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Article

Bos indicus bulls fattened under heat stress in pens provided with dome shade: Physiological and productive responses

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Abstract:

A total of 804 bulls were randomly housed in 12 pens (67 bulls/pen) with different types of shade (conventional with sheet metal [CS], double shade with sheet metal [DS], dome without fans [DNF], and dome with fans [DWF]) to determine the best shade system in intensive fattening of *Bos indicus* cattle based on thermoregulation and productive responses under subtropical conditions. Ten bulls/pen were randomly selected for the assessment of thermoregulation. The environmental conditions were of "moderate heat stress". The pens with CS and DWF promoted lower morning respiratory rate in the bulls, but in the afternoon, only the DWF pens maintained this effect. Regardless of the time, the DWF pens reduced the surface temperatures of the bulls' head, neck, back, rump, and eye compared to the other types of shades. In contrast, the DNF bulls had the highest total protein concentration than the others; the type of shade did not affect the hematological profile and the serum concentrations of glucose, cholesterol, triglycerides, urea, sodium, and chlorine. Thyroid hormone concentrations were higher in bulls with CS and DS than in bulls with DNF and DWF. Compared to CS and DS, DNF and DWF shades increased feed intake and feed efficiency, but reduced meat marbling, without affecting weight gain, carcass yield, and meat hardness or color. In conclusion, *Bos indicus* bulls under moderate heat stress showed a better physiological thermoregulation capacity and feed efficiency in pens equipped with dome shade and fans.

Keywords: Heat stress, Zebu cattle, Feed efficiency, Carcass traits, temperature-humidity index.

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Introduction

Global warming threatens the sustainability of animal production systems, so it also threatens food security, particularly in regions with tropical and subtropical climates[1]. In Mexico, it is estimated that the average ambient temperature (AT) has increased by 1.7 °C since the beginning of the twentieth century, exceeding the reported global average of between 1.1 and 1.4 °C[2]. This problem is more accentuated in the northwest of the country, where extreme hot climates predominate, which generate heat stress (HS) conditions for animals of zootechnical interest, being very noticeable in cattle fattened in open space pens[3]. These cattle easily develop hyperthermia (> 39 °C) in conditions of high AT and relative humidity, as they have a high metabolic rate and reduced water retention capacity[4].

Under this scenario, the installation of shade in feedlots represents one of the basic HS mitigation strategies, even when the animals are of thermotolerant breeds such as *Bos indicus*[5]. *Bos indicus* cattle have a greater capacity for thermoregulation than *Bos taurus* cattle because they have genes associated with thermotolerance and more efficient body heat loss mechanisms (e.g., lower metabolic rate, larger sweat glands, thin and light-colored skin, etc.); however, high ATs also partially reduce their productive capacity[4,6]. Barajas-Cruz *et al*[7] reported that the installation of shades in the corral increased weight gain and carcass weight by 14 % in Zebu crossbred cattle fattened in a subtropical environment. Nonetheless, there is a great deal of variation in the installation and handling of this environmental protection, particularly in relation to height, material, orientation, and size. In this sense, it is necessary to define the type of shade that best adapts to the type of livestock and the different environmental and production conditions. The increase in shade area in feedlots has been shown to be better than conventional-sized shades in both *Bos taurus* and *Bos indicus* cattle under natural conditions of severe HS in desert regions as it increases physiological thermoregulation capacity, growth rate, and feed efficiency[3]. Another study found that, in confined *Bos indicus* or *Bos taurus* cattle under HS conditions in a tropical climate, increasing the availability of shade with galvanized sheet metal (1.2 to 2.4 m^2/animal) or polyethylene plastic in a dome-shaped structure (total shading of the pen, 9.0 m^2/animal) improved feed intake without modifying the growth in the pen and carcass traits; nevertheless, dome shade combined with fans improved growth rate and weight and carcass yield in both types of cattle[8].

Although the installation of polyethylene tarpaulin domes with fans has been a good strategy for mitigating HS in Zebu cattle under conditions of the Mexican tropics, the background confirming this finding is still limited[8,9]. In addition, no information was found on the impact on meat quality and the physiological and metabolic mechanisms activated for such productive benefits to occur in fattening cattle. Thus, it was hypothesized that dome shade equipped with fans increases meat production and quality in heat-stressed *Bos indicus* cattle by improving the capacity for physiological thermoregulation and adjusting energy metabolism. The present study aimed to assess different types of shade structures in pens (conventional *versus* domes with or without fans) on the productive behavior, carcass traits, meat quality, and physiological-metabolic adjustments of *Bos indicus* beef cattle exposed to natural conditions of HS in a subtropical region.

Material and methods

This experiment was conducted in a commercial feedlot that has a TIF slaughterhouse (No. 111) and is located in Culiacán, Sinaloa, Mexico (24° 49’ N, 107° 32’ W). The climate in the region is subtropical, specifically of the warm dry type, with average temperatures of 25 °C (5 and 41 °C), average annual rainfall of 700 mm, and rainfall in summer and winter(10). The procedures carried out during this study were within the approved guidelines of the official Mexican standards on animal care in Mexico (NOM-051-ZOO-1995: Humane treatment in the transport of animals; NOM-033-SAG/ZOO-2014: Methods for killing domestic and wild animals). In addition, all experimental procedures were approved and supervised by the Ethics and Animal Care Committee of the Universidad Autónoma de Baja California.

The study lasted 70 d, from October 5 to December 14, 2014. A total of 804 bulls (young whole males) were used, which weighed 432 ± 28 kg at the beginning of the experiment and were of the biotypes *Bos taurus* (Angus, Charolaise, Brown Swiss, Jersey, and their crosses), *Bos indicus* (Zebu), and their crosses *Bos taurus* x *Bos indicus*. These bulls arrived at the feedlot approximately two months before the start of the experiment from different cattle farms in Sinaloa and other states of the Mexican Republic. Upon arrival, they were treated against internal and external parasites, vaccinated and reinforced with vitamins. The feed consisted of two diets, the first had a 75:25 grain:forage ratio (1.85 and 1.25 Mcal/kg DM of maintenance and gain), whereas the second had a 90:10 ratio (2.15 and 1.45 Mcal/kg DM of maintenance and gain); both were based on steamed-flaked corn. These diets were offered twice a day using a feed delivery truck. In the last 30 d of fattening, zilpaterol hydrochloride (6.4 mg/kg DM; Zilmax, MSD, Salud Animal, Mexico) was added to the diet, and said additive was removed 3 days prior to slaughter. The availability of food and water was *ad libitum*.

Treatments and experimental design

The treatments consisted of 15 x 40 m pens provided with four different shades structures (three pens with each of them): conventional (CS), double shade (DS), dome without fans (DNF), and dome with fans (DWF). The CS was built with galvanized sheet metal at a height of 3.5 m in the center of the corral, with an E-W direction, providing a shaded area of 1.3 m^2/bull. This treatment was considered the control group because it represented the typical pen and shade area used throughout the fattening. The DS was built like the CS but considering 2.6 m^2/bull. The DNF shade covered the entire pen with polyethylene tarpaulin (98 % sun block; Empresas Invergrow, S.A. de C.V., Culiacán, Mexico), which was installed on a greenhouse-type metal structure that in the center had a height of 6.5 m and an opening that allowed the air to escape to the outside (8.7 m^2/bull). Finally, the DWF shade had the same characteristics as the DNF, except for the presence of three fans per pen at a height of 4.5 m, and had no opening at the top. Each fan had a diameter of 6 m (Bigvento model BV06XA1508, Megaventilación, S.A. de C.V., Guadalajara, Jalisco, Mexico), with eight blades and a 1.5 HP motor, which produced an air movement of 6,023m^3/min with a coverage area of 1,365 m^2. The fans operated daily from 1000 to 1600 h. In general, the pens had 15 linear meters of feeder and two drinking troughs. The bulls were stratified by genotype and housed randomly across the 12 pens, leaving 67 animals in each one (8.95 m^2/head of cattle), ensuring a similar proportion of each genotype per pen.

Climatic and physiological variables

The prevailing environmental conditions inside the pens were determined by placing a thermohygrometer at a height of 1.50 m (Hydro-Button, Termotraker®, Lille, France) in each pen, which were programmed to record the ambient temperature (AT) and relative humidity (RH) every 20 min. At the end, the data were downloaded into Excel® to calculate the temperature-humidity index (THI) with the following formula[11]: THI = 0.81 × AT + (RH / 100) × (AT - 14.40) + 46.4. Additionally, five bulls of the *Bos indicus* genotype were randomly selected per pen to evaluate respiratory rate (RR) first and then body surface temperature (BST) twice a week at 0700 and 1400 h. The RR was measured by counting the number of breaths in 30 sec and multiplying it by 2, whereas the BST was determined from thermographic pictures taken of the right side of the animal and front head with an infrared camera (Fluke Ti400, Everett, WA, USA). The photos were analyzed with Fluke Smart View® 3.9 software, where the BST of the following anatomical regions was determined: neck, loin, chuck, belly, head and eye. These photos were taken at a distance of approximately 2 to 3 m and in the shade.

Blood analyte variables and blood counts

The selected *Bos indicus* bulls (n= 5/corral) also had blood samples taken by puncture of the jugular vein on d 1, 32, and 70 of the experiment, which was performed before serving the morning feed. Two samples were taken per animal in each sampling, one in 10 ml tubes with coagulation activator (red cap 368175, BD Vacutainer®, New Jersey, USA) for determination of analytes in serum, and the other in 4 ml tubes provided with k3 EDTA (purple cap 368171, BD Vacutainer®, New Jersey, USA) used for hematological profile analysis. The red-capped tubes were centrifuged at 3,500 ×g for 15 min at 10 °C to separate the serum and store it in duplicate in 2 ml vials at −20 °C until use in the measurement of concentrations of glucose, cholesterol, triglycerides, total protein, urea, sodium (Na^+), potassium (K^+), chlorine (Cl^-), triiodothyronine (T3), and thyroxine (T4). Serum concentrations of the metabolites were determined with a semi-automatic liquid-phase analyzer (EasyVet; KrontroLab, Morelia, Mich., Mexico), whereas electrolytes in an LW E60A analyzer (LandWind, Shenzhen, China). Thyroid hormones were determined using ELISA commercial kits (Monobind Inc., Lake Forest, CA, USA) on a fully automated equipment (Thunderbolt, Gold Standard Diagnostics, CA, USA); for the latter analysis, the coefficients of variation within and between trials were 5.4 and 6.7 % for T3, and 1.6 and 6.1 % for T4, respectively.

Blood counts were analyzed on a veterinary hematology equipment (MINDRAY, BC-2800 Vet, Shenzhen, China) within one hour of sample collection. The parameters included in the profile were: leukocyte and erythrocyte count (WBC), hemoglobin (HGB), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), erythrocyte distribution width (RDW), platelet count (PLT), mean platelet volume (MPV), platelet distribution width (PDW), and plateletcrit (PCT).

Variables of performance in the pen, carcass, and meat quality

Twenty (20) *Bos indicus* bulls were randomly selected from each pen (n= 240) to measure productive behavior and carcass traits, and of these, only 5 were evaluated for meat quality (n= 60). Live weight (LW) was recorded individually on d 1, 32, and 70 of the study, with which daily weight gain and total weight gained were calculated. Feed intake was recorded per pen, which was done twice a week during the study; these weights were used to calculate DM consumption and feed efficiency. Once the fattening period was over, the animals were led on foot to the slaughterhouse (TIF slaughterhouse 111), where after being slaughtered under the supervision of certified inspectors, the hot carcass weight (HCC) was recorded and the carcass yield was calculated by expressing the HCC as a percentage of the final LW. Subsequently, the carcasses were sectioned between ribs 12 and 13, after refrigeration in a cold room at 4°C for 24 h, to record dorsal fat thickness, amount of fat around the kidney, pelvis and heart (KPH fat), marbling, and rib eye area according to the procedure described by Avendaño-Reyes *et al*[12]. The weight of the KPH fat was expressed as a percentage of the HCC.

On the other hand, meat quality was evaluated in samples of the *Longissimus thoracis* muscle (LTM; between ribs 11 and 13), which was aged for 14 d with the aim of generating shelf conditions. After carcass assessment, two one-inch-thick portions of the LTM were taken, which were individually vacuum packed and sent to the Meat Quality Laboratory of the ICA-UABC Mexicali, B.C., in a thermal container with cooling gel at a temperature of 4 °C. Upon arrival, they were immediately placed in a refrigerator at a temperature between 0 and 4 ºC until they reached 14 d of aging. The samples were then removed from the vacuum bags and oxygenated for 30 min before proceeding to the following quality measurements: pH, shear force, drip weight loss, and meat color (lightness [L*], reddish [a*], yellowish [b*], chroma [C*] and hue angle [h°]). pH was measured by inserting a puncture electrode connected to a portable potentiometer (Hanna Instruments Digital, Model HI-2210, Woonsocket, RI). The color parameters were determined in triplicate by placing a previously calibrated portable colorimeter (NH300 Portable Colorimeter, Guangzhou, China) on different parts of the surface of the meat portion. Drip weight loss was measured using a validated technique(13). Finally, the meat portions were cooked until they reached an internal temperature of 71 °C on an electric grill (Cook Master Oster, model 3222-3, Mississauga, ON, Canada). The meat was then cooled for 20 min to reach room temperature (~ 27 °C) and three 1.27 cm-sided cubes were cut to evaluate the shear force by placing the muscle fibers perpendicular to the knife of the Warner-Bratzler equipment (Salter Model 235, GR Co., Manhattan, KS, USA). Averages were obtained per sample of each study variable.

Statistical analysis

All statistical analyses were performed using SAS software procedures(14). Physiological variables, blood analyte concentrations, and hematological parameters were analyzed with PROC MIXED under models of repeated measurements over time, which included the fixed effects of treatment, sampling day, and their interactions; in addition, the nested random effect of animal within pen was considered. In the case of the physiological variables model, the time of day and its interactions with the rest of the factors were also considered as a fixed effect. The triple interaction was not significant (P>0.05) for any response variable, considering only the interaction of treatment × time of day. In all the models developed, the compound symmetry and unstructured variance-covariance structures had the best fit given the lower values of the BIC and AIC criteria(15). The variables of productive behavior, carcass traits, and meat quality were analyzed with a completely randomized model with subsampling, nesting bulls in treatment. The means were compared using the LSMEANS/PDIFF command, declaring differences at a P≤0.05 and trends between 0.05≤P≤ 0.10.

Results

The maximum and average values of AT, RH, and THI during the study were 42.3 and 26.6 °C, 100 and 57.5 %, and 95.6 and 74.6 units, respectively (Figure 1). In general, regardless of shade type, in the first half of the study (0–35 d), cattle were exposed to HS conditions (77 to 83 THI units), and the rest of the time, to a thermoneutral environment (69 to 76 THI units; Figure 2). On the other hand, the physiological variables did not change (P>0.05) due to the effect of the triple interaction of shade type × time of day × week of sampling. Except for the shade type × time of the day interaction, which affected RR (P<0.01), the interactions between two factors did not modify (P≥0.21) the physiological variables (Table 1). DNF and DWF reduced (P<0.01) RR in the morning and afternoon, respectively, compared to CS and DS (Figure 3). In general, the BSTs of the head, neck, loin, rump, and eye were lower (P<0.01) in the DWF group compared to the rest of the treatments, except for the belly and chuck, where they were similar (P>0.05) to the DNF group. Consistently, the BSTs of all measured anatomical regions were lower (P<0.01) in the morning than in the afternoon.

Figure 1: Average values every two days for ambient temperature (AT), relative humidity (RH), and temperature-humidity index (THI) during the experimental period

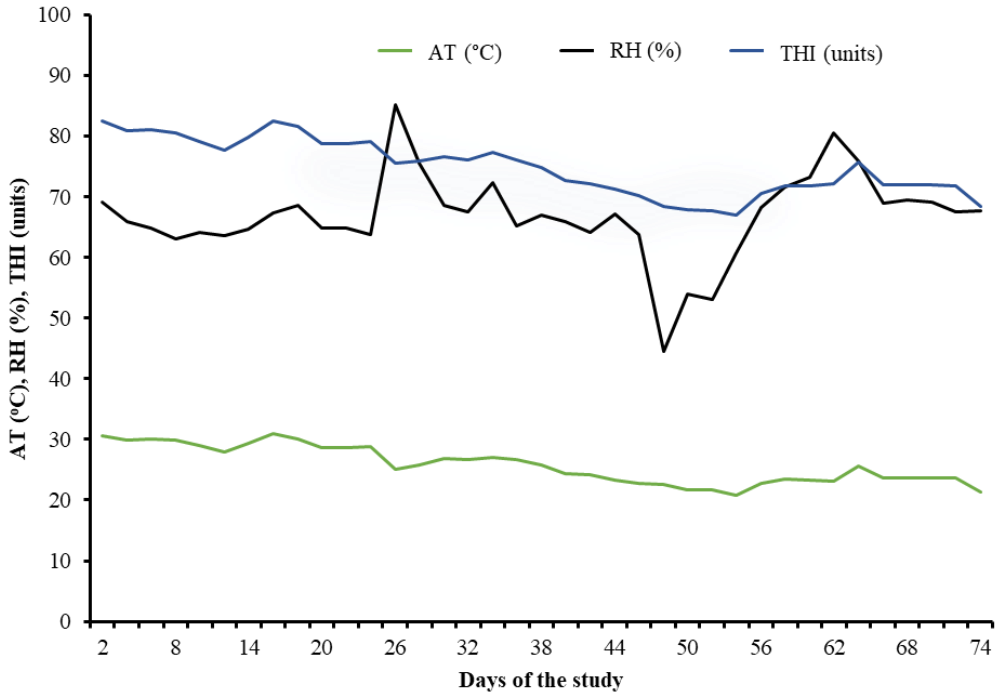


Figure 2: Climatic variables recorded during the experimental period in the different types of shades: conventional (CS), double (DS), dome without (DNF) and with fans (DWF)

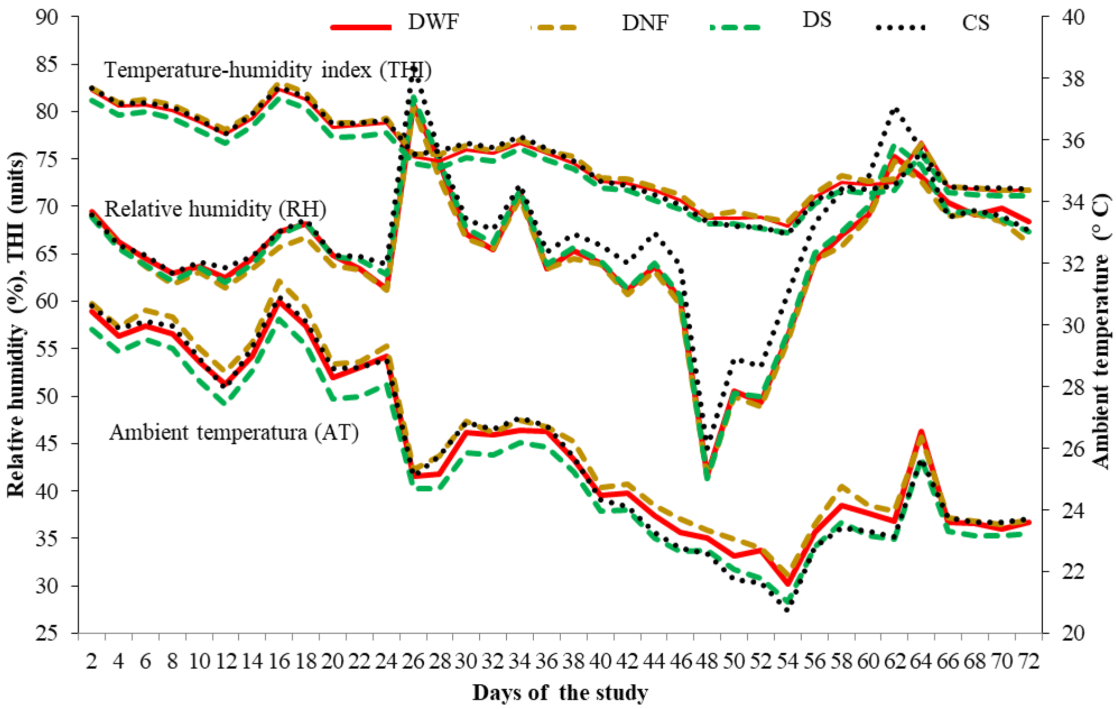
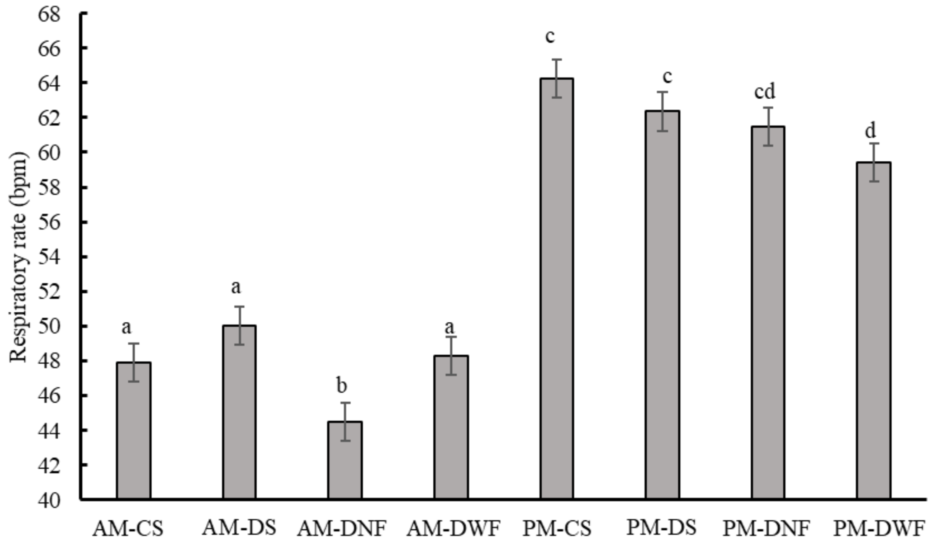


Table 1: Effect of shade type on physiological variables of *Bos indicus* bulls during fattening in a subtropical zone

	Type of shade (TS)				SEM	*P*-value			
	CS	DS	DNF	DWF		TS	Hour	Week	TS×Hour
RR, bpm	56.06[a]	56.18[a]	53.01[b]	53.85[b]	0.82	<0.01	<0.01	<0.01	<0.01
Body surface temperature (°C)									
Head	34.77[a]	34.59[a]	34.35[a]	32.90[b]	0.34	<0.01	<0.01	<0.01	0.39
Neck	34.68[a]	34.89[a]	34.30[a]	33.76[b]	0.16	<0.01	<0.01	<0.01	0.21
Loin	34.81[a]	34.90[a]	34.47[a]	33.90[b]	0.20	<0.01	<0.01	<0.01	0.74
Chuck	34.66[a]	34.89[a]	34.14[b]	33.83[b]	0.17	<0.01	<0.01	<0.01	0.92
Rump	34.95[a]	34.90[a]	34.72[a]	33.85[b]	0.19	<0.01	<0.01	<0.01	0.62
Belly	34.68[a]	35.01[a]	34.66[a]	33.92[b]	0.20	<0.01	<0.01	<0.01	0.98
Eye	35.44[a]	35.18[a]	34.83[b]	34.37[c]	0.15	<0.01	<0.01	<0.01	0.81

CS= conventional shade; DS= double shade; DNF= dome without fans; DWF= dome with fans; RR= respiratory rate; BST= body surface temperature; SEM= standard error of the mean.
[abc] Different letters within a row indicate differences at $P \leq 0.05$.

Figure 3: Effect of the interaction of time of day × type of shade on the respiratory rate of *Bos indicus* bulls in a subtropical zone



AM= morning, PM= afternoon; CS= conventional shade; DS= double shade; DNF= dome without fans; DWF= dome with fans.

The interaction of type of shade × week of sampling did not affect (P≥0.11) serum analyte concentrations (Table 2) and hematological profile (Table 3). In general, the concentrations of glucose, cholesterol, urea, Na^+ and Cl^-, as well as hematological parameters, did not vary (P≥0.12) with the type of shade. The total protein concentration was higher (P<0.01) in DNF-housed bulls and the K^+ concentration was lower (P=0.02) in CS-treated bulls compared to those protected with any of the other shade types. Serum T4 and T3 concentrations were higher (P≤0.04) in CS and DS than in DNF and DWF. Regardless of the type of shade, the week of sampling affected (P<0.05) most of the concentrations of analytes and hematological parameters.

Table 2: Effect of shade type on the metabolite, electrolyte and hormone concentrations of *Bos indicus* bulls during fattening in a subtropical zone

	Type of shade (TS)				SEM	*P-Value*		
	CS	**DS**	**DNF**	**DWF**		**TS**	**WE**	**TS×WE**
Metabolites, mg/dL								
Glucose	100.60[a]	96.10[a]	102.80[a]	94.70[a]	3.43	0.30	<0.01	0.73
Cholesterol	170.04[a]	179.65[a]	177.91[a]	167.27[a]	6.10	0.42	<0.01	0.67
Triglycerides	36.20[a]	34.15[a]	40.08[a]	36.23[a]	3.23	0.62	<0.01	0.11
Urea	22.20[a]	23.20[a]	23.10[a]	21.60[a]	1.23	0.76	<0.01	0.72
Total protein	7.74[b]	7.80[b]	8.47[a]	7.99[b]	0.16	<0.01	<0.01	0.99
Electrolytes, mmol/L								
Potassium	4.71[b]	4.92[a]	4.90[a]	4.98[a]	0.06	0.02	0.77	0.66
Sodium	139.39[a]	138.98[a]	139.65[a]	139.00[a]	0.81	0.93	0.10	0.89
Chloride	104.73[a]	105.00[a]	105.42[a]	104.75[a]	0.35	0.46	<0.01	0.99
Thyroid hormones								
T4 (µg/dL)	10.21[a]	10.33[a]	9.30[b]	9.20[b]	0.35	0.04	<0.01	0.80
T3 (ng/mL)	2.20[a]	2.12[a]	1.95[b]	1.89[b]	0.07	<0.01	<0.01	0.18

CS= conventional shade; DS= double shade; DNF= dome without fans; DWF= dome with fans; T4= thyroxine; T3= triiodothyronine; WE= week; SEM= standard error of the mean.

[ab] Different letters within a row indicate differences at $P \leq 0.05$.

Table 3: Effect of shade type on the hematological profile of *Bos indicus* bulls during fattening in a subtropical zone

	Type of shade (TS)				**SEM**	***P*-value**		
	CS	**DS**	**DNF**	**DWF**		**TS**	**Day**	**TS×Day**
Erythrocytes, x10^9/L	9.24[a]	9.55[a]	9.55[a]	9.63[a]	0.23	0.65	<0.01	0.97
Leucocytes, x10^{12}/L	11.90[a]	11.45[a]	12.69[a]	12.29[a]	0.44	0.24	0.95	0.11
Hemoglobin, g/L	12.22[a]	12.36[a]	12.61[a]	12.47[a]	0.26	0.76	<0.01	0.90
Hematocrit, %	40.03[a]	40.82[a]	40.76[a]	40.60[a]	1.00	0.94	<0.01	0.82
VCM, fL	43.91[a]	43.01[a]	42.80[a]	42.34[a]	0.74	0.52	0.04	0.81
HCM, pg	13.28[a]	14.14[a]	13.41[a]	13.02[a]	0.61	0.64	0.26	0.11
CHCM, g/L	30.34[a]	30.29[a]	31.53[a]	30.71[a]	0.59	0.47	0.02	0.50
RDW, %	19.36[a]	19.66[a]	19.66[a]	19.85[a]	0.17	0.29	<0.01	0.22
Platelets, x10^9/L	409.89[a]	398.64[a]	427.01[a]	434.46[a]	23.14	0.70	0.22	0.36
MPV, fL	4.72[a]	4.70[a]	4.81[a]	4.66[a]	0.10	0.75	<0.01	0.69
PDW, %	15.78[a]	15.82[a]	15.79[a]	15.71[a]	0.06	0.60	0.99	0.98
Plateletcrit, %	0.19[a]	0.18[a]	0.22[a]	0.20[a]	0.02	0.12	0.80	0.62

CS= conventional shade; DS= double shade; DNF= dome without fans; DWF= dome with fans; MCV= mean corpuscular volume; MCH= mean corpuscular hemoglobin; MCHC= mean corpuscular hemoglobin concentration; RDW= erythrocyte distribution width; MPV= mean platelet volume; PDW= platelet distribution width; SEM= standard error of the mean.

[ab] Different letters within a row indicate differences at $P \leq 0.05$.

Bulls had lower ($P<0.05$) DM consumption and higher ($P<0.05$) feed efficiency under DNF and DWF than under CS and DS, but no changes ($P>0.05$) were observed in growth rate and final weight. Regarding carcass traits, the type of shade did not affect ($P>0.05$) HCC, carcass yield, LTM area, and KPH fat deposition, but it did affect the thickness of dorsal fat, which was lower ($P<0.05$) in DS than in DNF and DWF. In terms of meat quality, the type of shade only affected ($P<0.05$) marbling, being higher ($P<0.05$) in the CS and DS groups compared to the DNF and DWF groups.

Discussion

Beef cattle experience HS conditions when the THI≥75 units, but the degree of severity increases (alert, danger, and emergency) as the THI changes from 75 to >84 units[16]. Therefore, the bulls in the present study were exposed to alert-type HS environmental conditions during the experimental period, as the THI remained around 75 units. Nonetheless, the severity of the thermal insult was greater in the first half of the experiment since it was classified as danger type (THI= 79 to 84 units) as there were higher daily average THI than those detected in the second half. In general, these climatic conditions that prevailed in autumn become evident from summer in tropical and subtropical regions, which highlights the need to implement HS mitigation measures in beef cattle even when they are more thermotolerant breeds, such as the *Bos indicus* breeds. In this genotype, less marked reductions have also been identified on productive and reproductive parameters compared to European cattle, as the welfare of cattle under environments of high AT and RH is compromised[4,17]. In this sense, there is evidence in the same study region indicating that the use of shade, at least of galvanized sheet metal, is essential for an acceptable pen performance of heat-stressed Zebu cattle[18].

The present study proposes the total shading of the pen with a dome-type shade in combination or not with industrial fans as a better strategy for mitigating HS in *Bos indicus* cattle under autumn conditions in a subtropical region. The findings showed that the dome shade promoted a better capacity for diurnal physiological thermoregulation in bulls, especially that equipped with fans, since it reduced the respiratory rate in the hottest hours of the day (afternoons), as well as the BSTs throughout the day, compared to the shades based on galvanized sheet metal (CS and DS). Thus, bulls under DWF prioritized their body heat losses through sensitive rather than latent means, which explains the reduction in RR in the afternoons. Although high RH in tropical and subtropical environments compromises the efficiency of heat losses through the skin in *Bos indicus* cattle[6], the forced air movement caused by the fans under the domes and the blocking of solar radiation could favor the bulls to dissipate by convection the body heat expelled through sweating and radiation on the skin. This, in turn, led to a significant drop in BSTs. A study carried out with Zebu fattening heifers under conditions of a THI= 78 units also indicates that the benefits of shade in thermoregulation could be improved when combined with cooling strategies, such as 10 min of bathing or 30 min of exposure to forced air with fans after grazing; in fact, the individual application of the strategies reduced the RT and RR by around 0.7 °C and 4 rpm, respectively, but this positive effect doubled when they were applied simultaneously[19]. Similarly, in heat-stressed *Bos taurus* Charolais bulls, another study reported that the installation of fans on the shade ceiling improved comfort, benefiting that the activity and rumination patterns tended to normalize as in thermoneutral conditions[20]. In general, the results of the present work, together with those published, support considering complementing the shades with mechanical ventilation to more effectively counteract the effects of heat on the fattening of *Bos indicus* cattle.

It is worth mentioning that thermoregulation adjustments in heat-stressed beef cattle are not only limited to physiological adjustments, but also metabolic, endocrine and hematological adjustments(4). In this sense, it is expected that a good strategy for mitigating HS in *Bos indicus* beef cattle will adjust the metabolism and hematological profile, favoring an improvement in production efficiency and meat quality(6). Here, the type of shade was not a factor that promoted changes in the energy metabolism (glucose, cholesterol, and triglycerides) and blood count of the bulls. However, the dome shade increased the concentration of total protein, which was regulated by promoting forced ventilation with the fans. Serum protein levels are positively associated with muscle catabolism, a metabolic process that occurs to increase the availability of glycogenic amino acids as an energy source in response to a reduction in feed intake of heat-stressed cattle(17). Although the bulls housed in DNF reduced their DM consumption, as did the DWF bulls, the HCC and the LTM area did not vary by the type of shade. This suggests that bulls housed in pens with a dome shade only did not present a situation of muscle catabolism(5). In addition, the concentrations of this metabolite should be considered to be within the reference range(21). On the other hand, *Bos indicus* bulls housed in pens equipped with a dome shade or double shade with galvanized sheet metal reduced body water losses through sweating; this is deduced based on the lower concentration of serum K^+ recorded in bulls housed in pens with CS. Low K^+ values in serum and urine of cattle exposed to HS are attributed to the loss of K^+ in sweat and an inhibition in the release of the hormone aldosterone(22).

Regardless of the installation of fans, the dome shade reduced metabolic activity (lower T3 and T4) and DM consumption while improving feed efficiency without affecting LW gain, carcass muscle mass deposition, and meat quality in bulls. It is widely known that cattle under HS reduce the activity of the thyroid gland and, consequently, feed consumption as a thermoregulation mechanism that allows them to lower endogenous heat production and, therefore, body heat load(4). In fact, *Bos indicus* cattle are more thermotolerant to hot climates than *Bos taurus* cattle because they have the ability to decrease their metabolic rate by reducing the size of the gastrointestinal tract and organs (liver, heart, others) with high metabolic activity, without changing cellular metabolism(6). Since feed intake was reduced without affecting the traits associated with growth in DNF and DWF bulls, it is speculated that the activation of this adaptive mechanism was more marked in these animals than in those kept under shades of galvanized sheet metal. This could explain why the bulls under dome shade reduced their metabolism and feed intake, but were more efficient in transforming the nutrients consumed into carcass muscle mass and weight gain. The latter is assumed because bulls with a dome shade consumed less feed and reached similar DWG, final LW, HCC, and LTM area than bulls with a traditional shade. It should be noted that the results of two previous studies carried out at the same site showed that DWF shade was more effective than DNF or traditional shades built with galvanized sheet metal since they significantly improved the comfort, LW gain, and HCC of the bulls by increasing feed intake(8,9). These findings partially differ from what was found in the present study, which may be due to the fact that 100 % *Bos indicus* genotypes were used here and in these works they were crossed with *Bos taurus*. Zebu crosses with European cattle are generally more susceptible to HS, but they can also respond more effectively to mitigation strategies that favor a better productive environment(6).

On the other hand, bulls housed in domed pens showed less marbling in the meat and increased their backfat thickness, without affecting the deposition of KPH fat, compared to CS or DS bulls. This finding partially coincides with what was reported by another study(8), where dome shade (DNF and DWF) *versus* CS decreased both intramuscular fat deposition and KPH without changes in subcutaneous fat. HS improves meat marbling in cattle, and this is because they prioritize internal fat deposition rather than subcutaneous fat to facilitate heat loss through the skin(23). The change in body fat deposition is an adaptive mechanism of thermoregulation that varies with the intensity of HS in cattle and the effectiveness of the mitigation strategy implemented(6). So the dome shade possibly prevented the activation of this mechanism in the bulls by having improved their physiological thermoregulation capacity, which would explain the results found regarding body fat deposition. It is worth mentioning that this was not reflected in the quality of the meat and, in fact, no type of shade prevented it from tending to be dark ($L^* < 38$ and $a^* < 18$)(24) and hard (shear force < 4.4)(25); a recurrent problem in Zebu cattle(26).

Conclusions and implications

Under natural HS conditions of a subtropical region, installing full dome shade in pens is more effective in improving the thermoregulation capacity and feed efficiency of *Bos indicus* bulls than traditional shades constructed of galvanized sheet metal. Additionally, it is recommended to place fans under the domes to increase the comfort and wellbeing of fattening cattle.

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