Stature (cm)	100	124.2	6.15	110	141
Body length (cm)	100	135.2	9.39	114	156
Flank circumference (cm)	100	173.5	13.44	141	206
Chest girth (cm)	100	164.1	10.11	142	186
Navel height (cm)	100	52.4	7.03	41	61
Dewlap size (cm)	100	41.4	4.87	29	52
Breed score	50	8.3	1.05	5	9
BCS	100	3.4	0.53	2.5	4.5
Heart rate (b/min)	200	51.1	7.70	33	68
Respiratory rate (br/min)	200	30.1	7.39	13	48
Rectal temperate (T°C)	200	38.8	0.51	37	40
T3 (nM/L)	200	3.9	1.63	1.2	13.7
T4 (nM/L)	200	17	4.20	3.5	28.6

Table 2: Least square means (±SE) of the effect of season, time of the day and coat colour on respiratory rate, heart rate, respiratory rate, blood thyroxine (T4) and triiodothyronine (T3) concentration of Mashona cows (n = 200)

	Physiological Parameters				
Parameter	Respiratory Rate (br/min)	Heart Rate (b/min)	Rectal Temperature (T°C)	T3 (nM/L)	T4 (nM/L)
Season					
Cold-dry	25.2 ± 1.16[b]	47.1 ± 1.23[b]	38.2 ± 0.09[b]	4.0 ± 0.29[a]	17.5 ± 0.72
Hot-wet	30.7 ± 1.16[a]	52.6 ± 1.23[a]	38.7 ± 0.09[a]	3.4 ± 0.29[b]	16.4 ± 0.72
Time					
Morning	26.7 ± 1.15[b]	47.9 ± 1.23[b]	38.6 ± 0.09	4.0 ± 0.29[a]	16.9 ± 0.71
Afternoon	29.1 ± 1.14[a]	51.8 ± 1.22[a]	38.6 ± 0.09	3.3 ± 0.29[b]	16.0 ± 0.72
Coat colour					
Black	26.5 ± 1.25[b]	48.2 ± 1.33[b]	38.5 ± 0.09	3.8 ± 0.31	17.0 ± 0.78
Brown	29.4 ± 1.14[a]	51.5 ± 1.2[a]	38.6 ± 0.09	3.6 ± 0.28	19.0 ± 0.71

br/min – breaths per minute; b/min – beats per minute; [ab] Values of each parameter in a column with different superscripts differ ($p < 0.05$)

respiratory rate, heart rate, and T3 and T4 concentration. Table 2 shows the effect of season, time of the day, and coat colour of the cows on respiratory rate, heart rate, rectal temperature, and T3 and T4 concentration. Heart rate was higher during the hot-wet season than the cold-dry season ($p < 0.05$). The concentration of T4 in blood during the hot-wet season in the afternoon was lower than during the cold-dry season in the morning ($p < 0.05$). Black-colored cows had higher heart rates than brown cows ($p < 0.05$). Rectal temperature and T4 concentration in blood were the same in black and brown cows ($p > 0.05$). Variation of rectal temperatures with breed score during the cold-dry and hot-wet season is shown in Figure 1. During the cold-dry season, rectal temperature was the same for all the cows ($p > 0.05$). Cows with low breed scores (5 and 6) had higher rectal temperatures during the hot-wet season than those with high breed scores ($p < 0.05$). Respiratory rates and T3 concentration in the blood of cows during the cold-dry and hot-wet seasons are shown in Figure 2 and 3, respectively. Season did not affect respiratory rate and blood T3 concentration in brown-colored cows ($p > 0.05$). Black-colored cows had higher respiratory rate and lower blood T3 concentration during the hot-wet season as compared to the cold-dry season ($p < 0.05$).

Principal component pattern coefficients of the varimax rotated components and aggregated groups of conformation traits, grouped using principal component analysis, are shown in Table 3. The conformation traits had three principal components, which contributed

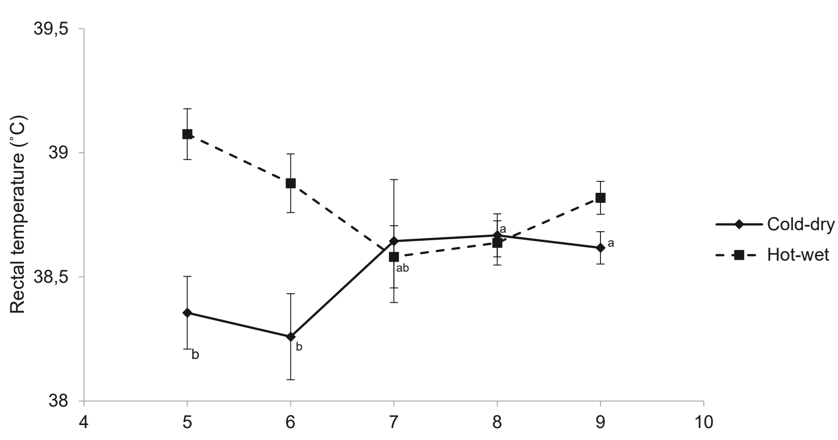

Figure 1: Effect of breed score of Mashona cows on rectal temperature during cold-dry and hot-wet seasons. [ab] Different letters indicate significant difference ($p < 0.05$)

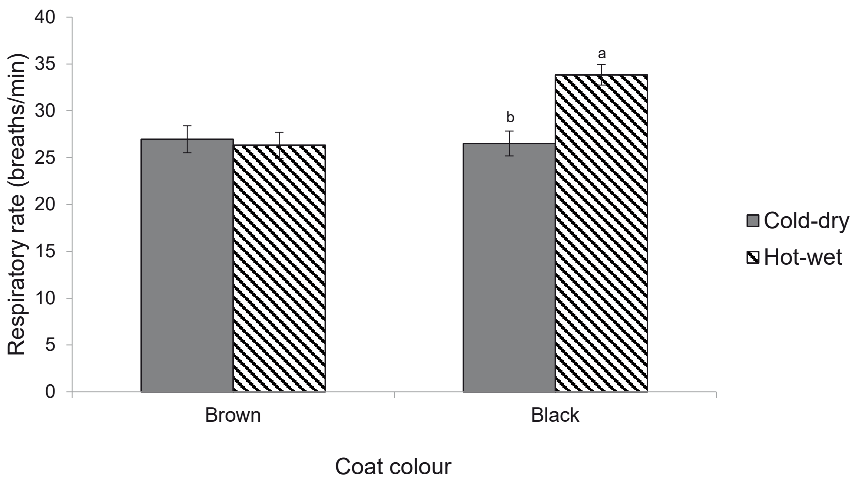

Figure 2: Respiratory rate of black and brown Mashona cows during the cold-dry and hot-wet season. [ab] Different letters indicate significant difference ($p < 0.05$)

53.76 % of the total variability of the original seven traits. Principal component 1, 2 and 3 accounted for 28.03 %, 14.20 % and 11.53 % of the total variance, respectively. Body depth, flank circumference and chest girth had significant principal component weights in principal component 1 (principal component weights > 0.55), whilst stature and body length had significant principal component weights in principal component 2. Principal component 3 was comprised of navel height and dewlap size (principal component weights > 0.55).

Relationships between principal components extracted from conformation traits and physiological parameters associated with heat stress did not vary with season ($p > 0.05$). Relationships between principal components extracted from conformation traits with heart rate, respiratory rate, rectal temperature, T3 and T4 concentration in blood are shown in Table 4. As principal component one increased respiratory rate, heart rate and rectal temperature decreased whilst T3 concentration in blood increased ($p < 0.05$). Cows characterised by deep bodies, large flanks and chest girths tended to show lower heart rate, respiratory rate and rectal temperature but higher T3 concentration in blood. Principal component two had significant negative linear and quadratic relationships with blood T4 concentration. As principal component two increased, respiratory rate increased quadratically ($p < 0.05$). Large-framed cows with long bodies had high respiratory rates and low T4 concentra-

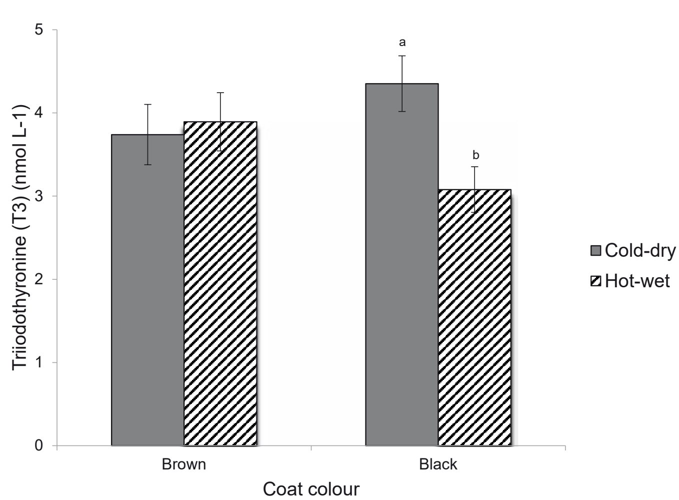

Figure 3: Concentration of serum triiodothyronine (T3) in black and brown Mashona cows during the cold-dry and hot-wet season. [ab] Different letters indicate significant difference ($p < 0.05$)

Table 3: Eigenvalues and share of total variance and principal component (PC) weights after rotation of conformation traits of Mashona cows

Traits	PC 1	PC 2	PC 3	Communality
Body depth	0.89*	0.15	−0.18	0.85
Stature	0.07	0.76*	−0.24	0.65
Body length	0.26	0.77*	0.19	0.70
Flank circumference	0.89*	0.05	−0.04	0.80
Chest girth	0.87*	0.18	−0.19	0.84
Navel height	−0.29	0.12	0.63*	0.50
Dewlap size	−0.02	0.37	−0.65*	0.57
Eigen Values	3.11	1.22	1.04	
Percent of total variance	28.03	14.20	11.53	

* Principal component weights equal to or > 0.58 were significant

tion in blood. As principal component three increased, respiratory rate increased quadratically ($p < 0.05$).

4 DISCUSSION

Cattle cannot dissipate their heat load effectively due to their large frames and ineffective sweating (Veissier et al., 2018). Ineffective heat dissipation, coupled with fermentation, which generates additional heat, results in heat stress and, consequently, reduced performance in cows (Dzavo et al., 2019). Conformation traits are becoming increasingly important to cow-calf farms due to their high heritability, ease of recording and close relationship with feed efficiency and energy balance in cows (Zindove et al., 2015). As a result, the conformation traits are being used as indicators for traits which are difficult to measure such as nutritional status, disease resistance and longevity (Larroque and Ducrocq, 2001; Zindove et al., 2015). Conformation traits such as body depth, body length, stature, flank circumference, chest girth, and BCS are, thus, expected to be related to physiological parameters associated to heat stress in cows.

The range of BCS was within reported values for Sanga and Zebu cattle in similar environments (Kanuya et al., 2006; Ndlovu et al., 2009; Zindove et al., 2015). To our knowledge, there is limited selection for conformation traits in beef cattle, so high variation in traits such as flank circumference and body length might be an indication that the traits respond more to the environment than those with low variation. The findings that heart rate and rectal temperature were higher during the hot-wet season than the cold-dry season confirmed assertions by Kadzere et al. (2002) and De Rensis and Scaramuzzi (2003) that it is common for cows to have relatively higher heart rates and rectal temperatures during hot seasons than cold seasons. An increase in heart rate of cows above normal ranges indicates heat intolerance (Scharf et al., 2010). Normal heart rates in beef cows ranges between 48 and 84 beats per minute (Rashamol et al., 2018). Although heart rates for the cows were higher during the hot-wet season than the cold-dry season, they were within the normal range. Observed high respiratory rate during the hot-wet season concurs with the findings of Svotwa et al. (2007) who reported higher respiratory rates in Mashona cows during hot periods compared to cold periods. This might be attributed to the fact that during hot periods, cows counter high temperatures through evaporative cooling by releasing moisture from respiratory tract (Veissier et al., 2018). Although rectal temperature was higher during the hot-wet season, it was within the normal range of 38.5 to 39.5 °C as suggested by Da Costa et al. (2015). Katiyatiya et al. (2017) measured rectal temperature in Nguni cows, a Sanga breed similar to Mashona cows, during the hot-wet season and found similar results. This could be an indication that Sanga cows are able to regulate their body temperatures during the hot-wet season without experiencing heat stress. Farmers raising cows on natural pastures in warm climates can thus be encouraged to adopt Mashona breed as they seem to tolerate high temperatures well. This postulation is supported by the findings herein that cattle carrying more Mashona breed genes, as indicated by high breed scores, had lower rectal temperatures during the hot-wet season.

The observation that black coloured cows had higher heart rates during the hot-wet season than brown coloured is in line with the findings of Katiyatiya et al. (2017) who reported higher heart rates in dark coloured cows. Since black cattle feel the effects of heat stress earlier and more than brown and white-coloured (Scasta et al., 2016), it can be inferred that black-coloured cows

Table 4: Regression coefficients (±SE) of principal components (PC) extracted from conformation traits on heart rate (HR), respiratory rate (RR), rectal temperature, blood triiodothyronine (T3) and thyroxine (T4) concentration in Mashona cows

Parameter	PC 1	PC 2	PC 3
Traits	BD; FC; CG	BL; ST	SH; DL
Linear			
RR ± SE	−0.4 ± 0.15**	0.1 ± 0.18^{ns}	0.3 ± 0.16^{ns}
HR ± SE	−0.5 ± 0.16**	−0.2 ± 0.19^{ns}	0.2 ± 0.17^{ns}
Rectal Temperature	−0.03 ± 0.011*T*	−0.003 ± 0.0013^{ns}	−0.02 ± 0.011^{ns}
T3	0.08 ± 0.034*	0.04 ± 0.020^{ns}	−0.02 ± 0.016^{ns}
T4	−0.05 ± 0.008^{ns}	−0.2 ± 0.10*	−0.08 ± 0.009^{ns}
Quadratic			
RR ± SE	−0.04 ± 0.014**	0.008 ± 0.0017*	0.03 ± 0.015**
HR ± SE	−0.03 ± 0.014**	−0.03 ± 0.018^{ns}	0.02 ± 0.016^{ns}
Rectal Temperature	−0.003 ± 0.00095**	−0.0005 ± 0.00012^{ns}	−0.002 ± 0.0011^{ns}
T3	0.007 ± 0.0031*	0.002 ± 0.0039^{ns}	−0.002 ± 0.0014^{ns}
T4	−0.001 ± 0.0019^{ns}	−0.02 ± 0.010*	−0.005 ± 0.0018^{ns}

* BD = body depth; ST = stature; BL = body length; FC = flank circumference; CG = chest girth; SH = navel height; DL = dewlap size. ** $p < 0.01$; * $p < 0.05$.; ^{ns} $p > 0.05$

had higher heart rates during the hot-wet season than brown-coloured to increase cooling rate. Low T3 concentration in the blood of black cows during the hot-wet season could be a result of heat stress. Although, to our knowledge, there are no comparable studies yet, Baumgard and Rhoads (2012) reported that heat stressed cattle reduces circulating blood T3 concentration. Low blood T3 concentration slows metabolic rates and consequently reduces heat production (Kahl et al., 2015). Lower blood T3 concentration in black cows could, therefore, be a consequence of higher body temperatures during the hot-wet season. High respiratory rates in black cows during the hot-wet season observed in the current study could also be a result of high temperatures. In a similar study on different species, McManus et al. (2009b) found that black sheep had higher respiratory rates indicating they are more susceptible to heat stress. The finding that black cattle are more susceptible to heat stress could be attributed to the fact that cows with darker hair have higher solar absorption as reported by Scasta et al. (2016). Light coat colours are therefore desired for heat stress management in cows. Beef cattle producers in hot climates should consider light coat colours when selecting breeding and replacement animals. Considering that only two coat colours were studied herein, further investigation on the impact of other coat colours on thermal regulations in beef cattle seem important. Some light coat colors such as white have been reported to be susceptible to photo-chemical damage (Lee et al., 2016) and, thus, might be undesirable under sunny conditions.

Low T3 concentration in blood of the cows in the afternoon observed in the current study agrees with previous work by Baek et al. (2019) who found that blood T3 concentration of steers subjected to warmer ambient temperatures was lower than in cooler ambient temperatures. Considering that low T3 concentration in blood is associated with heat stress in cattle (Baumgard and Rhoads, 2012), grazing in the afternoon during hot periods can be considered stressful to cattle. This assertion could be further strengthened by the current finding that respiratory and heart rate of the cows were higher in the afternoon than in the morning. Similarly, Neiva et al. (2004) reported that an increase in the temperature in the afternoon leads to increased heart and respiratory rate of livestock. During the afternoon when ambient temperature is high and air humidity low, there is more evaporative water loss through rapid breathing (Levente et al., 2012; Veissier et al., 2018). To avoid afternoon grazing and exposing cattle to heat stress during hot seasons, beef cattle producers should facilitate early morning and/or late afternoon grazing. Cattle can be released for grazing early in the morning and late in the afternoon whilst cattle handling activities can be done under the shade from noon up to about 4:00 pm. Limiting grazing time might, however, result in reduced feed intake and, consequently, peformance of the cows (Gregorini, 2012). It is, therefore, important in hot environments to come up with strategies, which will counter heat stress for grass-based beef cattle grazing systems throughout the day. Use of conformation traits for prediction of heat tolerance of cattle could be an option. In dairy production, composite indices of conformation traits are commonly used as predictors of traits of economic importance (Wu et al., 2013). The conformation traits used to form these indices are, however, strongly correlated and thus redundant (Olasege et al., 2019). A study by Zindove et al. (2015) showed that individual conformation traits in beef cows have high collinearity and correlations. There is a need to combine conformation traits of cows into smaller number of variables to reduce redundancy and collinearity before using them as indicators of traits of interest.

Principal component analyses showed biological associations underlying the phenotypic relationships for the six conformation traits under the study. In agreement with findings by Zindove et al. (2015), two of the three generated principal components derived in this study describe general size of the cows. The finding that body depth, chest girth and flank circumference, which describe aspects of a cow's body and rumen capacity (Hansen et al., 1999), were grouped into one principal component concurs with Zindove et al. (2015). Zindove et al. (2015) also grouped body length and stature into one principal component like in the current study. Body length and stature are commonly used as measurements for frame size in cows (Dubey et al., 2012). To avoid analysing large numbers of correlated traits, reduce computation burdens associated with analysing large and complex data and improve precision, beef producers recording conformation traits can use the three principal components instead of the individual traits.

The finding that cows characterised by deep bodies, large flanks and chest girths had lower heart rates, respiratory rates, and rectal temperatures and higher T3 concentrations in blood agrees with Abdurehman (2019) who argued that large flank circumference and chest girth of East African Shorthorn Zebu cows are anatomical adaptations, which contribute to lower respiratory rates, rectal temperatures, and heart rates even when the cows are subjected to high temperatures. This could be because of the interactions between body depth, chest girth size, metabolic heat production and heat dissipation by the cattle. Chest girth size influences the respiratory rate by limiting lung expansion (Brown-Brandl, 2018). Livestock with large chests are be able to inhale and exhale large air volumes thereby losing much heat to the environment through the released vapour without increasing their respiratory rate (Marai et al., 2007). Cows with deep bodies coupled with large flanks and chests have large guts resulting in high fermentation rates and metabolic heat production (Hansen et al., 1999). Thus, contrary to our findings that cows characterised by deep bodies, large flanks, and chest girths have low heart rate, respiratory rate, and rectal temperature coupled with high T3 concentration in blood, cows with large flanks, chests and deep bodies are expected to produce high metabolic heat. This implies that heat tolerance in cows with large flanks, chests and deep bodies could be mainly due to greater ability to dissipate heat and not because of reduced heat production (as result of reduced metabolic rates). Cows with large flanks, chests and deep bodies are, therefore, desirable for hot environments since they are able to tolerate high temperatures without reducing their metabolic rates. Based on the findings herein, beef cattle producers can use flank size, chest girth and body depth to come up with a classification system, which better explains variation in heat tolerance among their cattle.

The positive correlation between frame size of the cows (body length and stature) and T4 concentration in blood and negative relationship with respiratory rate reflects on the importance of frame size of cows in hot environments. In a similar study, Srikandakumar and Johnson (2004) found out that Australian Milking Zebu and Jersey cows had lower respiratory rates than Holsten cows and attributed it to differences in frame size. This implies that small-framed cows are more adapted to heat compared to their large-framed counterparts. This can be attributed the fact that the larger the body surface area the higher the amount of heat the cows absorb from the environment when environmental temperatures are high (Alfonzo et al., 2016). Based on the current studies and literature, beef producers in hot climates should be encouraged to prioritize small-framed cows. Although, to our knowledge, there are no comparable studies in cows, the higher respiratory rate was expected in cows with larger navel height and dewlap. The distance between ground and the bottom of belly of cows is critical to resilience against hyperthermia as it helps insulate cattle from the ground when it's hot (Brown-Brandl, 2018). Although the function of the dewlap remains largely unexplored, there are suggestions that excess skin of the dewlap is responsible for dissipating heat in large mammals (Bro-Jørgensen, 2016). Studies in elands and dairy cattle using infrared thermography confirmed the dewlap as a site of high heat loss (Kotrba et al., 2007). When principal component three was used for classification of beef cows, cows with large dewlaps coupled with higher distance between ground and navel should be considered more heat tolerant. It is, however, necessary to conduct more studies on the relationship of indicators of heat tolerance with navel height and dewlap size in beef cattle.

5 CONCLUSIONS

The present evidence suggests that heat production, absorption and heat dissipation in cattle are associated with physical characteristics such as coat colour, dewlap size, frame size, chest size and distance between abdomen and ground surface. Black cows are more prone to heat stress. Small-framed cows with large chest girths, large dewlaps and navel further away from the ground surface are less sensitive to high ambient temperatures. Further studies are required to support the relationship between conformation and heat tolerance in beef cows. It is also necessary to investigate the relationship between conformation and heat tolerance in other classes of beef cattle such as calves, steers, heifers and bulls.

6 REFERENCES

Abdurehman, A. (2019). Physiological and anatomical adaptation characteristics of Borana cattle to pastoralist lowland environments. *Asian Journal of Biological Sciences*, *12*(2), 364–372. https://doi.org/10.3923/ajbs.2019.364.372

Alfonzo, E. P. M., da Silva, M. V. G. B., dos Santos Daltro, D., Stumpf, M. T., Dalcin, V. C., Kolling, G., ... McManus, C. M. (2016). Relationship between physical attributes and heat stress in dairy cattle from different genetic groups. *International Journal of Biometeorology*, 60, 245–253. https://doi.org/10.1007/s00484-015-1021-y

Baek, Y. C., Kim, M., Jeong, J. Y., Oh, Y. K., Lee, S. D., Lee, Y. K., ... Choi, H. (2019). Effects of short-term acute heat stress on physiological responses and heat shock proteins of Hanwoo steer (Korean cattle). *Journal of Animal Reproduction and Biotechnology*, *34*(3), 173–182. https://doi.org/10.12750/JARB.34.3.173

Baumgard, L. H., & Rhoads, R. P. (2012). Ruminant production and metabolic response to heat stress. *Journal of Animal Science*, *90*(6), 1855–1865. https://doi.org/10.2527/jas.2011-4675

Bernabucci, U., & Mele, M. (2014). Effect of heat stress on animal production and welfare. The case of a dairy cow. *Agrochimica*, 58, 53–60.

Bro-Jørgensen, J. (2016). Evolution of the ungulate dewlap: Thermoregulation rather than sexual selection or predator deterrence? *Frontiers in Zoology*, *13*, Article 33. https://doi.org/10.1186/s12983-016-0165-x

Brown-Brandl, T. M. (2018). Understanding heat stress in beef cattle. *Revista Brasileira de Zootecnia*, *47*. https://doi.org/10.1590/rbz4720160414

da Costa, A. N. L., Feitosa, J. V., Montezuma, P. A., de Souza, P. T. & de Araújo, A. A. (2015). Rectal temperatures, respiratory rates, production, and reproduction performances of crossbred Girolando cows under heat stress in north-eastern Brazil. *International Journal of Biometeorology, 59*(11), 1647–1653. https://doi.org/10.1007/s00484-015-0971-4

De Rensis, F., & Scaramuzzi, R. J. (2003). Heat stress and seasonal effects on reproduction in the dairy cow. *Theriogenology, 60*(6), 1139–1151. https://doi.org/10.1016/S0093-691X(03)00126-2

Descheemaeker, K., Zijlstra, M., Masikati, P., Crespo, O., & Tui, S. H. K. (2018). Effects of climate change and adaptation on the livestock component of mixed farming systems: A modelling study from semi-arid Zimbabwe. *Agricultural Systems*, *159*, 282–295. https://doi.org/10.1016/j.agsy.2017.05.004

Dubey, A., Mishra, S., Khune, V., Gupta, P. K., Sahu, B. K., & Nandanwar, A. K. (2012). Improving linear type traits to improve production sustainability and longevity in purebred Sahiwal cattle. *Journal of Agriculture, Science and Technology*, *2*, 636–639.

Dzavo, T., Zindove, T. J., Dhliwayo, M., Chimonyo, M., & Tivapasi, M. T. (2020). Do haematological profiles of cows in drought prone areas differ with conformation? *Spanish Journal of Agricultural Research*, *18*(2), 12–26. https://doi.org/10.5424/sjar/2020182-16029

Dzavo, T., Zindove, T. J., Dhliwayo, M., & Chimonyo, M. (2019). Effects of drought on cattle production in sub-tropical environments. *Tropical Animal Health and Production*, *51*(3), 669–675. https://doi.org/10.1007/s11250-018-1741-1

Edmonson, A. J., Lin, I. J., Weaver, C. O., Farver, T., & Webster, G. (1989). A body condition scoring chart for Holstein cows. *Journal of Dairy Science*, *72*, 68–78. https://doi.org/10.3168/jds.S0022-0302(89)79081-0

Gregorini, P. (2012). Diurnal grazing pattern: its physiological basis and strategic management. *Animal Production Science*, *52*, 416–430. https://doi.org/10.1071/AN11250

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

Hansen, L. B., Cole, J. B., Marx, G. D., & Seykora, A. J. (1999). Productive life and reasons for disposal of Holstein cows selected for large versus small body size. *Journal of Dairy Science*, *82*, 795–801. https://doi.org/10.3168/jds.S0022-0302(99)75298-7

Kadzere, C. T., Murphy, M. R., Silanikove, N., & Maltz, E. (2002). Heat stress in lactating dairy cows. a review. *Livestock Production Science*, *77*(1), 59–91. https://doi.org/10.1016/S0301-6226(01)00330-X

Kahl, S., Elsasser, T. H., Rhoads, R. P., Collier, R. J., & Baumgard, L. H. (2015). Environmental heat stress modulates thyroid status and its response to repeated endotoxin challenge in steers. *Domestic Animal Endocrinology, 52*, 43–50. https://doi.org/10.1016/j.domaniend.2015.02.001

Kanuya, N. L., Matiko, M. K., Nkya, R., Bittegeko, S. B. P., Mgasa, M. N., Reksen, O., & Ropstad, E. (2006). Seasonal changes in nutritional status and reproductive performance of Zebu cows kept under a traditional agro-pastoral system in Tanzania. *Tropical Animal Health and Production, 38*, 511–519. https://doi.org/10.1007/s11250-006-4419-z

Katiyatiya, C. L. F., Bradley, G., & Muchenje, V. (2017). Thermotolerance, health profile and cellular expression of HSP-90AB1 in Nguni and Boran cows raised on natural pastures under tropical conditions. *Journal of Thermal Biology*, *69*, 85–94. https://doi.org/10.1016/j.jtherbio.2017.06.009

Khan, M. A., Khan, M. S., & Waheed, A. (2018). Morphological measurements and their heritabilities for Sahiwal cattle in Pakistan. *Journal of Animal and Plant Sciences*, *28*(2), 431–440.

Kotrba, R., Knížková, I., Kunc, P., & Bartoš, L. (2007). Comparison between the coat temperature of the eland and dairy cattle by infrared thermography. *Journal of Thermal Biology, 32*(6), 355–359. https://doi.org/10.1016/j.jtherbio.2007.05.006

Kong, X., Hu, C., & Duan, Z. (2017). Generalized Principal Component Analysis. In *Principal Component Analysis Networks and Algorithms* (pp. 185–233). Singapore: Springer. https://doi.org/10.1007/978-981-10-2915-8_7

Larroque, H., & Ducrocq, V. (2001). Relationships between type and longevity in the Holstein breed. *Genetics Selection Evolution*, *33*(1), 39–59. https://doi.org/10.1186/1297-9686-33-1-39

Lee, C. N., Baek, K. S., & Parkhurst, A. (2016). The impact of hair coat color on longevity of Holstein cows in the tropics. *Journal of Animal Science and Technology*, *58*, 1–7. https://doi.org/10.1186/s40781-016-0123-3

Levente, K., Krisztina, N., Kultus, K., Otto, S., & Janos, T. (2012). Heart rate and heart rate variability during milking in dairy cows. *Magy. Állatorv. Lapja*, *134*(11), 653–661.

Marai, I. F. M., El-Darawany, A. A., Fadiel, A., & Abdel-Hafez, M. A. M. (2007). Physiological traits as affected by heat stress in sheep – a review. *Small Ruminant Research*, *71*(1–3), 1–12. https://doi.org/10.1016/j.smallrumres.2006.10.003

Marcillac-Embertson, N. M., Robinson, P. H., Fadel, J. G., & Mitloehner, F. M (2009). Effects of shade and sprinklers on performance, behaviour, physiology, and environment of heifers. *Journal of Dairy Science*, *92*(2), 506–517. https://doi.org/10.3168/jds.2008-1012

McManus, C., Prescott, E., Paludo, G. R., Bianchini, E., Louvandini, H., & Mariante, A. S. (2009a). Heat tolerance in naturalized Brazilian cattle breeds. *Livestock Science*, *120*(3), 256–264. https://doi.org/10.1016/j.livsci.2008.07.014

McManus, C., Paludo, G. R., Louvandini, H., Gugel, R., Sasaki, L. C. B., & Paiva, S. R. (2009b). Heat Tolerance in Naturalized Brazilian Sheep. Physiological and Blood Parameters. *Tropical Animal Health and Production*, *41*(1), 95–101. https://doi.org/10.1007/s11250-008-9162-1

Mulliniks, J. T., Beard, J. K., & King, T. M. (2020). Invited review: effects of selection for milk production on cow-calf productivity and profitability in beef production systems. *Applied Animal Science*, *36*(1), 70–77. https://doi.org/10.15232/aas.2019-01883

Mugandani, R., Wuta, M., Makarau, A., & Chipindu, B. (2012). Re-classification of Agro – ecological Regions of Zimbabwe in conformity with Climate variability and change. *African Crop Science Journal*, *20*(S2), 361–369.

Mwai, O., Hanotte, O., Kwon, Y. J., & Cho, S. (2015). African indigenous cattle. Unique genetic resources in a rapidly changing world. *Asian-Australasian Journal of Animal Sciences, 28*(7), 911–921. https://doi.org/10.5713/ajas.15.0002R

Neiva, J. N. M., Teixeira, M., Turco, S. H. N., Oliveira, S. M. P., & Moura, A. A. A. N. (2004). Effects of Environmental Stress on Physiological Parameters of Feedlot Sheep in the Northeast of Brazil. *Revista Brasileira de Zootecnia*, *33*(3), 668–678. https://doi.org/10.1590/S1516-35982004000300015

Ndlovu, T., Chimonyo, M., & Muchenje, V. (2009). Monthly changes in body condition scores and internal parasite prevalence in Nguni, Bonsmara and Angus steers raised on sweetveld. *Tropical animal health and production*, *41*(7), 1169–1177. https://doi.org/10.1007/s11250-008-9297-0

Olasege, B. S., Zhang, S., Zhao, Q., Liu, D., Sun, H., Wang, Q., ... Pan, Y. (2019). Genetic parameter estimates for body conformation traits using composite index, principal component, and factor analysis. *Journal of dairy science*, *102*(6), 5219–5229. https://doi.org/10.3168/jds.2018-15561

Raines, C. R., Dikemen, M. E., Unruh, J. A., Hunt, M. C., & Knock, R. C. (2008). Predicting cattle age from eye lens weight and nitrogen content dentition, and maturity score. *Journal of Animal Science*, *86*(12), 3557–3567. https://doi.org/10.2527/jas.2007-0445

Rashamol, V. P., Sejian, V., Bagath, M., Krishnan, G., Archana, P. R., & Bhatta, R. (2018). Physiological adaptability of livestock to heat stress: An updated review. *Journal of Animal Behaviour* and *Biometeorology, 6*(3), 62–71. https://doi.org/10.31893/2318-1265jabb.v6n3p62-71

Rust, J. M., & Rust, T. (2013). Climate change and livestock production. A review with emphasis on Africa. *South African. Journal of Animal Science*, *43*(3) 255–267. https://doi.org/10.4314/sajas.v43i3.3

SAS. (2012). SAS/STAT User's Guide, release 9.4 edition. Cary, NC, USA: SAS Institute Inc.

Scasta, J. D., Lalman, D. L., & Henderson, L. (2016). Drought mitigation for grazing operations: matching the animal to the environment. *Rangelands, 38*(4), 204–210. https://doi.org/10.1016/j.rala.2016.06.006

Scharf, B., Carroll, J. A., Riley, D. G., Chase Jr, C. C., Coleman, S. W., Keisler, D. H., & Spiers, D. E. (2010). Evaluation of physiological and blood serum differences in heat-tolerant (Romosinuano) and heat-susceptible (Angus) Bos Taurus cattle during controlled heat challenge. *Journal of Animal Science*, *88*(7), 2321–2336. https://doi.org/10.2527/jas.2009-2551

Scholtz, M. M., & Theunissen, A. (2010). The use of indigenous cattle in terminal cross-breeding to improve beef cattle production in Sub-Saharan Africa. *Animal Genetic Resources*, *46*, 33–39. https://doi.org/10.1017/S2078633610000676

Srikandakumar, A., & Johnson, E. H. (2004). Effect of heat stress on milk production, rectal temperature, respiratory rate and blood chemistry in Holstein, Jersey and Australian Milking Zebu cows. *Tropical Animal Health and Production*, *36*(7), 685–692. https://doi.org/10.1023/B:TROP.0000042868.76914.a9

Svotwa, E., Makarau, A., & Hamudikuwanda, H. (2007). Heat tolerance of Mashona, Brahman and Simmental cattle breeds under warm humid summer conditions of natural region II area of Zimbabwe. *Electronic Journal of Environmental, Agricultural and Food Chemistry, 6*(4), 1934–1944.

Veissier, I., Palme, R., Moons, C. P., Ampe, B., Sonck, B., Andanson, S., & Tuyttens, F. A. (2018). Heat stress in cows at pasture and benefit of shade in a temperate climate region. *International Journal of Biometeorology*, *62*(4), 585–595. https://doi.org/10.1007/s00484-017-1468-0

Wu, X., Fang, M., Liu, L., Wang, S., Liu, J., Ding, X., ... Lund, M. S. (2013). Genome wide association studies for body conformation traits in the Chinese Holstein cattle population. *BMC genomics*, *14*(1), 1–10. https://doi.org/10.1186/1471-2164-14-897

Zindove, T. J., Chimonyo, M., & Nephawe, K. A. (2015). Relationship between linear type and fertility traits in Nguni cows. *Animal*, *9*(6), 944–951. https://doi.org/10.1017/S1751731114003231