

Heat stress amelioration in West African dwarf and Maradi goats using vitamin C and honey in a hot-dry season

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Abstract

Climate change associated heat stress is the most significant factor which negatively influences animal production in the tropical and semi-arid regions of the world. Hence, the need to mitigate the heat stress level through the use of antioxidants in order to boost production. This study was designed to evaluate the effects of vitamin C and honey administration on heat stress amelioration in West African dwarf (WAD) and Maradi goats in a hot-dry humid tropical environment of South-Western Nigeria. A total of 18 bucks (nine per breed) aged 1-1½ years of age and liveweight between 10-22kg were randomly distributed into three treatment groups of six animals each (3 WAD vs 3 Maradi) with treatment 1 been the control (i.e 0mL Vitamin C and 0mL honey); treatment 2 (10mL of vitamin C/head) and treatment 3 (10mL of honey/head) administered orally one hour before physiological measurements. Rectal temperature (RT), skin temperature (ST), respiratory rate (RR), pulse rate (PR), and heart rate (HR), measured weekly for 3 months before and after antioxidant administration in a 2x2x3 factorial arrangement. Results showed significant breed effect ($P<0.05$) on all physiological variables monitored except PR. Maradi goats exhibited higher RT (39.61 ± 0.04 vs $39.01\pm0.03^{\circ}\text{C}$) and HR (65.44 ± 0.68 vs 59.48 ± 0.58 beats/min). However, WAD goats showed elevated ST (37.54 ± 0.07 vs $36.12\pm0.08^{\circ}\text{C}$) and RR (62.31 ± 0.62 vs 38.63 ± 0.94 breaths/min). The interaction effect between breed, antioxidant treatment levels and time of antioxidant application were significant ($P<0.05$) for most variables except for pulse rate, with RT and HR highest in Maradi goats in the three treatment groups before and after antioxidant administration while ST and RR were the same in the WAD goats. These findings suggest that while breed characteristics strongly influence physiological heat stress responses, vitamin C and honey have potential ameliorative effects on heat stress in tropical goats

Keywords: Heat stress, West African dwarf goats, Maradi goats, Vitamin C, Honey

Atténuation du stress thermique chez les chèvres naines d'Afrique de l'Ouest et les chèvres de Maradi grâce à la vitamine C et au miel pendant la saison chaude et sèche



Résumé

Le stress thermique lié au changement climatique est le facteur le plus important qui influence négativement la production animale dans les régions tropicales et semi-arides du monde. D'où la nécessité d'atténuer le niveau de stress thermique par l'utilisation d'antioxydants afin de stimuler la production. Cette étude a été conçue pour évaluer les effets de l'administration de vitamine C et de miel sur l'atténuation du stress thermique chez les chèvres naines d'Afrique de l'Ouest (WAD) et les chèvres de Maradi dans un environnement tropical humide, chaud et sec du sud-ouest du Nigeria. Au total, 18 boucs (neuf par race) âgés de 1 à 1 an et demi et dont le poids vif était compris entre 10 et 22 kg ont été répartis de manière aléatoire en trois groupes de traitement de six animaux chacun (3 WAD contre 3 Maradi), le traitement 1 servant de groupe témoin (c'est-à-dire 0 ml de vitamine C et 0 ml de miel) ; le traitement 2 (10 ml de vitamine C par tête) et le traitement 3 (10 ml de miel par tête) ont été administrés par voie orale une heure avant les mesures physiologiques. La température rectale (TR), la température cutanée (TC), la fréquence respiratoire (FR), la fréquence du pouls (FP) et la fréquence cardiaque (FC) ont été mesurées chaque

semaine pendant 3 mois avant et après l'administration d'antioxydants, selon un plan factoriel $2 \times 2 \times 3$. Les résultats ont montré un effet significatif de la race ($P < 0,05$) sur toutes les variables physiologiques surveillées, à l'exception de la FC. Les chèvres de la race Maradi présentaient une TR plus élevée ($39,61 \pm 0,04$ contre $39,01 \pm 0,03$ °C) et une FC plus élevée ($65,44 \pm 0,68$ contre $59,48 \pm 0,58$ battements/min).

Cependant, les chèvres WAD présentaient une température corporelle (ST) plus élevée ($37,54 \pm 0,07$ contre $36,12 \pm 0,08$ °C) et une fréquence respiratoire (RR) plus élevée ($62,31 \pm 0,62$ contre $38,63 \pm 0,94$ respirations/min). L'effet d'interaction entre la race, les doses de traitement antioxydant et le moment d'administration de l'antioxydant s'est avéré significatif ($P < 0,05$) pour la plupart des variables, à l'exception de la fréquence cardiaque : la température rectale (RT) et la fréquence cardiaque (HR) étaient les plus élevées chez les chèvres de Maradi dans les trois groupes de traitement avant et après l'administration de l'antioxydant, tandis que la température corporelle (ST) et la fréquence respiratoire (RR) étaient identiques chez les chèvres WAD. Ces résultats suggèrent que, si les caractéristiques de la race influencent fortement les réponses physiologiques au stress thermique, la vitamine C et le miel ont des effets potentiellement bénéfiques sur le stress thermique chez les chèvres tropicales

Mots-clés : Stress thermique, chèvres naines d'Afrique de l'Ouest, chèvres de Maradi, vitamine C, miel

Introduction

Goats exhibit a higher level of heat tolerance than other species (Kojo, 2014). Globally, approximately 600 distinct goat breeds exist (Dwyer, 2009), each exhibiting varying abilities to adapt to different climatic conditions. Despite their exceptional tolerance, the heat-dissipation efficiency of these animals frequently dwindles because of heat stress (Banerjee, *et al.*, 2014). Livestock undergo various kinds of stress such as physical, nutritional, chemical, psychological and thermal. Among all, thermal stress is the most concerning nowadays in the ever changing climatic scenario (Silanikove, 2015). Thermal stress redistributes the body resources including protein and energy at the cost of decreased growth, reproduction, production and health. Environmental elements including high ambient temperature, sun radiation, and humidity directly and indirectly impact the animals' welfare (Collier *et al.*, 1982).

The ability of an animal to conserve energy, thermal, water, hormonal, and mineral balances is significantly hindered by high ambient temperatures (Silanikove, 1992). Exogenous vitamins serve as antioxidants by hunting reactive oxygen species (ROS), providing anti-oxidative functions that are beneficial in fighting stress (Min *et al.*, 2018). Vitamin C or L-ascorbic acid is a well-known antioxidant, reducing reactive oxygen species and regenerating oxidized α -tocopherol to reduced α -tocopherol (Khan *et al.*, 2012). Moreover, vitamin C

plays a role in the hydroxylation metabolism related to the collagen synthesis and vitamin D₃ activation (Whitehead and Keller, 2003). Vitamin-C, otherwise known as ascorbic acid (AA), is a potent antioxidant, and has been demonstrated to control mood and brain functions, and to ameliorate heat stress and the adverse effects of environmental conditions (Ladmakhi *et al.*, 1997). The AA can also be tolerated at high doses without apparent side effects (Balz, 2003). Honey contains over 200 bioactive compounds, including sugars, enzymes, amino acids, organic acids, vitamins, minerals, and a rich profile of antioxidants (Kafri and Cherry, 1985). Among these, key antioxidant constituents include phenolic acids, flavonoids, ascorbic acid, catalase, glucose oxidase, and carotenoids, all of which act through various mechanisms such as hydrogen atom donation, radical scavenging, and modulation of redox-sensitive signaling pathways.

Supplementation of vitamin C (VC) to the diets of ruminants is not a common practice because they can biosynthesize L-ascorbic acid through the glucuronic acid pathway in the liver and kidney (McDowell, 2000). However, plasma VC is usually depleted during stress and disease conditions (Ranjan *et al.*, 2005), hence a possibility of improvement if supplemented. Despite the positive outcome following VC supplementation, others have reported a non-significant effect. For example, oral VC (ascorbic acid) supplementation lessens body weight

loss in goats exposed to heat and transportation stress (Minka and Ayo, 2012). However, VC supplementation was found to have little or no effect on summer heat-induced stress in Rahmani ewes (Hashem *et al.*, 2016). There is paucity of information with respect to the use of honey in ameliorating heat stress in goats.

Considering the high atmospheric temperature during the hot-dry season in the humid tropics which confers a higher heat load on animals, it is therefore important to investigate the ameliorative potentials of vitamin c and honey in the West African Dwarf and Maradi goats during the hot-dry season.

Materials and Methods

Experimental site

The study was carried out between 1st February, 2024 to 31st April, 2024 at the Institute of Food Security Environmental Resources and Agricultural Research (IFSERAR) Farm, Federal University of Agriculture, Abeokuta. The region lies between latitudes 7°18'2"N and 7°18'30"N; and longitude 3°22'10"E and 3°22'41"E. The site is within the guinea savannah vegetation zone of South-Western Nigeria and the climate is humid. The mean annual rainfall of the area is 1,330 mm with a mean annual temperature of 29.3°C and relative humidity of 80%, respectively. Temperatures are fairly uniform with daytime values of 28–30°C during the early rainy season of the year (May–July) and late rainy season (August–October) and 30–34°C during the early dry season (November–January) and late dry season (February–April) with the lowest night temperature of around 24°C during the harmattan period between December and February. Relative humidity is high during the rainy season with values between 63% and 96 % as compared to the dry season (55–84%). The temperature of the soil ranges from 24.5 to 31.0 °C [source: FUNAAB (2012).

Experimental animals and management

Apparently healthy bucks (n=18) consisting of nine West African dwarf (WAD) and nine Maradi bucks aged between 1-1½ years with live weight between 10-18kg for WAD and 20-22kg for Maradi was used for this study. The animals were sourced from the experimental unit of the Small Ruminant (Goat Unit) of the Livestock Production Research Programme, Institute of Food Security, Environmental Resource

and Agricultural Research (IFSERAR), Federal University of Agriculture Abeokuta, Ogun state, Nigeria. The animals were managed semi-intensively throughout the experimental period. The animals were allowed to graze in a paddock planted with *Cenchrus purpureus* and *Megathyrsus maximus* grasses daily at 2% body weight dry matter basis supplemented with concentrate ration (see Table 1 for nutrient components of experimental diet) at 0.3-0.7kg/head/day (2% body weight dry matter basis). Water was provided *ad-libitum*.

Comparative study of heat stress amelioration in West African dwarf and Maradi goats

Apparently healthy bucks (n=18) consisting of nine West African dwarf (WAD) and nine Maradi bucks were randomly distributed into three treatment groups of 6 animals each (3 WAD vs 3 Maradi) with treatment 1 been the control (i.e 0mL Vitamin C and 0mL honey); treatment 2 (10mL of vitamin C/head) and treatment 3 (10mL of honey/head). The treatments were administered orally one hour (1pm) before the physiological readings at 2pm. The period between 1-2pm is the hottest time in the humid tropics of South-Western Nigeria, hence applying the antioxidant at 1pm allows for optimal absorbtion, so that plasma concentration of ascorbic acid and honey will have reached maximum at 2pm when physiological readings were taken. Physiological readings were recorded before the antioxidant administration and after once a week. The vitamin C and honey used for this study was purchased from a recognized pharmaceutical company. The physiological parameters recorded include; skin temperature, rectal temperature, heart rate, respiratory rate and pulse rate. On the data collection day (i.e once weekly) animals were allowed to stay in the pens and fed *Cenchrus purpureus* and *Megathyrsus maximus* grasses at 2% body weight dry matter basis on cut and carry basis supplemented with concentrate ration at 2% body weight dry matter basis.

Data analysis

Data obtained were subjected to analysis of variance (SAS, 1993) using least square method of the general linear model of SAS. Significant means were separated using Duncan multiple range test.

Experimental design

The experimental design for this study is a 2x3 factorial arrangement in a repeated measure design with the breed, antioxidant treatment levels and time of administration (before and after) as independent variables and physiological parameters as dependent variables.

Temperature - humidity index

The two broad seasons in Nigeria are classified into two: the early/late for both rainy and dry seasons (Akinseye *et al.*, 2012), April through June represents the early rainy season; July through September indicates the late rainy season; October to December is considered as the early dry season while January to December is designated as the late dry season. The temperature – humidity index an indicator of thermal

climatic conditions was determined from the data on ambient temperature and relative humidity collected with the aid of a thermo-hygrometer daily in the morning and afternoon throughout the three months experimental period using the heat index formula reported by (Ravagnolo *et al.*, 2000) as shown in Table 2:

$$THI = (1.8 \times T + 32) - \{(0.55 - 0.0055RH) (1.8 \times T - 26)\}$$

Where;

T= Ambient temperature (°C)

RH= Relative humidity (%)

Various stress level could be deduced as follows: No Heat Stress-THI below 70; Mild Heat Stress-THI between 70 and 72; Severe Heat Stress-THI above 72

Table 1: Nutrient components of experimental diet

Nutrients	Quantity (%)
Wheat bran	24
Cotton seed cake	30
Wheat offal	40
Bone meal	3
Salt	3
Total	100

Results

Temperature-humidity index (THI) throughout the experimental period

The temperature-humidity index as shown in Table 2 revealed that ambient temperature and humidity were higher in the afternoon than in the morning. THI in the afternoon throughout the experimental period was 86.13 while in the morning it was 77.83.

Breed effect on heat stress amelioration

The effect of breed on heat stress amelioration as shown in Table 3 revealed that breed had a high significant effect ($P < 0.05$) on all heat stress parameters except the pulse rate. Rectal temperature and heart rate were higher in the Maradi than the West African dwarf goats (39.61 ± 0.04 vs 39.01 ± 0.03 °C; 65.44 ± 0.68 vs 59.48 ± 0.58 beats/min). On the other hand, skin temperature and heart rate were higher in

the West African dwarf than the Maradi goats (37.54 ± 0.07 vs 37.54 ± 0.07 ; 62.31 ± 0.62 vs 38.63 ± 0.94).

Antioxidant treatment levels effect on heat stress amelioration

Antioxidant treatment levels effect on heat stress amelioration as highlighted in Table 4 showed that there was no significant ($P > 0.05$) antioxidant treatment level effect with respect to all the physiological parameters measured in this study.

Effect of time of administration of antioxidant on heat stress amelioration

The effect of time of administration on heat stress amelioration as highlighted in Table 5 also showed that there was no significant ($P > 0.05$) difference in time of administration across all the physiological parameters measured in this study.

Table 2: Temperature-humidity index throughout the experimental period

Hot-dry season	
Morning	
Ambient temperature (°C)	32.48±1.91
Relative humidity (%)	29.25±0.18
THI	77.83
Afternoon	
Ambient temperature (°C)	38.86±1.25
Relative humidity (%)	34.57±0.18
THI	86.13

Table 3: Breed effects on heat stress amelioration

Physiological parameters	Breeds		P value
	Maradi	West African Dwarf	
Rectal Temperature (°C)	39.61±0.04 ^a	39.01±0.03 ^b	0.0001
Skin Temperature (°C)	36.12±0.08 ^b	37.54±0.07 ^a	0.0001
Pulse rate (pulses/min)	61.24±0.73	60.63±0.96	0.2508
Respiratory rate (breaths/min)	38.63±0.94 ^b	62.31±0.62 ^a	0.0001
Heart rate (beats/min)	65.44±0.68 ^a	59.48±0.58 ^b	0.0001

^{a,b} means in the same row with different superscript differ significantly (p<0.05)

Table 4: Antioxidant treatment levels effect on heat stress amelioration

Physiological parameters	Antioxidant treatment levels		P value
Rectal Temperature (°C)	0-control	39.28±0.05	0.1288
	1-10mL Vitamin C	39.21±0.05	
	2-10mL Honey	39.35±0.05	
Skin Temperature (°C)	0-control	36.95±0.13	0.8352
	1-10ml Vitamin C	36.91±0.11	
	2-10mL Honey	36.86±0.11	
Pulse rate (pulses/min)	0-control	61.37±0.87	0.1982
	1-10ml Vitamin C	59.51±0.74	
	2-10mL Honey	61.04±0.74	
Respiratory rate (breaths/min)	0-control	49.69±1.56	0.3025
	1-10ml Vitamin C	52.39±1.34	
	2-10mL Honey	52.53±1.28	
Heart rate (beats/min)	0-control	62.98±0.85	0.4859
	1-10ml Vitamin C	62.09±0.72	
	2-10mL Honey	61.58±0.83	

Table 5: Effect of time of administration of antioxidant on heat stress amelioration

Physiological parameters	time of administration		P value
Rectal Temperature (°C)	Before	39.25±0.04	0.3274
	After	39.31±0.07	
Skin Temperature (°C))	Before	37.01±0.09	0.0834
	After	36.79±0.09	
Pulse rate (pulses/min)	Before	60.81±0.55	0.6305
	After	60.37±0.71	
Respiratory rate (breaths/min)	Before	51.75±1.10	0.9485
	After	51.65±1.16	
Heart rate (beats/min)	Before	66.06±0.61	0.0485
	After	61.24±0.69	

Interaction effect of breed and time of antioxidant administration on heat stress amelioration

The interaction effect of breed and time of administration on heat stress amelioration shown in

Table 6 revealed that the interaction effect had a high significant ($P<0.05$) on all the physiological parameters measured except for pulse rate which had no significant effect ($P>0.05$). Rectal temperature and heart rate were higher before and after antioxidant treatment in the Maradi goats. However, mean values for both physiological parameters were higher in the Maradi than WAD goats after antioxidant administration. Skin temperature was lower after antioxidant administration in the Maradi goats while it was higher before and after antioxidant administration in WAD goats. Respiratory rate was higher in the WAD goats before and after antioxidant administration while it was lower in the Maradi goats before and after antioxidant administration.

Interaction effect of breed and antioxidant treatment levels on heat stress amelioration

The breed and antioxidant treatment levels effect on heat stress amelioration shown in Table 7 revealed that there is a high significant ($P<0.05$) breed and antioxidant treatment levels effect on all the physiological parameters measured in this study except for pulse rate which had no significant effect ($P>0.05$). Rectal temperature was highest in the Maradi goats ($39.74\pm0.07^{\circ}\text{C}$) in the treatment group administered 10mL honey. All the three treatment groups in the WAD goats recorded lower rectal temperature. Skin temperature was highest in the WAD goats in the control group.

Table 6: Interaction effect of breed and time of antioxidant administration on heat stress amelioration

Source of Variation	Breed	Antioxidant regime	LSM $\pm$ SEM	P value
Rectal Temperature ($^{\circ}\text{C}$)	Maradi	before	39.66 $\pm$ 0.08 ^a	0.0001
		after	39.56 $\pm$ 0.05 ^a	
	West African Dwarf	before	38.92 $\pm$ 0.04 ^c	
		after	39.10 $\pm$ 0.05 ^b	
Skin Temperature ($^{\circ}\text{C}$)	Maradi	before	36.35 $\pm$ 0.11 ^b	
		after	35.88 $\pm$ 0.12 ^c	
	West African Dwarf	before	37.55 $\pm$ 0.10 ^a	
		after	37.53 $\pm$ 0.11 ^a	
Pulse rate (pulses/min)	Maradi	before	61.32 $\pm$ 0.65	0.6677
		after	61.01 $\pm$ 0.98	
	West African Dwarf	before	60.39 $\pm$ 0.85	
		after	59.86 $\pm$ 1.01	
Respiratory rate (breaths/min)	Maradi	before	39.92 $\pm$ 1.37 ^b	
		after	37.34 $\pm$ 1.26 ^b	
	West African Dwarf	before	61.36 $\pm$ 0.94 ^a	
		after	63.27 $\pm$ 0.79 ^a	
Heart rate (beats/min)	Maradi	before	66.46 $\pm$ 0.91 ^a	0.0001
		after	64.42 $\pm$ 0.99 ^a	
	West African Dwarf	before	60.30 $\pm$ 0.72 ^b	
		after	58.66 $\pm$ 0.89 ^b	

^{a,b} means in the same column with different superscript differ significantly ($P<0.05$)

Table 7: Interaction effect of breed and antioxidant treatment levels on heat stress amelioration

Breed	antioxidant treatment levels	Rectal Temperature (°C)	Skin Temperature (°C)	Pulse rate (pulses/min)	Respiratory rate (breaths/min)	Heart rate (beats/min)
Maradi	0-control	39.54±0.07 ^b	36.02±0.14 ^c	60.68±1.19	36.57±1.48 ^b	65.96±1.15 ^a
	1-10mL Vitamin C	39.55±0.09 ^b	36.21±0.14 ^c	60.00±0.89	38.83±1.59 ^b	64.20±1.08 ^a
	2-10mL Honey	39.74±0.07 ^a	36.11±0.21 ^c	62.63±0.97	40.19±1.75 ^b	66.12±1.25 ^a
West African Dwarf	0-control	39.03±0.04 ^c	37.89±0.12 ^a	62.07±1.27	62.82±1.18 ^a	60.00±1.14 ^b
	1-10mL Vitamin C	38.97±0.05 ^c	37.40±0.13 ^b	59.17±1.11	62.07±1.15 ^a	60.59±0.94 ^b
	2-10mL Honey	39.05±0.07 ^c	37.45±0.11 ^b	59.79±1.06	62.21±0.90 ^a	58.02±0.94 ^b
P value		0.0001	0.0001	0.164	0.0001	0.0001

^{a,b,c} means in the same column with different superscript differ significantly (P<0.05)

Interaction effect of time of administration and antioxidant treatment levels on heat stress amelioration

The interaction effect of time of administration and antioxidant treatment levels on heat stress amelioration shown in Table 8 revealed that there was no significant (P>0.05) effect on all the physiological parameters measured in this study.

Interaction effect of breed, time of administration and antioxidant treatment levels on heat stress amelioration

Breed, time of administration and antioxidant treatment levels interaction had a high significant (P<0.05) effect on all the physiological parameters except for pulse rate which was not significant (P>0.05) as shown in Table 9. Rectal temperature was highest in the Maradi and lowest in the WAD goats

before and after antioxidant administration in all the treatment groups. Mean values were particularly lower in the WAD goats after antioxidant administration. Skin temperature was highest in WAD goats in the three treatment groups before antioxidant administration and lowest in Maradi goats in the group administered 10mL honey. Respiratory rate were highest in both breeds in the three treatment groups before and after antioxidant administration. However, mean respiratory rate values were lower in the Maradi compared to the WAD goats. Heart rate values was lowest in the WAD goats after the administration of 10mL honey while highest mean values were recorded in the Maradi goats before and after antioxidant administration in all the treatment groups

Table 8: Interaction effect of time of administration and antioxidant treatment levels on heat stress amelioration

Time of administration	antioxidant treatment levels	Rectal Temperature (°C)	Skin Temperature (°C)	Pulse rate (pulses/min)	Respiratory rate (breaths/min)	Heart rate (beats/min)
Before	0-control	39.23±0.07	37.07±0.18	61.61±1.03	50.21±2.22	62.86±1.09
	1-10mL Vitamin C	39.18±0.09	36.96±0.14	59.75±0.99	50.39±1.81	63.07±0.89
	2-10mL Honey	39.34±0.09	37.02±0.13	61.28±0.86	53.96±1.77	63.25±1.17
After	0-control	39.32±0.06	36.89±0.18	61.14±1.42	49.82±2.22	63.04±1.32
	1-10mL Vitamin C	39.24±0.06	36.83±0.13	59.45±1.11	54.05±1.96	61.28±1.13
	2-10mL Honey	39.37±0.07	36.69±0.16	60.64±1.20	50.88±1.87	59.84±1.14
P value		0.4416	0.5744	0.6843	0.4241	0.1661

Table 9: Interaction effect of breed, time of administration and antioxidant treatment levels on heat stress amelioration

Breed	antioxidant treatment levels	Time of administration	Rectal Temperature (°C)	Skin Temperature (°C)	Pulse rate (pulses/min)	Respiratory rate (breaths/min)	Heart rate (beats/min)
Maradi	0-control	Before	39.55±0.11 ^{ab}	36.10±0.18 ^{cd}	60.79±1.03	37.00±1.94 ^c	66.07±1.45 ^a
	1-10mL Vitamin C	Before	39.53±0.08 ^b	35.93±0.20 ^{cd}	60.57±2.18	36.14±2.27 ^c	65.86±1.82 ^{ab}
	2-10mL Honey	Before	39.58±0.17 ^{ab}	36.46±0.18 ^c	60.27±1.19	38.80±2.38 ^{bc}	65.60±1.45 ^{ab}
	0-control	After	39.51±0.09 ^b	35.93±0.20 ^{cd}	59.73±1.33	38.87±2.18 ^{bc}	62.80±1.59 ^{abcd}
	1-10mL Vitamin C	After	39.83±0.12 ^a	36.47±0.20 ^c	62.73±1.12	43.42±2.59 ^b	67.58±1.79 ^a
	2-10mL Honey	After	39.65±0.08 ^{ab}	35.76±0.21 ^d	62.55±1.60	36.97±2.26 ^c	64.67±1.73 ^{abc}
West African Dwarf	0-control	Before	38.93±0.05 ^c	38.04±0.16 ^a	62.43±1.79	63.43±1.83 ^a	59.64±1.42 ^{de}
	1-10mL Vitamin C	Before	39.13±0.06 ^c	37.75±0.18 ^{ab}	61.71±1.85	62.21±1.52 ^a	60.36±1.81 ^{cde}
	2-10mL Honey	Before	38.89±0.06 ^c	37.33±0.19 ^b	59.29±1.46	59.09±1.60 ^a	61.19±1.02 ^{bcd}
	0-control	After	39.05±0.06 ^c	37.47±0.19 ^c	59.05±1.69	65.05±1.52 ^a	60.00±1.58 ^{cde}
	1-10mL Vitamin C	After	38.95±0.099 ^c	37.45±0.015 ^c	60.14±1.24	62.24±1.48 ^a	59.86±1.33 ^{cde}
	2-10mL Honey	After	39.15±0.09 ^c	37.44±0.09 ^c	59.43±1.73	62.19±1.06 ^a	56.19±1.27 ^e
P value			0.0001	0.0001	0.7041	0.0001	0.0001

^{a-e} means in the same column with different superscript differ significantly (P<0.05)

Discussion

The high rectal temperature in the Maradi goats during the hot dry season could be due to heat tolerance differences. Maradi goats originating from the hotter, drier northern Nigeria exhibit lower tolerance to heat stress in the humid tropical environment resulting in elevated rectal temperature. This corroborates the findings of Oguntade *et al.*

(2024) on the genetic variation in the thermotolerant traits of three Nigerian goat breeds reared in the humid tropics. The high skin temperature and respiratory rate in the WAD compared to the Maradi goats could be due to their smaller body size hence, a larger body surface area to volume ratio. This anatomical feature can lead to heat loss through the skin resulting in higher skin temperature as they struggle to dissipate heat effectively in hot conditions

(Otuma and Onu, 2013). The high respiratory rate could also be due to the grazing pattern of the WAD goats which are more active during the hottest part of the day as compared to the Maradi which engage in less activity during peak heat periods. This causes them to exhibit a higher metabolic rate which can contribute to a higher respiratory rate.

The non-significant effect of the antioxidant treatment levels on physiological parameters could be due to the fact that these parameters are regulated by thermoregulatory and autonomic mechanism that respond quickly to high ambient temperature and humidity often overpowering moderate antioxidant supplementation.

The similarity in means in all the physiological parameters measured before and after antioxidant administration could be due to the fact that antioxidants primarily target oxidative stress rather than directly altering core body temperature regulation.

The high rectal temperature in WAD goats arising from this could be due to the antioxidant vitamins notably vitamin C help in maintaining vascular integrity under heat or transport which normalize heat distribution between the core and the periphery.

The higher skin temperature in the WAD before and after antioxidant administration could primarily be due to innate breed differences in thermoregulatory mechanisms and adaptation to humid environment.

The WAD goats are adapted to the hot-humid regions while the Maradi goats are adapted to the hot-dry savanna, thus influencing how they manage heat (Habibu *et al.*, 2021). The higher respiratory rate in the WAD before and after antioxidant administration could be due to the intense metabolism associated with the WAD goats leading to higher levels of oxidative stress and a greater need for physiological cooling (higher RR) to maintain homeostasis compared to the Maradi breed.

The highest rectal temperature recorded in the 10mL honey group in the Maradi goats could be as a result of the fact that honey as an energy-dense substrate that can transiently increase metabolic activity in the rumen and tissues, generating more internal heat. This corroborates the findings of Adekunle *et al.* (2017). The highest skin temperature mean observed in the

WAD goats in the control group could be that the control group lacked antioxidant supplementation leading to elevated skin temperature when exposed to high temperature–humidity index. The highest respiratory rate values recorded in the WAD goats in the three treatment groups can be attributed could be due to the lower thermal tolerance in high-temperature environments, resulting in higher respiratory rates compared to the WAD goats.

The highest rectal temperature recorded in the three treatment groups in the Maradi goats before and after antioxidant administration can be attributed to their larger body size and have a different ratio of mass to surface area compared to the smaller WAD, thereby influencing heat production and retention. The highest skin temperature recorded in the three treatment groups in the WAD goats before and after antioxidant administration can be attributed to the inherent metabolic heat production which creates more body heat when there is elevated ambient temperature which if not rapidly dissipated can result in elevated skin temperature (Oguntade *et al.*, 2024). The highest respiratory rate recorded in the three treatment groups in the WAD goats before and after antioxidant administration could be that the fact that during the hot-dry season in the humid tropics, ambient temperature increased which caused the WAD goats to rely on breathing faster to dissipate heat.

Conclusion

It can be concluded from this study that skin temperature and respiratory rate were highest in the WAD goats while rectal temperature and heart rate were highest in the Maradi goats in the three treatment groups before and after antioxidant administration. The use of 10mL honey and vitamin C as antioxidant did not fully mitigate heat stress immediately considering the inherent physiological differences between the two breeds.

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Date received: 11th August, 2025

Date accepted: 9th September, 2026