Journal of Applied Veterinary Sciences, 9 (2):42-54 (April, 2024).
ISSN: Online: 2090-3308, Print: 1687-4072
Journal homepage : https://javs.journals.ekb.eg

High Environmental Temperature Induces Oxidative Stress, Reduced Sow Productivity and Increased Piglet Mortality

Oladipo Olufemi Omotosho[1*], Olusola Fowowe[1], John Olusoji Abiola[1], Ademola Adetokunbo Oyagbemi[2] and Temidayo Olutayo Omobowale[1]

[1]Department of Veterinary Medicine, Faculty of Veterinary Medicine, University of Ibadan, Nigeria
[2]Department of Veterinary Physiology ad Biochemistry, Faculty of Veterinary Medicine, University of Ibadan, Nigeria

*__Corresponding Author:__ Oladipo Olufemi Omotosho, **E-Mail:** oo.omotosho@gmail.com

ABSTRACT

Heat stress is a limiting factor for livestock productivity in many countries. This study was designed to evaluate the influence of exposure of exotic pigs to high environmental temperatures on physiology, oxidative stress biomarkers and productivity. Multiparous sows (n = 40) in two equal groups (Groups N and H) were investigated. The pen temperature, relative humidity and Temperature-Humidity Index (THI) were measured for 30 days. The skin temperature, respiratory rate and rectal temperature were measured weekly. Haematology, serum biochemistry and oxidative biomarkers were also evaluated. The production records, including farrowing events (NFE), number of piglets at birth (NPB), number of piglets at weaning (NPW) and piglet mortality (NPM) were obtained per sow for the preceding 24 months. Data were analyzed using descriptive statistics and a student T-test at P<0.05. Pen indoor temperature was significantly higher and relative humidity significantly lower in Group H (30.23$\pm$0.99 ^{0}C, 48.90$\pm$7.94 %) compared to Group N (25.21$\pm$0.94 ^{0}C, 58.97$\pm$6.21 %). The THI was higher in Group H (78.40$\pm$1.99). There was a significant increase in skin surface temperature and respiratory rate in Group H (37.70$\pm$1.40 ^{0}C and 39.70$\pm$4.28 bpm) with a slight increase in rectal temperature compared to Group N (33.86+0.95 ^{0}C and 35.79+2.89 bpm). There was a slight increase in PCV, blood urea nitrogen and a decrease in the levels of sodium, chloride, and bicarbonate in sows in Group H. There was a significant increase in hydrogen peroxide generation, nitric oxide contents and malondialdehyde levels, with a decrease in superoxide dismutase activity and glutathione content in Group H when compared to Group N. There was a reduction in farrowing events (N = 3.45$\pm$0.20; H = 3.00$\pm$ 0.19), number of piglets at birth (N = 29.15$\pm$1.92; H = 27.95+ 2.44), the number of piglets at weaning (N = 27.65$\pm$1.89; H = 25.90$\pm$ 2.25), and an increase in piglet mortality (N = 1.5$\pm$0.21; H = 2.05$\pm$0.42) in sows exposed to higher temperatures. The orientation of the pig housing in the north-south direction reduced its effectiveness. Exotic sows exposed to heat stress had altered physiology, experienced oxidative stress, were prone to renal and hepatic injury, and had reduced productivity. Adequate thermal comfort should be ensured in pig husbandry in the tropics for optimal health and productivity.

Original Article:
DOI:https://dx.doi.org/10.21608/javs.2024.255494.1300

Received : 14 December, 2023.
Accepted :08 February, 2024.
Published in April, 2024.

Keywords: Heat stress, Free radicals, Pig, Sow productivity, Thermal comfort.

J. Appl. Vet. Sci., 9(2): 42-54.

INTRODUCTION

Heat stress is a major challenge to profitable livestock production in many parts of the world and may increase with future climate change **(Sejian *et al.*, 2018).** Heat stress occurs when environmental temperature rises beyond the thermal comfort zone of an animal, which is established by an equilibrium between external heat load, internal heat production, and heat dissipation **(Rauw *et al.*, 2017; Rojas-Downing *et al.*, 2017; Lacetera, 2019)**. It remains a major environmental issue negatively affecting animal welfare and production efficiency in almost every livestock sector, especially in the tropical and subtropical regions **(Mayorga *et al.*, 2019; Patra and Kar, 2021).** Livestock in temperate countries are also affected during warm summer months **(Renaudeau *et al.,* 2012)** and it remains one of the costliest issues in the U.S. pork industry causing an estimated annual loss of nearly US$1 billion **(Pollmann, 2010).**

The response mechanisms initiated by animals for adaptation to climatic stressors contribute to reducing their productivity **(Pragna *et al.,* 2018).** These mechanisms include morphological, behavioural, physiological, neuro-endocrine, blood biochemical, metabolic, cellular, and molecular responses **(Sejian *et al*., 2018).** In heat-stressed animals, there is activation of thermoregulatory, physiological, and behavioural responses beyond what is needed for regular maintenance of body temperature **(Rauw *et al.,* 2017).** Therefore, nutrients are diverted to body temperature maintenance and other survival responses above the synthesis of useful and profitable products such as growth, milk production and foetal development. Higher ambient temperatures associated with climate change also reduce the availability of water, quality, and quantity of feeds and increase outbreaks of livestock diseases **(Mutua *et al*., 2020).**

In comparison to other livestock, pigs are prone to heat stress because they do not have functional sweat glands. This is aggravated by their relatively small lungs, which reduce their ability to disseminate heat by panting **(D'Allaire *et al*., 1996)**. Therefore, when exposed to high environmental temperatures, pigs increase their respiratory rate and reduce voluntary feed intake, leading to significant economic losses. Heat stress often accompanied by a drop in feed consumption, is associated with a reduction in the feed conversion rate, poor sow performance, a drop in milk production, reduced and inconsistent growth, decreased carcass quality, mortality, and morbidity (**Rauw *et al.,* 2017**; **Mutua *et al*., 2020).**

In addition to rising environmental temperatures, the recent fast-growing lean pigs, apart from improved productivity, are known to generate more heat than earlier breeds and their congeners living in the wild **(Brown-Brandl *et al.,* 2001)** coupled with the intensive system of production that ensures a denser population in confined housing, which makes it difficult for pigs to express natural instincts that aid their body temperature control **(Huynh *et al.,* 2006).**

When environmental temperature rises above the thermo-neutral zone of pigs, they start making clear physiological changes to dissipate heat. The upper limit of the comfort zone and the thermo-neutral zone for sows at different physiological states range between 18-23^{0}C and 21-26^{0}C, respectively. The upper limit reduces in the order of empty-pregnant-lactating sows **(Vermeer and Aarnink, 2023).** To maintain optimal health and productivity in intensively raised pigs, the housing facility must be effective. The effectiveness of a swine building/facility is defined as how well a building can provide the conditions needed for optimum pig performance and how well these conditions are maintained throughout the year **(Zulovich, 2012).** The facility should ensure optimal conditions in the thermal, gaseous, and physical environments **(Gonyou *et al.,* 2006).** It must meet the requirements of pigs in terms of air temperature, humidity level, air velocity or air movement, indoor air quality, space, manure removal or handling, feed, and water access.

In a swine housing system, the existing modes of heat transfer include: (i) sensible heat transfer (by conduction/contact; by convection or a solid body to an air or gaseous environment; and by radiation); and (ii) latent heat transfer (by evaporation of moisture from the warm, moist surface of a pig and by condensation from the surrounding air with a relatively high dew point temperature to the pig's body with a relatively low dew point or surface temperature) **(Zulovich, 2012).**

In view of the ongoing global climate change and the tendency of pigs raised in tropical environments to be exposed to high temperatures for an extended period of the year, this study was designed to investigate the effect of exposure of exotic sows to high environmental temperatures on their physiology, oxidative stress biomarkers and productivity.

MATERIALS AND METHODS

Study location

The study was conducted on the swine unit of the Teaching and Research Farm (TRF), University of Ibadan, Nigeria, located within Latitude 7° 23' 28.19" N and Longitude 3° 54' 59.99" E. Ibadan is the capital city of Oyo State, located in its south-eastern part, in a wooded area near the border between the rain forest and the savannah climatic zone, in the south-western part of Nigeria. The city is situated about 110 km northeast of Lagos with an average altitude of 200 m and 160 km off the Atlantic coast. The climate of Ibadan is tropical and sub-humid, with distinct wet and dry seasons. It has a bimodal annual rainfall pattern of April-July and August-November with a mean annual rainfall of about 1250 mm and a temperature range of 21 ^{0}C ± 1.5 and 30 °C ± 3.5. Annually, the prevalent winds in the city during the rainy season are the moist maritime south-west monsoon, which blows inland from the Atlantic

Ocean, while the dry dust-laden winds blow from the Sahara desert during the dry season, which is from November to February **(Ajayi and Olufayo, 2002; Egbinola and Amobichukwu, 2013; Ahmed *et al*., 2022).**

Study design, animal selection and housing conditions

The investigation was prospective and retrospective. The prospective study was designed to investigate the level of exposure of 40 selected sows to heat stress for 30 consecutive days in the dry season (January, 2023) and a retrospective review of the production performance of the same selected sows in the preceding 24 months (January 2021-December 2022). Only apparently healthy sows without physical deformities and with a proven breeding record were included in the study. They were sows with a minimum of two previous farrowing events within the preceding 24 months without complications. They were within the age range of 38 -50 months and weight range of 64-96 kg. They were in two groups (20 each) sorted from sows that were permanently housed in the existing farm buildings. Based on the farm housing layout, the long-axis of the first pen (Group N) is oriented on the East-West direction, adjacent to the second wing (Group H) oriented on the North-South direction. The dimensions of the building, floor type, roofing design, feeding and watering facilities are described **(Table 1).**

Table 1 Pig housing design, dimensions and construction materials used in a tropical environment.

	Parameters	Group N	Group H
1	Orientation of long axis of building	East-West	North-South
2	Number of cubicles divided in 2 rows	20	24
3	Highest point of roof within cubicle	8.1 feet	8.1 feet
4	Low point of roof within cubicle	7.6 feet	7.6 feet
5	Breath of walkway between rows	4.2 feet	4.2 feet
6	Dimensions of cubicles	14.3 by 5.2 feet	14.3 by 5.2 feet
7	Highest point of roof (middle of building)	11. 6 feet	11. 6 feet
8	Height of wall partitions	4.8 feet	4.8 feet
9	Floor length across breadth of house	32.8 feet	32.8 feet
10	Length of floor covered by roof along house breadth	23.4 feet	23.4 feet
11	Length of floor not covered by roof	9.4 feet (4.7ft / each side)	9.4 feet (4.7 ft /each side)
12	Feeders, waterers, and cooling facilities	Concrete troughs, open drinkers. Same for both	
13	Materials used for the building (Same for both)	Cement floors, block walls, metal pillars for roof, wooden rafters and corrugated asbestos roof sheets.	

*The roof design of both housing does not provide complete cover for the full length of the cubicles.

Measurement of meterological parameters

The pen indoor temperature and relative humidity at peak heat (1-2 pm) were measured using a thermo-hygrometer which was suspended in the pen. Measurements were taken for 30 consecutive days in the dry season (January, 2023). The length of the pen floor exposed to direct sun radiation at sunrise (10 am) and sunset (6 pm) were noted. The heat stress index was determined using the formula:

THI (^{0}C) = 0.8T + (RH/100) x (T-14.3) + 46.4

Reference: THI≤ 74 is safe, 74<THI<79 is critical, 79≤THI<84 is dangerous and THI ≥84 is emergency **(NOAA, 1976).**

Measurement of physiological parameters

The Skin Temperature (ST), Respiratory Rate (RR) and Rectal Temperature (RT) of the sows were taken once in a week, between 1-2 pm. Skin temperature (°C) were measured using infrared thermometer, the respiratory rate was taken by observation of respiratory movements from a distance while the sows were at rest with measurements recorded as breathes per minutes (bpm) while rectal temperature (°C) was taken with a digital thermometer inserted into the rectum till reading was constant.

Blood sample collection

Blood samples were collected at the end of the experiment (Day 30) from each of the sows for hematology, serum biochemistry and evaluation of markers of oxidative stress. 6 mL of blood was collected aseptically using sterile needle and syringe through the anterior vena cava and discharged equally into labelled sample bottles containing ethylene diamine tetra-acetic acid (EDTA) for hematology and plain bottles for serum biochemistry and biomarkers of oxidative stress. All samples were transported on icepack to the laboratory for analysis.

Laboratory analysis

Haematology and serum biochemistry

The blood samples were analysed on an auto-haematology analyzer (SYSMEX Automated Haematology Analyzer pocH-100iV Diff., United Kingdom). The packed cell volume (PCV), haemoglobin concentration (Hb), red blood cell count (RBC), white blood cell count (WBC), platelet count, neutrophils, lymphocytes, eosinophils, and monocytes were determined. To harvest serum, samples were centrifuged at 2500 x gravitational units (g) for 10 minutes. The harvested serum was stored in cryovials at -20 °C until use. The serum samples were used for the determination of biochemical parameters using analytical-grade reagent kits (Randox Laboratories Limited, United Kingdom) following the manufacturer's instructions. The analytes measured included total protein (TP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), blood urea nitrogen (BUN), and creatinine.

Oxidative stress and antioxidants assay

Glutathione peroxidase activity was determined by the method of **Rotruck *et al.* (1973).** The Malondialdehyde was determined according to the method of **Varshney and Kale (1990).** Total sulfhydryl (thiol) groups and the content of reduced glutathione (GSH) in the samples were quantified using the methods of **Ellman (1959)** and **Jollow *et al.* (1974),** respectively. Glutathione S-transferase activity was determined according to **Habig *et al.*, (1974).** Superoxide dismutase (SOD) activity was estimated by the method of Misra and Fridovich (1972) with slight modification (Oyagbemi et al., 2015). The content of nitric oxide (NO) was evaluated as described by **Olaleye *et al.* (2007).** The content of H_2O_2 generated was measured according to the method of **Wolff (1994).**

Sow productivity and Piglet mortality

The production records of the 40 selected sows for the preceding 24 months (January 2021-December 2022) were reviewed. Data on parity, number of farrowing events (NFE), number of piglets at birth (NPB), number of piglets at weaning (NPW) and number of piglet mortality (NPM) were obtained for each sow.

Ethical Statement

All of the animals received humane care according to the criteria outlined in the Guide for the Care and the Use of Laboratory Animals prepared by the National Academy of Science and published by the National Institute of Health. The ethics regulations were followed in accordance with national and institutional guidelines for the protection of the animals' welfare during experiments **(PHS, 2015).**

Statistical Analysis

All values are expressed as mean±SD. Data were analyzed using descriptive statistics and Student T-test to evaluate the difference between the variance and means of the two groups at $P<0.05$. Analysis was done using excel and SPSS version 26.

RESULTS

The housing design, dimensions and construction materials of the two buildings were similar, except for the orientation of their lengths (long-axis), which was different. The meterological measurements reveal a significant increase in the pen indoor temperature and a significant reduction in relative humidity in Group H (30.23±0.99 °C, 48.90±7.94 %) compared to Group N (25.21±0.94 °C, 58.97±6.21 %) **(Table 2).**

Table 2: Meterological parameters measured in the pen of two groups of sows exposed to different temperature

	Group N			Group H		
Week	Temperature	Humidity	THI	Temperature	Humidity	THI
1	25.64±0.69	59.29±5.47	73.62±0.83	30.14±1.25	53.86±6.89	79.06±2.10
2	25.67±0.93	60.71±3.35	73.82±1.11	30.63±1.19	53.14±8.03	79.60±2.23
3	24.79±0.91	57.43±6.90	72.24±1.29	30.29±0.76	46.43±4.72	78.04±0.92
4	24.83±0.97	58.56±8.25	72.45±1.72	29.94±0.81	43.67±7.38	77.21±1.85
Total	25.21±0.94^{b}	58.97±6.21^{a}	72.99±1.43^{b}	30.23±0.99^{a}	48.90±7.94^{b}	78.40±1.99^{a}
Range	23.00-26.70	45.00-71.00	69.32-75.39	28.00-32.40	32.00-65.00	74.30-82.44

THI: Temperature- Humidity index.

Superscripts (a>b) indicates significant difference in corresponding values along the row at p<0.05.

The calculated Temperature Humidity Index revealed a significant increase in the risk of heat stress in Group H (78.40±1.99) compared to Group N (72.99±1.43). A greater proportion of the pen floor in Group H (44.8; 48.1 %) was exposed to direct sunrays than in Group N (28.1, 26.8 %) at sunrise and at sunset **(Fig. 1).** The physiological measurements revealed significant increases in skin surface temperature and respiratory rate in Group H (37.70±1.40 °C and 39.70±4.28 bpm) compared to Group N (33.86+0.95 °C and 35.79+2.89 bpm). Although the increase in rectal temperature was not significant, it was higher in Group H (38.88±0.68 °C) than in Group N (38.08±0.57 °C) **(Table 3).**

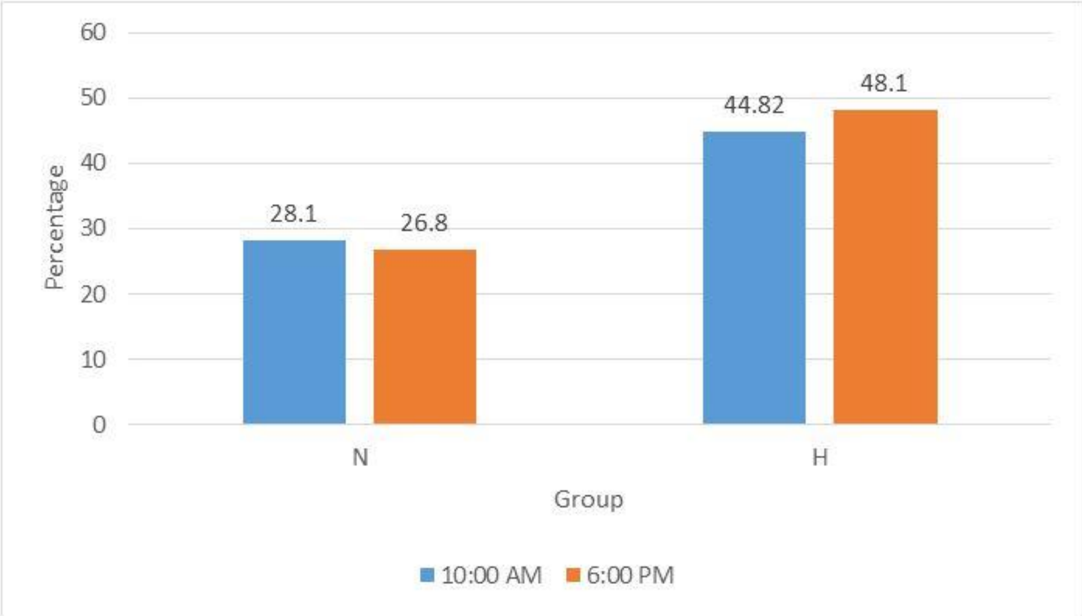

Fig.1: Proportion of pen floor exposed to direct sunrays at sunrise and sunset in two pens in a tropical environment.

Table 3: Skin Temperature, Rectal Temperature and Respiratory rate of two groups of exotic sows exposed to different environmental temperature in a tropical environment:

Indicator	Description	Group N	Group H	Significance level
ST	Week 1	33.44±0.69	38.24±0.57	0.003
	Week 2	33.57±0.80	37.70±0.60	
	Week 3	33.90±1.11	37.80±0.53	
	Week 4	34.54±0.79	37.57±0.51	
	Total	33.86±0.95	37.70±1.40	
	Range	32.00-36.40	36.00-39.40	
RR	Week 1	35.80±2.78	40.35±5.23	0.000
	Week 2	36.00±3.15	37.90±3.57	
	Week 3	36.20±3.35	42.05±3.41	
	Week 4	35.15±2.30	38.50±3.65	
	Total	35.79±2.89	39.70±4.28	
	Range	28.00-41.00	30.00-47.00	
RT	Week 1	38.15±0.42	38.89±0.68	0.057
	Week 2	38.08±0.69	38.90±0.65	
	Week 3	38.17±0.75	38.85±0.75	
	Week 4	37.91±0.32	38.89±0.68	
	Total	38.08±0.57	38.88±0.68	
	Range	37.00-40.00	37.00-40.00	

The haematology and serum biochemistry values were mostly within physiologic ranges with slight changes. In group H, there was a slight increase in packed cell volume **(Table 4),** with changes in serum biochemistry including a decrease in the levels of sodium, chloride, and bicarbonate and an increase in blood urea nitrogen **(Tables 4 and 5).**

Table 4: Hematology values of two groups of exotic sows exposed to different environmental temperature in a tropical environment:

Parameters	Group N	Group H	Reference
PCV, %	41.1±3.54	44.3±4.61	36-43
HB, $g.dL^{-1}$	12.04±1.23	14.99±1.67	10-16
RBC, $x10^{12}/L$	7.6±1478.45	8.8±1818.04	5-8
WBC, $x10^9/L$	20.67±1724.16	18±1393.37	11-22
Neutrophils, $x10^9/L$	1.7±7.30	2.2±6.10	0-4
Platelets $x10^9/L$	369±77.1	376±813.4	200-500
Lymphocytes $10^9/L$	47.6±7.1	25.4±6.30	39-62
Monocytes $10^9/L$	2.5±0.7	1.1±1.10	2-10
Eosinophils $10^9/L$	6.0±0.4	1.2±0.28	0.5-11
Basophils $10^9/L$	0±0	0.25±0.45	0-2

* Data are expressed as mean ± Standard Deviation. PCV, packed cell volume; Hb, haemoglobin; RBC, red blood cell count, WBC, white blood cell count. **(Klem *et al.*, 2010; MSDVetmanual.com).**

Table 5: Serum biochemical values of two groups of exotic sows exposed to different environmental temperature in a tropical environment:

Parameter	Group N	Group H	Reference
Sodium (Na) mmol/L	142.8±6.5	104.3±4.50	143-156
Potassium (K) mmol/L	4.3±1.17	4.0±1.10	4.3-7.8
Chloride (Cl), mmol/L	110±3.30	84±3.96	99.5-112.3
Bicarbonate (HCO_3), mmol/L	21.9±4.20	12.3±3.10	18-27
Blood Urea Nitrogen (BUN), mmol/L	10.18±1.70	32.4±2.10	3.6-10.7
Creatinine (Cr), µmol/L	98.46±6.20	123.50±10.20	88-130
Total Protein (g/L)	72.9±4.80	56.9±6.40	49-67
Alanine aminotransferase (ALT), U/L	49.6±2.50	83.4±2.30	0-103
Aspartate aminotransferase (AST), U/L	42.9±2.60	104.3±2.50	0-125
γ-Glutamyltransferase (GGT), U/L	28.9±2.20	24±2.40	0-82
Alkaline phosphatase (ALP), U/L	46.8±60	52±6.60	0-300

Reference range **(Klem *et al.* 2010; MSDVetmanual.com).**

Changes in specific biomarkers of oxidative stress in group H when compared to group N included an increase in hydrogen peroxide generation, nitric oxide contents and malondialdehyde levels, with a decrease in superoxide dismutase activity and glutathione content **(Table 6).**

Table 6: Oxidative stress biomarkers of two groups of exotic sows exposed to different environmental temperature in a tropical environment:

S/N	Parameters	Group H	Group N
1	GSH (µmol/mg protein)	$95.49±12.07^a$	$75.94±5.72^b$
2	GPx activity (units/mg protein)	55.63±8.99	48.19±3.65
3	GST (µmol/mg protein)	0.012±7.04	0.08±0.02
4	SOD (units/mg protein)	$14.52±2.19^a$	$10.44±0.42^b$
5	MDA (µmol/mg protein)	$2.29±0.20^b$	$7.79±1.32^a$
6	NPT (µmole/mg protein)	27.12±4.70	26.19±1.84
7	Thiol (µmole/mg protein)	$101.7±6.40^a$	$86.47±9.90^b$
8	H_2O_2 (mmole/min/mg protein)	$45.48±4.78^b$	$67.2±8.27^a$
9	NO (µmole/mg protein)	$1.40±0.28^b$	$5.54±0.90^a$

*Superscripts (a>b) indicates significant difference in corresponding values along the row at p<0.05.

GSH: Glutathione, GPx: Glutathione peroxidase, GST: Glutathione S-Transferase, SOD: Superoxide dismutase, MDA: Malondialdehyde, NPT: Non-Protein Thiol, THIOL: Protein Thiol, NO: Nitric Oxide, H_2O_2: Hydrogen peroxide.

There was a reduction in the parameters of sow productivity in the exotic sows exposed to higher environmental temperatures (Group H) compared to those exposed to moderate temperatures (Group N). There was a reduction in the number of farrowing events (N = 3.45±0.20; H = 3.00±0.19), the number of piglets at birth (N = 29.15±1.92; H = 27.95±2.44), and number of piglets at weaning (N = 27.65±1.89; H = 25.90±2.25), and an increase in the number of piglet deaths (N = 1.5±0.21; H = 2.05±0.42; **Table 7).**

Table 7: Productivity of two groups of exotic sows exposed to different environmental temperature in a tropical environment:

	Indicator	Description	Environmental Temperature level		Significance level
			Group N; MT (n=20)	Group H; HT(n=20)	
1	NFE	Mean±SD	3.45±0.20	3.00±0.19	0.731
		Range	2-5	2-4	
		Total (for 20 sows)	69	60	
2	NPB	Mean±SD	29.15±1.92	27.95±2.44	0.281
		Range	17-46	14-51	
		Total (for 20 sows)	583	559	
3	NPW	Mean±SD	27.65±1.89	25.90±2.25	0.489
		Range	16-45	14-46	
		Total (for 20 sows)	553	518	
4	NPM	Mean±SD	1.5±0.21	2.05±0.42	0.046
		Range	0-4	0-6	
		Total (for 20 sows)	30	41	
5	NPM (%)		5.1	7.3	

NFE: Number of farrowing events per sow in 24 months; NPB: Number of piglets at birth per sow in 24 months; NPW: Number of piglets at weaning per sow in 24 months; NPM: Mortality of piglets/sow in 24 months. MT: Moderate Temperature, HT: High temperature.

DISCUSSION

Previous investigations have established that factors in the environment, including temperature, relative humidity, solar radiation, and wind speed influence the performance of livestock **(Sejian *et al.*, 2018).** Therefore, maintaining an adequate indoor microclimate with sufficient thermal comfort is central to improving the welfare and health of intensively raised pigs. The housing design, construction, and facilities should support adequate heat transfer between the pigs and the environment, as excess heat transfer will lead to cold stress while insufficient transfer will lead to heat stress **(Lacetera, 2019).** In our study, we observed that the housing design, dimensions, and construction materials had low cost and low maintenance implications and were suited for a tropical environment where there is a need for sufficient air circulation for heat dissipation. The observed open-sided housing design is the model usually preferred in tropical environments **(Stender *et al.*, 2003; Godyń *et al.*, 2020)**, but such facilities should be upgraded with additional technology to improve the cooling of the animals in the face of rising ambient temperatures.

The roofing of the pig houses was made of a poor heat conductor which therefore reduced the rate of rise in indoor temperature during the day. We observed that the only difference in the design of the two buildings that was responsible for the difference in indoor temperature was the building orientation. The North-South oriented building allowed more access to direct sunrays at sunrise and sunset, thereby increasing the floor and, hence, the indoor temperature. It is established that housing designs that allow moderate access to direct sunrays have benefits, as the UVB radiation from sunlight aids the synthesis of vitamin D and influences bone health in pigs **(Turner and Anderson, 2012; Larson-Meyer *et al.*, 2017).** The open-sided housing also improves the pigs' well-being through improved ventilation and the feeling of outdoor experience. Higher indoor temperatures will reduce the efficiency of heat exchange between the sows and the environment, as heat exchange is done by heat gradient. The housing with the higher temperature was observed to have a lower humidity and a higher temperature-humidity index. The THI is an established measure of the risk of exposure of livestock to heat stress. While the pigs in the housing with a moderate temperature (THI: 72.99± 1.43), were within the thermo-neutral zone for sows (**Vermeer and Aarnink, 2023)**, the other group exposed to a higher temperature (78.40±1.49), were critically affected by heat stress and tending towards the dangerous limits based on the THI reference **(NOAA, 1976).** The sows exposed to higher temperatures were observed to have consistently higher skin surface temperature and respiratory rate, which were significantly higher than the other group. The increase observed in rectal temperature in this group of sows was not significant. This is because rectal temperature is a delayed indicator of heat stress (**Huynh and Aarnink, 2005).** The sows were observed to present other behavioural coping responses, including panting and wallowing, in drinkers in response to the higher indoor temperatures. These respiratory responses tend to be insufficient in pigs because they do not have functional sweat glands and possess relatively small lungs; therefore, they cannot efficiently dissipate high heat loads through enhanced respiratory and sweating rates like some other livestock **(D'Allaire *et al.*, 1996; Sejian *et al.*, 2018).**

We observed that exposure of a larger floor area to direct sunlight was associated with a higher indoor temperature, as expected. Maintaining an optimal floor temperature is important in heat exchange, as pigs are known to spend up to 79% of the day (19 hours) resting with a large surface area of their body in contact with the floor **(Huynh and Aarnink, 2005).** In group housing for pigs, there should be provision of adequate floor space to aid their resting behaviours and heat exchange. Strategies and facilities for optimal thermal control should be incorporated into farm operations and housing design in pig husbandry. Some of the cooling strategies that may be adopted include increased water supply, skin wetting, nutritional manipulations, adequate ventilation, increased floor space, adequate insulation, and the provision of shades **(Adebiyi *et al.*, 2017).** Facilities for fogging, misting or showers, as well as evaporative pads or fans, have been effectively used in various pig housing facilities to improve heat loss **(Godyń *et al.*, 2020),** with each having its merits and demerits.

In our study, water was provided in open drinkers ad-libitum and the sows cooled by wallowing in the drinkers. The use of drinkers as wallows for pigs conserves more water than sprinkling but may aid the buildup of pathogens in the drinkers. We observed that the sows exposed to high ambient temperatures had a higher rectal temperature, showing progression towards excessive heat accumulation. Heat accumulation in the body has been linked to immune dysregulation and elevated oxidant production, which results in cellular oxidative stress and lipid peroxidation of cell membranes, making farm animals more susceptible to infectious diseases and having a higher mortality rate **(Varasteh *et al.*, 2015; Patra and Kar, 2021).** Additionally, the haematological investigation revealed an increase in PCV and Hb concentrations under heat stress. Previous reports have also observed an association between heat stress and an increase in PCV and Hb concentrations in farm animals **(Okoruwa, 2014; Rana *et al*., 2014; Chaudhary *et al.*, 2015).** The findings were attributed to some factors, including the need for more haemoglobin to meet the demand for an increase in oxygen circulation during panting or because of reduced blood volume associated with dehydration.

Serum biochemistry revealed a range of metabolic changes in response to high ambient temperatures. Although most of the values were within reference ranges, comparatively, there was a decrease in the levels of sodium, chloride, and bicarbonate, with an increase in blood urea nitrogen, creatinine, aspartate aminotransferase (AST), alanine aminotransferase (ALT) and alkaline phosphatase (ALP) in the heat-stressed sows. The metabolic changes reveal tendencies for kidney and liver damage in pigs exposed to heat stress. These findings of a rise in liver enzymes have also been reported in other animals, including broiler chickens **(Hosseini-Vashana *et al.*, 2019)**, sheep and goats **(Nazifi *et al.*, 2003; Gupta *et al.*, 2013; Shilja *et al.*, 2016)** and pigs (**Lu *et al.*, 2014**). An increase in hematocrit level and BUN are established indicators of dehydration, which accompanies heat stress **(Rana *et al*., 2014).** Prolonged exposure of sows to heat stress will ultimately reduce their productivity while increasing the cost of production due to expenses on disease control **(Patra and Kar, 2021).**

Factors that initiate an increase in the generation of reactive oxygen species (ROS) or reactive nitrogen species (RNS) beyond their rate of neutralisation by antioxidants lead to oxidative stress **(Sirini and Amarakoon, 2017).** There are several antioxidants produced in the body to catalyse reactions that neutralize free radicals to prevent free radical-induced cell damage **(Gupta *et al.*, 2013).** The more important enzymatic antioxidants include superoxide dismutase (SOD), glutathione peroxidase

(GPx), glutathione reductase, and catalase (CAT), while the non-enzymatic antioxidants include ascorbic acid (Vitamin C), α-tocopherol (Vitamin E), glutathione (GSH), carotenoids, flavonoids and others **(Valko *et al.*, 2006).** We observed more disruptions in the oxidative balance in sows exposed to high temperatures when compared to those exposed to moderate temperatures. There was a substantial generation of hydrogen peroxide and nitric oxide. There was also an increase in the marker of lipid peroxidation, Malondialdehyde and a decrease in superoxide dismutase and glutathione. This is like the findings in heat-stressed broilers **(Tang *et al.*, 2022).** There was a similar finding but with lower SOD activity in pigs exposed to acute heat stress **(Bing *et al.*, 2023).** High ambient temperatures evidently reduce the efficiency of the antioxidant systems in sows.

Several previous studies have demonstrated the benefits of antioxidant supplementation in animals exposed to high temperatures. Some have shown the benefits of certain plant extracts, by-products, and phenolic compounds in alleviating lipid peroxidation and increasing the concentrations of antioxidant enzymes and total antioxidant capacity in different animal species **(Lu *et.*, 2014; Hassan *et al.*, 2016; Hosseini-Vashana *et al.*, 2019; Ao and Kim, 2020; Mu *et al.*, 2021; Urkmez and Biricik, 2022).** Therefore, in pig husbandry in tropical environments, the use of antioxidant supplements should be embraced to improve pig health, in addition to efficient housing.

The pride of the pig is their high fecundity and faster growth rate beyond most other livestock. Pigs are choice production animal for achieving animal protein security globally and are increasingly being embraced as such in Nigeria **(Omotosho *et al.*, 2016).** Despite the expected fecundity and growth performance of the exotic breeds of pigs, their performance while in production over successive generations in the tropics has been observed to reduce with time. This may be due to the suboptimal management conditions, which are rife in the husbandry systems, and the influence of tropical animal diseases. We observed reduced productivity in large white breeds of sows that were exposed to high environmental temperatures. There was a decrease in the number of farrowing events and the number of piglets at birth, while there was an increase in piglet mortality, leading to a reduced number of piglets at weaning. It is known that an increase in free radicals adversely affects reproduction in animals through damage to sperm and oocyte DNA, disruption of testicular functions, dysfunction of the ovary and endometrium, and a decrease in fertilization rate **(Zhong and Zhou, 2013; Sirini and Amarakoon, 2017).** Free radicals are also involved in the pathophysiology of preeclampsia **(Buhimschi *et al.*, 1998),** endometriosis **(Uchiide *et al.*, 2002),** birth defects and infertility **(Cutler *et al.*, 2006; Celi, 2011)** and increase the risk of abortions in gestating sows **(Zhong and Zhou, 2013).**

There was also an increase in mortality, leading to a reduced number of weaned piglets in the heat-stressed group. Contributory to this finding is the influence of free radicals in utero and in the pre-weaning period. Heat stress in late gestation reduces umbilical oxygen supply to the newborn, with an associated higher risk of piglet stillbirth and impairment on neonatal survivability and development **(Johnson and Baumgard, 2019; Zhao *et al.*, 2022).** Pigs are also known to reduce voluntary feeding to reduce digestion and metabolic heat production, leading to poor performance **(Cui *et al.*, 2016).** The deleterious effects of heat stress on the welfare, health and productivity of pigs are many **(Godyń *et al.*, 2020)**, with impacts in pregnancy, the nursing period and throughout all stages of production. Our findings provide more insights into the contributing factors to some of the previously reported disease occurrences in pigs in Nigeria **(Abiola *et al.*, 2017; Igbokwe and Maduka, 2018; Ogundijo *et al.*, 2023)** and also provide useful information for adjusting pig housing conditions in the tropics for improved productivity.

CONCLUSION

In conclusion, the ongoing climate change demands a critical review of pig husbandry systems and housing facilities especially in the tropics, where high ambient temperatures subsists for an extended period of the year. Utilizing effective housing that can provide a stable and suitable microclimate for pig production throughout the year is desirable. The exposure of sows to high environmental temperatures causes heat stress, which interferes with their welfare, health, and productivity. For improved welfare, health, and productivity of exotic pigs in the tropics, optimal housing conditions and antioxidant-supplemented nutrition are recommended.

Acknowledgment

We appreciate the management and staff of the swine unit of the Teaching and Research farm, University of Ibadan for providing the facilities for the investigation and Mr. Jacob Olayemi for his support.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

ABIOLA, J. O., OMOTOSHO, O. O., and IGADO, O. O., 2017. Meningoencephalocele, bilateral anorchia with radial and fibular hemimelia in a piglet. Journal of Morphological Science, 34 (3) p. 152-155. https://doi.org/10.4322/jms.107716

ABDEL-AZIZ, H. O., HAMDAN, H. M., and RAGAB, E. E., 2018. The histological effects of zinc oxide nanoparticles on the kidney of adult male rabbits. Sohag Medical Journal, 22(2), 297-301. https://doi.org/10.21608/smj.2018.40959

AHMED, M. O., OGEDENGBE, K., and LAWAL, N. S., 2022. Innovative Trend Analysis of Hydro-Meteorological variables in Ibadan, Nigeria. Journal of Fundamental and Applied Sciences. 14(1), 288-311. doi: http://dx.doi.org/10.4314/jfas.v14i1.15

AJAYI, A. E., and OLUFAYO, A. A., 1998. The sequence of wetanddrydays at Ibadan and Onne (sub-humid zone of Nigeria). Nigerian journal of technology 21(1):38-44

AO, X., and KIM, I.H., 2020. Effects of grape seed extract on performance, immunity, antioxidant capacity, and meat quality in Pekin ducks. Poultry Science 99, 2078–2086. https://doi.org/10.1016/j.psj.2019.12.014

ADEBIYI, O. A., MUIBI, M. A., and ALABA, O., 2017. Performance and behavioural characteristics of Pigs as affected by types and duration of evaporative cooling. Nigerian Journal of Animal Science 2017 (2):103 – 113

BING XIA, WEIDA WU, WEI FANG, XIAOBIN WEN, JINGJING XIE, and HONGFU ZHANG, 2022. Heat stress-induced mucosal barrier dysfunction is potentially associated with gut microbiota dysbiosis in pigs, Animal Nutrition 8. Pp. 289-299, https://doi.org/10.1016/j.aninu.2021.05.012.

BROWN-BRANDL, T. M., R. A. EIGENBERG, J. A. NIENABER, and S. D. KACHMAN. 2001. Thermoregulatory profile of a newer genetic line of pigs. Livestock Production Science 71: 253-260. https://doi.org/10.1016/S0301-6226(01)00184-1

BUHIMSCHI, I. A., SAADE, G. R. CHWALISZ, K., and GARFIELD, R. E., 1998. The nitric oxide pathway in preeclampsia: pathophysiological implications. Human Reproduction Update 4: 25-42. https://doi.org/10.1093/humupd/4.1.25

CELI, P. 2011. Biomarkers of oxidative stress in ruminant medicine. Immunopharmacology and Immunotoxicology 33: 233-240. https://doi.org/10.3109/08923973.2010.514917

CHAUDHARY, S. S., SINGH, V. K., UPADHYAY, R. C., PURI, G., ODEDARA, A. B., and PATEL, P. A., 2015. Evaluation of physiological and biochemical responses in different seasons in Surti buffaloes. Veterinary World 8, 727–731. https://doi.org/10.14202/vetworld.2015.727-731

CUI, Y., HAO, Y., LI J., BAO, W., LI, G., GAO, Y., and **GU, X., 2016.** Chronic Heat Stress Induces Immune Response, Oxidative Stress Response, and Apoptosis of Finishing Pig Liver: A Proteomic Approach. International Journal of Molecular Sciences 17(5) :393. https://doi.org/10.3390/ijms17050393.

CUTLER, R. S., FAHY, V. A., CRONIN, G. M., and SPICER, E. M., 2006. Preweaning mortality. In BE Straw, JJ Zimmerman, S D'Alliare, DJ Taylor, eds. Diseases of Swine, 9th ed. Ames, IA: Blackwell Publishing, pp. 1005–1006.

D'ALLAIRE, S., DROLET, R., and BRODEUR, D., 1996. Sow mortality associated with high ambient temperatures. The Canadian Veterinary Journal 37, 237–239. PMID: 8801022, PMCID: PMC1576357

EGBINOLA, C. N., and AMOBICHUKWU A. C., 2013. Climate Variation Assessment Based on Rainfall and Temperature in Ibadan, South-Western, Nigeria. Journal of Environment and Earth Science. Vol. 3, No.11

ELLMAN, G. L. 1959. Tissue sulfhydryl groups. Arch Biochem Biophys 82(1):70–77. https://doi.org/10.1016/0003-9861(59)90090-6

GODYŃ, D., HERBUT, P., ANGRECKA, S., and CORRÊA VIEIRA, F. M., 2020 Use of differentcooling methods in pig facilities to alleviate the effects of heatstress—a review. Animals. 10(9):1459. https://doi.org/10.3390/ani10091459

GONYOU, H.W., LERMAY, S.P., and ZHANG, Y., 2006. Effects of the environment on productivity and disease. In BE Straw, JJ Zimmerman, S D'Allaire, DJ Taylor, eds. Diseases of Swine, 9th ed. Ames, IA: Blackwell Publishing, pp. 1027–1038.

GUPTA, M., KUMAR, S., DANGI, S. S., and JANGIR, B. L., 2013. Physiological, biochemical and molecular responses to thermal stress in goats. International Journal of Livestock Research 3, 27–38. https://doi.org/10.5455/ijlr.20130502081121

HABIG, W. H., PABST, M. J., and JACOBY, W. B., 1974. Glutathione-S-transferase activity: The first enzymatic step in Mercapturic Acid formation. Journal of Biological Chemistry, 249, 7130–7139. PMID: 4436300

HASSAN, F. A., MAHROSE, K.M., and BASYONY, M.M., 2016. Effects of grape seed extract as a natural antioxidant on growth performance, carcass characteristics and antioxidant status of rabbits during heat stress. Archives of Animal Nutrition 70 (2), 141–154. https://doi.org/10.1080/1745039x.2016.1139609.

HOSSEINI-VASHANA, S. J., SAFDARI-ROSTAMABADA, M., PIRAYB, A. H., and SARIR, H., 2019. The growth performance, plasma biochemistry indices, immune system, antioxidant status, and intestinal morphology of heat stressed broiler chickens fed grape (Vitis vinifera) pomace. Animal Feed Science and Technology 259, 114343. https://doi.org/10.1016/j.anifeedsci.2019.114343

HUYNH, T. T. T., and AARNINK, A. J. A., 2005. Heat stress in growing pigs. available at https://research.wur.nl/en/publications/heat-stress-in-growing-pigs. Accessed on 14 December, 2023.

HUYNH, T. T. T., AARNINK, A. J. A., TRUONG, C. T., KEMP B., and VERSTEGEN, M. W. A., 2006: Effects of tropical climate and water-cooling methods on growing pigs' responses. Livestock Science, 104(3): 278-291. https://doi.org/10.1016/j.livsci.2006.04.029

IGBOKWE, I. O., and MADUKA, C. V., 2018. Disease burden affecting pig production in Nigeria: Review of current issues and challenges. Revue D'élevage et de Médecine Vétérinaire Des Pays Tropicaux. 71 (1-2): 87-95 https://doi.org/10.19182/remvt.31290

JOHNSON, J. S., and BAUMGARD, L. H., 2019. PHYSIOLOGY SYMPOSIUM: Postnatal consequences of in utero heat stress in pigs. Journal of Animal Science 97(2):962-971. https://doi.org/10.1093/jas/sky472.

JOLLOW, D. J., MITCHELL, J. R., and ZAMPAGLIONE, N., 1974. Bromobenzene-induced liver necrosis. Protective role of glutathione and evidence for 3, 4- bromobenzene oxide as the hepatotoxic metabolite. Pharmacology 11(3): 151–169. https://doi.org/10.1159/000136485 32.

KLEM, T. B., BLEKEN, E., MORBERG, H., THORESEN, S. I., and FRAMSTAD, T., 2010. Hematologic and biochemical reference intervals for Norwegian crossbreed grower pigs. Veterinary Clinical Pathology 39:221–226. https://doi.org/10.1111/j.1939-165X.2009.00199.x.

LACETERA N 2019. Impact of climate change on animal health and welfare. Animal Frontiers 9, 26–31. https://doi.org/10.1093/af/vfy030

LARSON-MEYER, D. E., INGOLD, B. C., FENSTERSEIFER, S. R., AUSTIN, K. J., WECHSLER, P. J., HOLLIS, B. W., MAKOWSKI, A. J., and ALEXANDER, B.M., 2017 Sun exposure in pigs increases the vitamin D nutritional quality of pork. PLoS One. 12(11):e0187877. https://doi.org/10.1371/journal.pone.0187877.

LU, T., HARPER A., ZHAO J., ESTIENNE M., and DALLOUL R., 2014. Supplementing antioxidants to pigs fed diets high in oxidants: I. Effects on growth performance, liver function, and oxidative status. Journal of animal science 92: 5455-5463. https://doi.org/10.2527/jas.2013-7109

MAYORGA, E. J.; DAVID, R., RAMIREZ, B. C., ROSS J. W. and BAUMGARD, L. H. Heat stress adaptations in pigs. Animal Frontiers. v. 9. No. 1. p. 54–61. 2019. https://doi.org/10.1093/af/vfy035

MISRA H. P. and FRIDOVICH I. 1972. The role of superoxide anion in the autoxidation of epinephrine and a simple assay for superoxide dismutase. Journal of Biological Chemistry 247(10):3170–3175. https://doi.org/10.1016/S0021-9258(19)45228- 9

MSDVetmanual 2023, Serum Biochemical Analysis Reference Ranges available at https://www.msdvetmanual.com/multimedia/table/serum-biochemical-analysis-reference-range. Accessed on November 29, 2023.

MU, C., HAO, X., ZHANG, X., ZHAO, J. and ZHANG, J. 2021. Effects of high-concentrate diet supplemented with grape seed procyanidins on the colonic fermentation, colonic morphology, and inflammatory response in lambs. Animal Feed Science and Technology. 281, 115118 https://doi.org/10.1016/j.anifeedsci.2021.115118.

MUTUA J. Y., MARSHALL K., PAUL B. K. and NOTENBAERT A. M. O. 2020. A methodology for mapping current and future heat stress risk in pigs. Animal, 14(9). https://doi.org/10.1017/S1751731120000865.

NAZIFI S., SAEB M., ROWGHANI E. and KAVEH K. 2003. The influences of thermal stress on serum biochemical parameters of Iranian fat-tailed sheep and their correlation with triiodothyronine (T3), thyroxine (T4) and cortisol concentrations. Comparative Clinical Pathology 12, 135–139. https://doi.org/10.1007/s00580-003-0487-x

NOAA: National Oceanic and Atmospheric Administration. 1976. Livestock Hot Weather Stress. Operations Manual Letter c-31- 76. Kansas City.

OGUNDIJO O. A., OMOTOSHO O. O., AL-MUSTAPHA A. I., ABIOLA J. O. AWOSANYA E. J., ODUKOYA A, OWOICHO S., OYEWO M., IBRAHIM A. ORUM T. G., NANVEN M. B., BOLAJOKO M. B., LUKA P. and ADEYEMO O. K. 2023. A multi-state survey of farm-level preparedness towards African swine fever outbreak in Nigeria, Acta Tropica, 246. https://doi.org/10.1016/j.actatropica.2023.106989

OKORUWA M. I 2014. Effect of heat stress on thermoregulatory, live bodyweight and physiological responses of dwarf goats in southern Nigeria. European Science Journal 10, 255–264. Corpus ID: 261543298

OLALEYE, S. B., ADARAMOYE, O. A., ERIGBALI, P. P., and ADENIYI, O. S., 2007. Lead exposure increases oxidative stress in the gastric mucosa of HCl/ ethanol-exposed rats. World Journal of Gastroenterology, 13, 5121–5126. https://doi.org/10.3748/wjg.v13.i38.5121.

OMOTOSHO O.O, EMIKPE B.O., LASISI O. T and OLADUNJOYE V. O. 2016. Pig Slaughtering in Southwestern Nigeria: Peculiarities, Animal Welfare Concerns and Public Health Implications. African Journal of Infectious Diseases. 10(2): 146 – 155. https://doi.org/10.21010/ajid.v10i2.11

OYAGBEMI, A. A., OMOBOWALE, T. O., AKINRINDE, A. S., SABA, A. B., OGUNPOLU, B. S., and DARAMOLA, O., 2015. Lack of reversal of oxidative damage in renal tissues of lead acetate-treated rats. Environmental Toxicology, 30, 1235–1243. https://doi.org/10.1002/tox.21994

PATRA, A.K. and KAR, I., 2021. Heat stress on microbiota composition, barrier integrity, and nutrient transport in gut, production performance, and its amelioration in farm animals, 63 (2), 211–247. https://doi.org/10.5187/jast.2021.e48.

PHS (Public Health Service) (2015). Public health service policy on humane care and the use of laboratory animals. Washington, DC: US Department of Health and Human Services. Available at https://olaw.nih.gov/policies-laws/phs-policy.htm accessed 10 December 2022

POLLMANN, D. S. 2010. Seasonal effects on sow herds: industry experience and management strategies. Journal of Animal Science 88 (Suppl. 3):9 (Abstr) available at https://www.asas.org/docs/midwest/2010mwabstract.pdf?sfvrsn=5372c05e_2

PRAGNA, P., SEJIAN, V., SOREN, N.M., BAGATH, M., KRISHNAN, G., BEENA, V., DEVI, P.I., and BHATTA, R., 2018. Summer season induced rhythmic alterations in metabolic activities to adapt to heat stress in three indigenous (Osmanabadi, Malabari and Salem Black) goat breeds. Biological Rhythm Research 49, 551–565. https://doi.org/10.1080/09291016.2017.1386891

RANA, M. S., HASHEM, M. A., SAKIB, M. N., and KUMAR, A., 2014. Effect of heat stress on blood parameters in indigenous sheep. Journal of Bangladesh Agriculture 12, 91–94. https://doi.org/10.3329/jbau.v12i1.21253

RENAUDEAU, D., A. COLLIN, S. YAHAV, V. DE BASILIO, GOURDINE, J. L., and COLLIER, R. J., 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal 6:707–728. https://doi.org/10.1017/s1751731111002448

RAUW, W. M., MAYORGA, E. J., LEI, S. M., DEKKERS, J. C. M., PATIENCE, J. F., GABLER, N. K., LONERGAN, S. M., and BAUMGARD, L H., 2017. Effects of Diet and Genetics on Growth Performance of Pigs in Response to Repeated Exposure to Heat Stress. Front. Genet. 8:155. https://doi.org/10.3389/fgene.2017.00155

ROJAS-DOWNING, M. M., NEJADHASHEMI, A. P., HARRIGAN, T., and WOZNICKI, S. A., 2017. Climate change and livestock: impacts, adaptation, and mitigation. Climate Risk Management 16, 145–163. https://doi.org/10.1016/j.crm.2017.02.001

ROTRUCK, J. T,, POPE, A. L., GANTHER, H. E., SWANSON, A. B., HAFEMAN, D. G., and HOEKSTRA, W. G., 1973 Selenium: biochemical role as a component of glutathione peroxidase. Science 179: 588e90. https://doi.org/10.1126/science.179.4073.588

SEJIAN, V., BHATTA, R., GAUGHAN, J.B., DUNSHEA, F.R., and LACETERA, N., 2018. Review: Adaptation of animals to heat stress, Animal, Volume 12, Supplement 2, Pages s431-s444, ISSN 1751-7311, https://doi.org/10.1017/S1751731118001945.

SHILJA, S., SEJIAN V., BAGATH, M., MECH, A., DAVID, C. G., KURIEN, E. K., VARMA, G., and BHATTA, R., 2016. Adaptive capability as indicated by behavioural and physiological responses, plasma HSP70 level, and PBMC HSP70 mRNA expression in Osmanabadi goats subjected to combined (heat and nutritional) stressors. International Journal of Biometeorology 60, 1311–1323. https://doi.org/10.1007/s00484-015-1124-5

SIRINI, A.M., and AMARAKOON, B. K., 2017. Regulation of oxidative stress in weaned piglets challenged with Escherichia coli. A Thesis submitted to Faculty of Graduate studies of The University of Manitoba.https://mspace.lib.umanitoba.ca/items/52199d05-9e68-4d0f-9a77-dda5f1627475

STENDER, D. R., HARMON, J. D., WEISS, J. D., and COX, D., 2003. Comparison of different styles of swine finishing facilities within a uniform production system. Appl. Eng. Agric. 19, 79–82. https://doi.org/10.13031/2013.12734

TANG, L. P., LIU, Y. L., ZHANG, J. X., DING, K. N., LU, M. H., and HE, Y.M., 2022. Heat stress in broilers of liver injury effects of heat stress on oxidative stress and autophagy in liver of broilers. Poultry Science 101(10). https://doi.org/10.1016/j.psj.2022.102085

TURNER, A. G., ANDERSON, P. H., and MORRIS, H. A., 2012. Vitamin D and bone health. Scandinavian Journal of Clinical and Laboratory Investigation 243: 65–72. **https://doi.org/10.3109/00365513.2012.681963**

UCHIIDE, I., IHARA, T., and SUGAMATA, M., 2002. Pathological evaluation of the rat endometriosis model. Fertility and sterility 78: 782-786. https://doi.org/10.1016/s0015-0282(02)03327-7.

URKMEZ, E., and BIRICIK, H., 2022. Grape seed extract supplementation in heat-stressed preweaning dairy calves: I. Effects on antioxidant status, inflammatory response, hematological and physiological parameters, Animal Feed Science and Technology, 292. https://doi.org/10.1016/j.anifeedsci.2022.115421.

VALKO, M., RHODES, C., MONCOL, J., IZAKOVIC, M., and MAZUR, M., 2006. Free radicals, metals and antioxidants in oxidative stress-induced cancer. Chemico-biological interactions 160: 1-40. https://doi.org/10.1016/j.cbi.2005.12.009.

VARASTEH, S., BRABER, S., AKBARI, P., GARSSEN, J., and FINK-GREMMELS, J., **2015** Differences in susceptibility to heat stress along the chicken intestine and the protective effects of galacto-oligosaccharides. PLOS ONE. 10:e0138975. https://doi.org/10.1371/journal.pone.0138975.

VARSHNEY, R., and KALE, R. K., 1990. Effect of calmodulin antagonists on radiation induced lipid peroxidation in microsomes. International Journal of Biological Macromolecules 158: 733-441. https://doi.org/10.1080/09553009014552121

WOLFF S. F. 1994 Ferrous ion oxidation in the presence of ferric ion indicator xylenol orange for measurement of hydrogen peroxides. Methods Enzymol 233(2):182–189. https://doi.org/10.1016/0003-2697(92)90122-n

VERMEER, H. M., and AARNINK A. J. A., 2023. Review on heat stress in pigs on farm. EU Reference Centre for Animal Welfare (Pigs). Wageningen Livestock Research, The Netherlands. Available at https://edepot.wur.nl/587090 .

ZHAO, W, ARTAIZ, O. IQBAL, Y., LE, H.H., DIGIACOMO, K, LEURY, B.J., FOTHERGILL, L.J., FURNESS, J.B., LIU, F., GREEN, M.P., FINGER, B.J., NAVARRO, M., ROURA, E., D'SOUZA, D.N., DUNSHEA, F.R., PLUSH, K.J., and COTTRELL, J.J., 2022. Heat stress of gilts around farrowing causes oxygen insufficiency in the umbilical cord and reduces piglet survival, animal, 16 (11). https://doi.org/10.1016/j.animal.2022.100668.

ZHONG, R. Z., and ZHOU, D.W., 2013. Oxidative stress and role of natural plant derived antioxidants in animal reproduction. Journal of Integrative Agriculture 12: 1826-1838. https://doi.org/10.1016/S2095-3119(13)60412-8

ZULOVICH, J. M. 2012. Effect of the Environment on Health. In Diseases of Swine, Tenth Edition. Edited by Jeffrey J. Zimmerman, Locke A. Karriker, Alejandro Ramirez, Kent J. Schwartz, Gregory W. Stevenson. pp 60-66. John Wiley & Sons, Inc. Published 2012 by John Wiley & Sons, Inc.

How to cite this article:
Oladipo Olufemi Omotosho, Olusola Fowowe, John Olusoji Abiola, **Ademola Adetokunbo Oyagbemi and Temidayo Olutayo Omobowale, 2024.** High Environmental Temperature Induces Oxidative Stress, Reduced Sow Productivity and Increased Piglet Mortality. Journal of Applied Veterinary Sciences, 9 (1): 41-54. https://dx.doi.org/10.21608/javs.2024.255494.1300