PJN
ISSN 1680-5194

PAKISTAN JOURNAL OF NUTRITION

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
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OPEN ACCESS Pakistan Journal of Nutrition

ISSN 1680-5194
DOI: 10.3923/pjn.2018.480.486

Research Article
Effect of Barn Roof Design on General Physiological Changes, Animal Welfare Behavior and Growth Performance of Thai Native Cattle in Rural Conditions in Sakon Nakhon Province, Thailand

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Abstract

Background and Objective: If cattle barns are not suitable for animals as they do not provide a comfortable environment and heat stress can affect animal growth. The objective of this research was to investigate the effects of different barn roof designs on the general physiological, welfare and growth performance parameters of Thai native cattle (TNC). **Methodology:** Data for this research were randomly obtained from intra class sampling of 90 farmers who raised TNC in Sakon Nakhon Province and underwent random-cluster sampling in which the farmers were divided into three groups, each with 30 farmers: Group 1, farmers who raised cattle using a free-range system and a barn with no roof, group 2, farmers who raised cattle in barns with a single-tiered roof and group 3, farmers who raised cattle in barns with a two-tiered roof. All data were used for analysis of variance. **Results:** The results of the experiment showed that the ambient environment caused a mean temperature-humidity index (THI) of 86.64±4.86. The THIs for group 1 and 2 were significantly higher ($p<0.01$) than those for group 3 (80.28±5.04, 78.76±4.82 and 76.14±2.54, respectively). The ambient environment did not affect hematological values ($p>0.05$) but did significantly affect general physiological factors ($p<0.05$). **Conclusion:** It can be concluded from these results that a two-tiered barn roof design could reduce the THI from 80 to 76, which would improve conditions for raising cattle. A two-tiered roof could also reduce heat stress in cattle as indicated by the measured physiological factors.

Key words: Barn Roof designs, general physiological changes, animal welfare behavior, growth performance, Thai native cattle

Received: August 24, 2017 Accepted: July 06, 2018 Published: September 15, 2018

Citation: Umpapol H., Songwicha C., Jitrajak T., Patkit A. and Sripandon J., 2018. Effect of barn roof design on general physiological changes, animal welfare behavior and growth performance of Thai native cattle in rural conditions in Sakon Nakhon province, Thailand. Pak. J. Nutr., 17: 480-486.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Thai native cattle (TNC) are compact and adapted to the local environment. They have advantages of good heat tolerance, high grazing ability and effective reproductive systems, which allow them to calve annually. Thai farmers prefer to raise TNC over other cattle breeds because they require less maintenance. However, small-scale farmers sometimes face problems such as feedstuff shortages, pathogen infection and parasite infestation, which are detrimental to cattle health and stunt cattle growth. If farmers are aware of these issues, they can implement preventive measures by improving management during rearing, such as feed management, animal sanitation and animal care, which can lead to increased growth and development of TNC. Specifically, Thai farmers should focus on barn construction because Thailand is located in a tropical zone and well-made and efficient barns must therefore be provided to protect cattle from wind, rain and solar radiation. Solar radiation affects the body heat balance of an animal and limits its capacity for thermoregulation[1]. Changes to the mechanisms for regulating body heat cause an increase in body temperature[2] and can lead to physiological changes in the animal, including hormonal changes[3]. Although, TNC are quite well adapted to high ambient temperatures, if cattle barns do not provide a comfortable environment for the animals, heat stress can affect their growth. Therefore, this research aimed to explore the effect of barn roof design on the general physiology, heat tolerance coefficient, sweating rate, water consumption, hematological values, cortisol levels, animal welfare and growth performance of TNC.

MATERIALS AND METHODS

A total of 90 farmers who raised TNC in Sakon Nakhon Province were randomly selected by intra class sampling and divided into three groups of 30 farmers each using random cluster sampling[4]. Group 1 consisted of farmers who raised cattle using a free-range system and a barn with no roof. Group 2 consisted of farmers who raised cattle in barns with a single-tiered roof made of mixed metals, including zinc but without a ceiling. The barns were open and exposed to the natural environment and were at ambient temperature and with ventilation, whereas inside, the barns were divided into individual stalls with individual waterers and feeders. Group 3 consisted of farmers who raised cattle in barns with two-tiered roofs made of mixed metals, including zinc and without a ceiling, the barns were open to the natural environment, at ambient temperature and with ventilation and inside, the barns were divided into individual stalls with individual waterers and feeders. In Group 3, there were shade trees near the barns, which decreased heat stress and the high ambient temperatures by creating a cooler microclimate.

The experimental tools included a survey or studying the ambient environmental factors that influenced the general physiology and growth performance of TNC, tool invention and development were completed by studying the assessment forms of Srisa-ad[4]. The item-objective congruence (IOC) value was 0.92 and the reliability of the assessment was 0.876.

Data were collected from cattle blood samples, with four cattle randomized from each group and allocated in a randomized complete-block design[5]. Blood was collected from a total of 12 cattle pre-, during and post-experiment to analyze hematological variables, namely, hematocrit, hemoglobin, blood glucose and blood urea nitrogen. Meteorological factors such as temperature, relative humidity, temperature of a black-globe thermometer and temperatures of dry-bulb and wet-bulb thermometers were recorded daily at 2 pm. for the duration of the experiment. Data were measured and recorded for general physiological parameters such as respiration rate, rectal temperature, pulse rate[6], heat tolerance coefficient[7,8] and hematocrit (measured via the micro-hematocrit method), hemoglobin content (measured via the acid hematin method[9]) and cortisol levels[10] (measured via the RIA method and using an Amerlex Cortisol RIA Kit) (Code IM 2021, Kodak Clinical Diagnostics, LTD., Amersham, UK). The compositions of roughage and concentrate were evaluated using chemical analyses of dry matter, crude protein, lipid, ash, calcium and phosphorus contents[11]. Roughage was also analyzed to examine the percentages of acid detergent fiber (ADF) and neutral detergent fiber (NDF)[12].

Data analyses were conducted based on the relation between the meteorological factors and the general physiological parameters using polynomial regression analysis and analysis of variance[5]. The differences in the means of each factor were analyzed using the least-squares method. The animal welfare parameters of the TNC were analyzed using the assessment tools developed by the researchers for this experiment. The properties, barns and TNC used in this experiment belonged to local farmers in Sakon Nakhon Province. The following hematological values were analyzed: Hematocrit, hemoglobin, blood glucose, blood urea nitrogen and cortisol levels. The feed compositions were analyzed at the Science Center of Sakon Nakhon Rajabhat University. This experiment was conducted from October, 2012 to April, 2013.

RESULTS

The ambient environment showed a mean temperature-humidity index (THI) of 86.64±4.86 and the THIs of group 1, 2 and 3 were 80.28±5.04, 78.76±4.82 and 76.14±2.54, respectively, with the mean THIs for group 1 and 2 being significantly higher than that of Group 3 ($p<0.01$) (Table 1 and 2). The ambient environment did not affect the hematological values of groups 1, 2 and 3 ($p>0.05$) but there were significant increases ($p<0.05$) in heat tolerance coefficients and significant decreases ($p<0.05$) in sweating rates in group 3 compared to those in group 1 and 2 (Table 3 and 4). An assessment of the farmers' opinions regarding the influence of the ambient environment on the welfare parameters of the cattle yielded values of 3.75±0.58, 3.67±0.53 and 3.65±0.49 for group 1, 2 and 3, respectively, with farmers indicating a strong influence but no significant differences ($p>0.05$). Additionally, assessment of the farmers' opinions concerning the influence of the

Table 1: Ambient temperatures and environmental factors during the experimental period

Temperature and environmental factors	Means
Maximum temperature (°C)	34.86±0.62
Average temperature (°C)	29.80±0.40
Minimum temperature (°C)	24.74±0.18
Temperature range (°C)	10.12±0.07
Relative humidity (%)	77.75±4.84
Temperature of black-globe thermometer (°C)*	49.64±5.16
Temperature of dry-bulb thermometer (°C)	37.42±0.20
Solar radiation (°C)	12.22±0.10
THI	86.64±4.86

*Temperature as measured from the middle of a brass bulb thermometer that had been spray painted black, this figure represents the dry-bulb temperature plus additional heat from solar radiation

Table 2: Values for environmental factors that influence climatic conditions associated with different cattle barn roof patterns during the experiment

Temperature and environmental factors	Group 1	Group 2	Group 3
Black-globe temperature (°C)	36.30±0.46^a	34.62±0.62^a	32.40±0.34^b
Dry-bulb temperature (°C)	33.76±0.48^a	32.46±0.32^a	30.78±0.32^b
Temperature of solar radiation (°C)	2.54±0.07^a	2.16±0.08^a	1.62±0.06^b
Average inside temperature of barn (°C)	29.86±0.40^a	28.24±0.36^a	27.76±0.28^b
Temperature range (°C)	11.62±0.16^a	10.48±0.14^a	8.12±0.08^b
THI	80.28±5.04^a	78.76±4.82^a	76.14±2.54^b

Means within the same row with different superscripts differed significantly ($p<0.05$)

Table 3: Means of hematological values and cortisol levels for Thai native cattle

Parameters	Group 1	Group 2	Group 3
Hematocrit (%)			
Pre-experiment	29.46±0.32	29.68±0.42	29.38±0.32
During experiment	29.74±0.30	32.47±0.36	32.98±0.39
Post-experiment	29.86±0.28	33.94±0.34	36.46±0.46
Whole experimental period	29.68±0.30	32.03±0.37	32.94±0.39
Hemoglobin (%)			
Pre-experiment	32.45±0.48	32.68±0.67	32.74±0.54
During experiment	34.26±0.42	35.49±0.62	36.34±0.57
Post-experiment	36.12±0.52	38.63±0.66	38.24±0.48
Whole experimental period	34.28±0.47	35.60±0.65	35.77±0.53
Blood glucose (mg/100 mL)			
Pre-experiment	40.87±0.64	40.58±0.37	40.38±0.69
During experiment	42.17±0.41	44.04±0.63	44.67±0.61
Post-experiment	44.58±0.51	46.49±0.46	47.86±0.58
Whole experimental period	42.54±0.52	43.70±0.47	44.30±0.63
Blood urea nitrogen (mg/100 mL)			
Pre-experiment	12.54±0.35	12.64±0.37	12.58±0.35
During experiment	13.78±0.48	15.62±0.40	16.87±0.40
Post-experiment	16.42±0.36	17.39±0.46	18.60±0.42
Whole experimental period	14.25±0.40	15.22±0.41	16.02±0.39
Cortisol level (µg mL^{-1})			
Pre-experiment	14.46±0.02	13.84±0.03	12.94±0.02
During experiment	10.08±0.03	9.50±0.03	9.64±0.03
Post-experiment	10.07±0.04	9.44±0.02	9.78±0.04
Whole experimental period	11.54±0.03	10.92±0.03	10.78±0.03

Means within the same row did not differ significantly ($p>0.05$)

Table 4: Influence of barn roof design on general physiological parameters of Thai native cattle

General physiological parameters	Group 1	Group 2	Group 3
Rectal temperature (°C)	39.42±0.24[a]	39.28±0.36[a]	39.18±0.32[b]
Pulse rate (BPM)	72.64±5.26[a]	68.12±4.34[a]	62.74±3.06[b]
Respiration rate (breaths/sec)	51.78±2.54[a]	48.16±2.04[a]	46.36±1.84[b]
Heat tolerant co-efficient (%)	82.78±4.64[a]	84.78±3.92[a]	86.40±2.84[b]
Sweating rate (mL m^{-2} h^{-1})	912.12±14.46[a]	894.48±12.72[a]	886.76±10.86[b]
Water consumption (L/day)	22.48±4.82[a]	20.94±4.48[a]	26.86±3.75[b]

Means within the same row with different superscripts differed significantly ($p<0.05$)

ambient environment on the growth of cattle yielded values of 3.63±0.63, 3.8±0.64 and 4.45±0.65 in Groups 1, 2 and 3, respectively, with farmers indicating a strong influence but no significant differences ($p>0.05$) (Table 5).

DISCUSSION

General physiological parameters: Under normal conditions, TNC in a barn without a roof or in a barn with a single-tiered roof exhibited general physiological changes, such as increases in rectal temperature, pulse rate, respiration rate and sweating rate. These changes are associated with the maintenance of normal body temperature and heat transfer by sweat evaporation, a process that increases energy requirements. These changes revealed that the TNC faced heat stress that impacted their supply of energy available for body maintenance[13], thereby decreasing hematocrit and hemoglobin levels[14]. Thermoregulation, which involves sweating evaporation, increases the need for water[15], thus, plasma levels increased, causing an increase in damaged red blood cells and resulting in decreases in hematocrit and hemoglobin levels. The hematocrit and hemoglobin levels of the cattle in barns with single-tiered roofs decreased and were lower than those in the cattle in barns with two-tiered roofs[16]. When TNC are exposed to high temperatures for a long time, their body heat production can decrease, mainly because of a reduction in feed intake, which results in a low net energy level due to the direct impacts of high ambient temperatures on the function of the hypothalamus and anterior pituitary gland[17]. This causes the adrenal cortex to increase cortisol secretion but when cattle are under prolonged heat stress, cortisol levels decline[18]. The body can reduce heat production from food metabolism by increasing cortisol levels or by adjusting cortisol metabolism, thereby suppressing the function of 17-hydroxylase in the adrenal cortex, subsequently increasing the threshold for sensitivity to cortisol and leading to reduced food intake.

The TNC in this study faced heat stress throughout the experiment and experienced a high THI, which caused a decline in the heat tolerance coefficient[19] and affected the functioning of the endocrine glands, thus increasing cortisol levels and decreasing body heat production by reducing feed intake[20]. Later, the cattle could regulate their body heat balance by decreasing cortisol levels, returning to a normal body temperature[21].

Animal welfare parameters

Gasping respiration: High ambient temperatures and high relative humidity caused heat stress in the TNC. We found that the TNC showed general physiological changes, such as increases in rectal temperature, that were related to animal behavior. These behaviors included gasping to increase the frequency of respiration, this behavior relieves heat exhaustion via the respiration-regulating center of the hypothalamus[22], which is sensitive to changes in blood temperature. When the blood temperature in cattle is high, the respiration-regulating center increases the rate of respiration to relieve heat exhaustion and assist in thermoregulation[1].

Rumination: Under high ambient temperatures, the TNC faced heat stress. They also experienced an increase in body heat from fiber fermentation in the rumen, this increase in body heat must be counteracted for normal thermoregulation to occur[23]. Therefore, the TNC decreased their rumination activities to maintain heat balance in their body[24].

Standing and walking to drink water: Under high ambient temperatures, TNC drank more water to regulate their body heat. Water has a high specific heat value and can conduct heat well when the temperature changes, preventing rapid changes in body temperature[22]. In addition, some water is used in sweating, which is an efficient mechanism of transferring heat from the body[17]. The cattle tried to use gasping respiration to regulate their body heat[25] but this behavior was not sufficient to maintain a normal body temperature, so the cattle required much more water for body temperature regulation[26]. This suggests that cattle stand up and drink water frequently under high ambient temperatures[27].

Table 5: Influence of barn roof design on animal welfare parameters and growth performance of Thai native cattle

	Group 1		Group 2		Group 3	
Animal behavior and performance	$\bar{X}\pm SD$	INTP*	$\bar{X}\pm SD$	INTP*	$\bar{X}\pm SD$	INTP*
Animal welfare parameters	(3.75±0.58)	(high)	(3.67±0.53)	(high)	(3.65±0.49)	(high)
Heat tolerance	3.78±0.62	high	3.89±0.54	high	4.27±0.70	high
Rumination	3.52±0.78	high	3.60±0.72	high	3.84±0.63	high
Gasping respiration	4.14±0.47	high	4.04±0.34	high	3.52±0.40	high
Standing and walking to drink	3.82±0.36^a	high	3.44±0.28^a	MOD.	3.32±0.44^b	MOD.
Resting and lying down	3.48±0.68^a	high	3.40±0.79^a	MOD.	3.32±0.26^b	MOD.
Growth performance	(3.63±0.63)	(high)	(3.83±0.64)	(high)	(4.45±0.66)	(high)
Roughage and concentrate intake	3.64±0.57	high	3.92±0.62	high	4.38±0.60	high
Growth, weight gain, fatness/thinness based on age	3.70±0.72	high	3.94±0.67	high	4.52±0.68	highest
Body conformation and body condition score	3.63±0.60	high	3.88±0.61	high	4.54±0.64	highest
Parts of head, chest, muzzle, eye and neck	3.66±0.62	high	3.96±0.63	high	4.34±0.68	high
Fore parts of body, shoulder, chest, forelegs and belly	3.56±0.67	high	3.78±0.67	high	4.47±0.64	high
Parts of body, backbone region, fore flank/rear flank and ribs	3.60±0.62	high	3.71±0.64	high	4.48±0.60	high
Rear parts of body, rump, rear legs, base of tail, outside of thigh and inside of thigh	3.62±0.64	high	3.64±0.66	high	4.45±0.67	high

Means within the same row with different superscripts differed significantly ($p<0.05$), INTP*: Interpretation, MOD.: Moderate

Resting and lying down: Under high ambient environmental temperatures, TNC showed general physiological changes that caused gasping respiration, a function performed using intercostal muscles and the diaphragm and requiring more metabolizable energy, including increased metabolism of lipids from ingested food[28]. If the cattle had less metabolizable energy, production performance parameters, such as growth and carcass quality, could be affected[13]. Hence, when cattle are fattened under high ambient temperatures, they must adapt by reducing their body movements and by keeping still or lying down to rest[18,29].

TNC have become adapted through evolution in the tropical zone. This has led to them having wrinkled skin and large ears, similar to Zebu (*Bos indicus*). Many experiments have been performed to study the functions and roles of the hump in Zebu in heat tolerance. Humped cattle and humpless cattle show the same heat tolerance. However, TNC have wrinkled skin, which provides more surface area to dissipate body heat, helping them to maintain a normal body temperature and alleviate heat stress more efficiently than cattle with tight skin. The theory of heat transfer asserts that a larger surface area can dissipate heat more effectively than a smaller surface area over the same period of time, this includes sensible heat and latent heat. Stefan's Law stated that the rate of heat transfer by radiation from a body to the surroundings depends on body temperature, surrounding temperature, emissivity and surface area of the body. Newton's Law of Cooling stated that the rate of cooling (by forced convection) of a body is directly proportional to the temperature difference between the body and the surroundings. Furthermore, according to the laws of geometry, surface area changes according to the 2/3 power of body mass for bodies with similar shapes. However, animals belonging to the same species might have different body.

Many reports of general animal behavior have shown that European cattle (*Bos taurus*) avoid grazing during the daytime to conserve energy. Typically, Zebu decrease their feed intake less than European cattle under high ambient temperatures because Zebu have higher critical temperatures than European cattle[21]. In addition, the higher critical temperatures of Zebu are associated with a greater capacity for thermoregulation, resulting in lower body temperatures than in European cattle[30]. Growth efficiency is defined as the ratio of energy used to metabolizable energy used and the difference between the two energy values represents heat energy[31]. Therefore, the heat energy balance is a factor that causes a close correlation between thermoregulation and growth rate. When under stress, TNC undergo changes in their general physiological parameters, hematological values and endocrine gland function that regulate their roughage intake[27]. This helps regulate body temperature, which is important because animals require energy to transfer heat from their body to their surroundings. In turn, this transfer changes the same physiological parameters mentioned above to restore normal body temperature[26]. Lipid metabolism is similarly affected by heat stress[32].

CONCLUSION

High ambient environmental temperatures affected the ambient air temperature in cattle barns with the three roof designs studied. Under the three barn roof designs studied, the TNC had high heat tolerances and their hematological values were not differentially affected. However, general physiological parameters (heat tolerance coefficient, sweating rate and water consumption) were affected by the roof design when high ambient environmental temperatures caused a high THI. The ambient environmental temperature affected the general physiological parameters and growth performance of TNC but the cattle could tolerate these conditions and grew quite well under high ambient environmental temperatures because they are adapted to a hot environment.

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