

ORIGINAL ARTICLE

Rabbits and Rodents

Herbal inclusions ameliorate effect of heat stress on haematology, proinflammatory cytokines, adipokines and oxidative stress of weaned rabbit does in humid tropics

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Abstract

A study was designed to evaluate the effect of *Moringa oleifera*, *Phyllanthus amarus* and *Viscum album* leaf meal as herbal inclusions to alleviate the detrimental outcomes of heat stress in weaned female rabbits. Forty (40) weaned rabbit does (527.99 ± 10.35 g; 28 days old) were randomly allotted to four dietary groups consisting of Diet 1 (control diet; without leaf meal), Diets 2 (supplemented with 10% *V. album*); 3 (supplemented with 10% *M. oleifera*) and 4 (supplemented with 10% *P. amarus*) in an 84 days trial at the peak of heat stress in Southwest Nigeria. At the end of the trial, blood samples were collected to assess physiological responses and oxidative status of the rabbit does. The results obtained revealed that rabbit does were exposed to heat stress; rabbit does fed control diet had higher leucocyte and neutrophil/lymphocyte ratio compared to rabbit does fed on herbal inclusions. The herbal inclusions enhanced oxidative stability of rabbit does by lowering lipid peroxidation and enhancing antioxidant activities during heat stress conditions. Rabbit does fed control-based diet had significantly higher heat shock protein 70, leptin and adiponectin compared to rabbit does on *M. oleifera*, *P. amarus* and *V. album* supplemented diets. The herbal inclusions tend to suppress proinflammatory cytokines in rabbit does during heat stress condition. In conclusion, the herbal inclusions suppress inflammation, adipokines and promotes oxidative stability of rabbit does exposed to heat stress conditions.

KEYWORDS

heat stress, herbs, leptin, oxidative status, rabbit does

1 | INTRODUCTION

Global warming undoubtedly is a serious challenge facing livestock production in tropical climate, subjecting animals to heat stress condition, leading to multiple physiological alterations such as atypical

systemic immune and unequal expression of inflammatory molecules, and ignition of lipid peroxidation in cell membranes (Mehaisen et al., 2017). The body homeostasis activates endogenous cellular defense mechanism in an attempt to cope with heat stress that induces inflammation and oxidative stress (Jang et al., 2014). Heat

stress adversely influences the immunity of the animals and invokes inflammatory reactions (Hirakawa et al., 2020; Sheiha et al., 2020), which results in inadequate productive and reproductive performances due to altered animal behaviour hormonal imbalances, and higher free radical production (Abdelnour et al., 2021). Heat shock protein 70 (HSP70) is a heat shock protein that is stress induced. The ability of a cell to release HSP at high environmental temperature empowers it to withstand heat stress marshalling to the elevation of stress tolerance and coherently enhancing the survival rate of stressed cells (Shehata et al., 2020). The HSPs accumulation is associated with cell apoptosis resistance suggesting its importance to the survival of cells under stress (Shehata et al., 2020). HSP70 prevents cells from death mediated by reactive oxygen species and free radicals which explains the elevated levels of HSP70 when animals are exposed to heat stress conditions (Jiang et al., 2020). There is a notion that natural feed additives ameliorate the negative effects on heat stress of animals by improving the immune system, oxidative status and proinflammatory cytokines on stressed rabbits due to the antioxidant, antimicrobial and immune-booster effects of these herbal plants (Abdelnour et al., 2020). Several herbal plant extracts and its components have been reported to elevate anti-inflammatory IL-10 production, reducing proinflammatory IL-6 or TNF- α production (Mueller et al., 2010). Furthermore, *Moringa oleifera* has been reported to decrease the production of TNF- α , IL-6 and IL-8 in different disease conditions confirming its effectiveness in treatment of inflammation (Kou et al., 2018). *Phyllanthus amarus* contains phytonutrients that serve as healthy inclusions and growth enhancer in animal feed (Jimoh et al., 2020). *Viscum album* act effectively as antioxidants and peroxy radical scavengers, possess immunomodulatory, anti-inflammatory and antimicrobial effects (Jimoh, Ihejirika, Balogun, & Uwaeziozi, 2018). Previously, documentary evidences had established anti-inflammatory properties of *P. amarus* (Harikrishnan et al., 2018) and *V. album* (Hegde et al., 2011). Polyphenols have the ability to boost up the expression of stress response proteins and antioxidant enzymes, which can restrain reactive oxygen species (Hu et al., 2019). Therefore, this study aimed to assess the effects of herbal inclusions on haematology, serum oxidative stress, proinflammatory cytokines, adipokines of heat-stressed rabbit does.

2 | MATERIALS AND METHOD

2.1 | Experimental site

This study was carried out in South-Western agro-ecological zone of Nigeria from January to March, 2020. Severity of heat stress based on a combination of temperature and humidity (Temperature-Humidity Index [THI]) was established to peak in Southern Nigeria between February and March (Jimoh & Ewuola 2016; Jimoh & Ewuola, 2018; Jimoh, Oyeyemi, & Oyeyemi, 2021). At 08:00 h, 12:00 h and 18:00 h daily, temperature and relative humidity (RH) of the rabbitry unit was recorded using a Thermo-Hygrometer throughout the period of study. Daily records of the ambient temperature and RH were used to

compute the THI as outlined by Jimoh et al. (2017). Briefly, $THI = t - [(0.31 - 0.31 \times RH) (t - 14.4)]$. Where RH = relative humidity/100. t = ambient temperature. The values of THI obtained for the temperate and tropical region are classified as:

<27.8°C = absence of heat stress, 27.8–28.9°C = moderate heat stress, 28.9–30°C = severe heat stress and above 30°C = very severe heat stress.

2.2 | Phytonutrients processing and evaluation

Fresh *M. oleifera*, *P. amarus* and *V. album* leaves were harvested from an established orchard within the Ado-Ekiti metropolis of Ekiti State, Nigeria. The herbal plants were identified and indexed with herbarium voucher numbers; *V. album* UILH/002/084/1210/2021; *M. oleifera* UILH/001/1008/2021; *P. amarus* UILH/003/1109/2021. The fresh leaves were detached from twigs and shade-dried until it was crispy to touch while retaining their greenish coloration. The leaves were milled and stored in air-tight containers until when added into the animal diets.

2.3 | Experimental animals and management

Forty (40) weaned female rabbits with average weight of 527.99 ± 10.35 at 4 weeks old were used for the experiment. The rabbits were randomly assigned to the four (4) dietary groups in five (5) replicates of two (2) does per replicate; and they were housed individually in a Completely Randomized Design for a 12-week feeding trial.

2.3.1 | Experimental diet

The four experimental diets were formulated to meet the nutrient requirement for growing rabbit based on the National Research Council (2012) recommendation. The leaf meals (test ingredients) were added and mixed thoroughly with other feedstuffs and formulated according to each groups inclusion rate. Diet 1 (control) without the leaf meal (the control diet; and Diets 2, 3 and 4 contained 10% *V. album* (Mistletoe: MILM), 10% *M. oleifera* (MOLM) and 10% *P. amarus* (PHLM), respectively, as shown in Table 1 (Jimoh, Oyeyemi, Okin-Aminu, et al., 2021). The diets were pelleted and fed at 4% of their body weight. Clean water and Animal feeds were added *ad libitum* throughout the 12 weeks feeding trial.

2.3.2 | Blood collection and analysis

At the end of the feeding trial, blood samples were collected from all the animals via jugular venipuncture into heparinized and plain bottles for evaluation. Samples in heparinized bottles were analyzed for packed cell volume (PCV), haemoglobin (HB), red blood cells,

TABLE 1 Gross composition of experimental diets (g/100 g).

Ingredient	Control	Moringa	Mistletoe	Phyllanthus
Rice bran	6	1	1	1
Salt	0.25	0.25	0.25	0.25
Wheat offal	5	5	5	5
Brewer dried grain	5.0	0	0	0
Grower premix	0.25	0.25	0.25	0.25
Maise	25	25	25	25
Methionine	0.40	0.40	0.40	0.40
Soyabean meal	17.0	17.0	17.0	17.0
Lysine	0.10	0.10	0.10	0.10
Bone meal	1.0	1.0	1.0	1.0
Groundnut hauluns	40.0	40.0	40.0	40.0
Moringa	0	10	10	0
Mistletoe	0	0	10	0
Phyllanthus	0	0	0	10
Vegetable oil	0.20	0.20	0.20	0.20
Total	100	100	100	100
Calculated nutrient composition				
Dry matter %	88.05	85.41	81.2	87.45
Crude protein %	16.47	16.58	17.94	17.667
Digestable energy kcal/kg	2721.6	2515.35	2479.6	2509.4
Ether extract %	3.344	3.022	3.754	2.419
Crude fibre %	16.5	17.325	15.378	16.32
Lysine %	1.0085	0.9385	0.9385	0.9385
Methionine %	0.7482	0.7162	0.7162	0.7162
Calcium %	1.5999	1.7479	1.7159	1.5979
Phosphorus %	0.4491	0.5181	0.5211	0.4211

white blood cells (WBC) and its differential counts using standard procedures. Samples in plain bottles were centrifuged; serum obtained was stored at -20°C for analysis.

2.3.3 | Proinflammatory cytokines and adipokines assay

Serum obtained were also assayed using different commercial ELISA kits according to the manufacturer's instructions for each assay. HSP70, Catalogue No: E0522Ra (Bioassay Technology Laboratory, www.bt-laboratory.com, 1008 Junjiang International), leptin, Catalogue No: E0561Ra (Bioassay Technology Laboratory, www.bt-laboratory.com, 1008 Junjiang International), interleukin 6 (IL-6), Catalogue No: E-EL-R0015 (Elabscience Biotechnology Inc),

TABLE 2 THI of rabbit pen.

THI range	THI @ 8:00 h	THI @ 12:00 h	THI @ 18:00 h
Average	24.05	30.89	30.15
Minimum	18.15	28.14	24.45
Maximum	32.63	33.04	33.26

Abbreviation: THI, temperature–humidity index.

adiponectin, Catalogue No: E0758Ra (Bioassay Technology Laboratory, www.bt-laboratory.com, 1008 Junjiang International), interleukin 1 Beta (IL-1 β), Catalogue No: E-EL-R0012 (Elabscience Biotechnology Inc), tumour necrosis factor alpha (TNF- α), Catalogue No: E-EL-R0019 (Elabscience Biotechnology Inc), interferon Gamma (IFN- γ), Catalogue No: E-EL-R0009 (Elabscience Biotechnology Inc) using enzyme-linked immunosorbent assay.

2.3.4 | Oxidative stress marker assay

Determination of serum total antioxidant capacity activities, superoxide dismutase (SOD), glutathione peroxidase, catalase (CAT) activities and lipid peroxidation assay according to Jimoh (2019) procedures.

2.4 | Statistical analysis

The statistical model applied is as follows: $Y_{ijl} = \mu + B_i + e_{ijl}$, where Y_{ijl} represents the value of haematological indices, oxidative stress, proinflammatory cytokines and adipokines measured in the l th animal; μ is the overall mean for each character; B_i is the fixed effect of i th herbal supplement administered and e_{ijl} is the random residual effect. For the experiment, $p < 0.05$ was declared as significant and experimental data values are presented as mean $\pm$ SEM (standard error mean) or pooled SEM. The experiment was replicated ten times and within experiment. Data obtained from the study was tested using generalized linear model procedure of one-way Analysis of variance according to statistical analysis software IBM SPSS 20.

3 | RESULT

3.1 | THI of rabbit pen

The THI of the rabbit pen is shown in Table 2. The THI obtained at 08:00 h indicate that the does were exposed to average THI values of 24.05 (absence of heat) with a range between 18.15 (absence of heat stress)–2.63 (very severe heat stress). At 12:00 h, average THI values obtained was 30.89 which indicates very severe heat stress with a range of THI of 28.14 (severe heat stress)–33.04 (very severe heat stress). The average THI value at 18:00 h was 33.26 (very severe heat

TABLE 3 Haematological indices of rabbit does fed herbal inclusions during heat stress condition.

Parameters	Control	MILM	MOLM	PHLM	SEM
Packed cell volume (%)	33.00 ^b	34.00 ^{ab}	36.67 ^a	31.33 ^b	0.73
Leucocytes ($\times 10^9$ /L)	12.60 ^a	8.00 ^{ab}	6.37 ^b	5.23 ^b	0.98
Erythrocyte ($\times 10^6$ /L)	4.63	4.73	5.50	4.50	0.29
Mean cell haemoglobin concentration (g/dL)	32.27	33.47	32.33	33.29	0.24
Mean cell volume (fL)	74.52	72.51	69.79	71.23	3.90
Mean cell haemoglobin (pg/cell)	24.84	24.17	23.26	23.74	1.30
Haemoglobin (g/dL)	11.00 ^b	11.33 ^{ab}	12.22 ^a	10.44 ^b	0.24
Neutrophils ($\times 10^9$ /L)	4.30 ^a	2.10 ^{ab}	1.87 ^b	1.38 ^b	0.39
Lymphocytes ($\times 10^9$ /L)	8.15 ^a	5.85 ^b	4.41 ^{bc}	3.82 ^c	0.74
Monocytes ($\times 10^9$ /L)	0.15 ^a	0.06 ^{ab}	0.05 ^{ab}	0.03 ^b	0.04
Neutrophil/lymphocyte ratio	0.68 ^a	0.36 ^b	0.46 ^{ab}	0.45 ^{ab}	0.09

Note: a, b, ab, bc, c mean in the same row with different superscripts are significantly ($p < 0.05$) different. Diets ($n = 10$ /treatment; 100% females). Abbreviations: MILM, diet with mistletoe leaf meal; MOLM, diet with moringa leaf meal; PHLM, diet with phyllanthus leaf meal; SEM, standard error of mean.

stress), and a range of values 24.45 (absence of heat stress)–30.15 (very severe heat stress) were recorded.

3.2 | Haematological indices of heat-stressed does fed on herbal inclusions

Haematological indices of rabbit does fed herbal inclusions during heat stress condition is shown in Table 3. Rabbit does fed *M. oleifera* (MOLM) diet had significantly ($p < 0.05$) higher PCV and HB than those fed the control diet, and *P. amarus* (PHLM) group. The PCV and haemoglobin of does on MILM was not significantly ($p > 0.05$) different from does on other treatments. Erythrocyte, MCV, MCH and MCHC were not significantly ($p > 0.05$) affected by the treatments. Rabbit does fed control diets had significantly ($p < 0.05$) higher leucocyte, its differential counts and neutrophil/lymphocyte ratio compared to rabbit does fed on MILM, PHLM and MOLM inclusions.

3.3 | Proinflammatory cytokines of heat-stressed does fed on the herbal supplement

Proinflammatory cytokines of rabbit does fed on herbal supplement during heat stress condition is shown in Table 4. IL-6 of does fed control were significantly ($p < 0.05$) higher than does on PHLM. IL-1 β

TABLE 4 Proinflammatory cytokines of rabbit does fed herbal inclusions during heat stress condition.

	Control	MILM	MOLM	PHLM	SEM
Interleukin 6 (ng/L)	129.09 ^a	63.68 ^{ab}	62.26 ^{ab}	44.19 ^b	16.70
Interleukin 1 β (pg/mL)	3.29 ^a	0.52 ^b	0.63 ^b	1.04 ^{ab}	0.63
Tumour necrosis factor α (pg/mL)	94.99 ^a	60.04 ^b	61.09 ^{ab}	61.47 ^{ab}	7.49
Interferon γ (pg/mL)	29.25 ^a	21.59 ^{ab}	20.19 ^b	21.28 ^{ab}	1.09

Note: a, b, ab, mean in the same row with different superscripts are significantly ($p < 0.05$) different. Diets ($n = 10$ /treatment; 100% females). Abbreviations: MILM, diet with mistletoe leaf meal; MOLM, diet with moringa leaf meal; PHLM, diet with phyllanthus leaf meal; SEM, standard error of mean.

TABLE 5 Adipokines of rabbit does fed herbal inclusions during heat stress condition.

	Control	MILM	MOLM	PHLM	SEM
Heat shock protein 70 (ng/mL)	0.32 ^a	0.21 ^{ab}	0.19 ^b	0.23 ^{ab}	0.03
Leptin (ng/mL)	3.30 ^a	1.62 ^b	1.56 ^b	1.70 ^{ab}	0.44
Adiponectin (mg/L)	16.10 ^a	14.08 ^{ab}	14.43 ^{ab}	12.70 ^b	0.64

Note: a, b, ab, mean in the same row with different superscripts are significantly ($p < 0.05$) different. Diets ($n = 10$ /treatment; 100% females). Abbreviations: MILM, diet with mistletoe leaf meal; MOLM, diet with moringa leaf meal; PHLM, diet with phyllanthus leaf meal; SEM, standard error of mean.

of does on control were statistically ($p > 0.05$) similar to does on PHLM and the significantly ($p < 0.05$) least values were recorded in does on MILM and MOLM. TNF α was significantly ($p < 0.05$) higher in does fed on control diets compared to does on MILM. IFN- γ of does on control were significantly higher than does on MOLM group.

3.4 | Adipokines of rabbit does fed on herbal supplement

Adipokines of rabbit does fed herbal supplement during heat stress condition is shown in Table 5. Does fed the control diet had significantly higher HSP70, leptin and adiponectin compared to does fed MOLM, PHLM and MILM-supplemented diets.

3.5 | Oxidative status of heat-stressed does fed on herbal inclusions

Oxidative status of does fed on herbal inclusions during heat stress condition is shown in Table 6. Does fed on MOLM-based diets had significantly ($p > 0.05$) similar total antioxidant activity than does on MILM and PHLM, while the significantly ($p < 0.05$) least values were

TABLE 6 Oxidative status of rabbit does fed herbal inclusions during heat stress condition.

Parameter	Control	MILM	MOLM	PHLM	SEM
Total antioxidant activity (mmol/L)	0.92 ^b	3.08 ^{ab}	3.69 ^a	2.48 ^{ab}	0.19
Lipid peroxidation ($\times 10^{-5}$ MDA/mg protein)	2.19 ^a	0.77 ^{ab}	0.34 ^b	0.91 ^{ab}	0.28
Superoxide dismutase (U/min/mg protein)	2.67 ^b	10.11 ^a	10.50 ^a	5.33 ^{ab}	1.94
Glutathione peroxidase (mg GSH/min/mg protein)	46.52 ^b	115.61 ^a	93.72 ^{ab}	70.36 ^{ab}	13.19
Catalase (nm H ₂ O ₂ /min/mg protein)	0.21 ^b	1.43 ^{ab}	4.14 ^a	1.75 ^{ab}	0.54

Note: a, b, ab, mean in the same row with different superscripts are significantly ($p < 0.05$) different. Diets ($n = 10/\text{treatment}$; 100% females).

Abbreviations: MDA, malondialdehyde; MILM, diet with mistletoe leaf meal; MOLM, diet with moringa leaf meal; PHLM, diet with phyllanthus leaf meal; SEM, standard error of mean.

obtained in does on control. Lipid peroxidation of does on MOLM were statistically ($p < 0.05$) lower to does on control, while both groups were ($p > 0.05$) similar to does on MOLM and PHLM-based diets. Does on MILM and MOLM had significantly ($p < 0.05$) higher SOD activity than does on control. GPx of does on MILM-based diets were significantly ($p < 0.05$) higher than does on control group. Does fed on MOLM and PHLM had significantly ($p > 0.05$) similar values with does fed on MILM. CAT activity of does on control group was significantly ($p < 0.05$) lower to does on MOLM.

4 | DISCUSSION

From the result obtained in this study, the rabbit does were exposed to severe heat stress according to the range of THI recorded. This study reveals that moringa inclusions promoted PCV and HB among all the treatments. Leucocytes and its differential counts were lowered by the herbal inclusions, which was accompanied with lower neutrophil/lymphocyte ratio compared to does without inclusions on control during heat stress condition. These findings on haematological indices were contrary to the results obtained on nonstressed rabbits fed moringa, Phyllanthus and MILM. Such as Ewuola et al. (2012) reported that the inclusion of *M. oleifera* leaf meal does not alter the haematological indices of rabbits. Also, Jimoh et al. (2020) reported that the addition of *P. amarus* in rabbit diets did not alter the haematological indices of the rabbits. These suggest that the physiological state of the animals and the environmental condition played a part in the animals' response to these inclusions.

The trend of results indicates that herbal inclusions tend to suppress proinflammatory cytokines in does during heat stress condition occasioned by hot dry climate. MOLM depressed IFN- γ in does compared to those on control diet during stressed condition. As obtained in does on control diets in this study, increased TNF- α was associated with increased IFN- γ and decreased IL-10 as has been reported in heat-stressed animals (Abdel-Latif et al., 2018). Increased production of proinflammatory cytokines (TNF- α , IL-6 and IL-1 β) has adverse effect on inflammatory responses (Makarov, 2000). Similar to

the result of this study are that *Moringa oleifera* leaves extracts inhibits TNF- α , interleukin-6 (IL-6 and IL-8) induced by cigarette smoke and lipopolysaccharide in humans (Kooltheat et al., 2014).

Proinflammatory cytokines initiated for immune responses are hepatotoxic and cause adverse pathophysiological damages to the liver (Shawki & McCole, 2017). Poor liver function can suppress antioxidant enzymes and causes homeostatic imbalances, thereby increasing reactive oxygen species (Huang et al., 2015). TNF α overexpression promotes the reduction of feed intake and body weight, as the reduced feeding potentially derived from a TNF α increase might account for the weight loss in obese animals (Decara et al., 2018). This shows the mechanism by which the herbal inclusions improve the welfare and productivity of rabbit does exposed to heat stress.

The trend of reduced TNF α and adiponectin in does fed on herbal inclusions during heat stress in this study, is explained by claims of Decara et al. (2018) that an increase in TNF α occur as a feedback mechanism to block the production of more adiponectin, and reduce feed intake and weight by promoting satiety. Similarly, licorice extract has also been credited for inhibition of IL-6 and TNF α , IL-1 β and IL-8 were reduced (Mueller et al., 2010). Also, several herbal active compounds, plant extracts and isolated compounds were reported to be more efficient in the reduction of IL-6 and TNF- α secretion (Mueller et al., 2010).

HSP70 is the protein responsible for protein folding and the inhibition of protein aggregation which is involved in cell protection and tissue repair from different pathological conditions. The protein maintains cellular homeostasis during and after physiological and environmental stress such as oxidative stress, chemical stresses and pathogenic stresses (Wang et al., 2014). Adiponectin is a protein hormone (adipokines: cell-signalling proteins) that modulates various metabolic processes of fatty acid oxidation, insulin secretion and glucose regulation (Al-Braich et al., 2014). Adipokines are secreted in the cells to modulate inflammation and insulin resistance (Elekofehinti et al., 2017). Our study revealed that herbal inclusions fed to the rabbit does during heat stress conditions reduced HSP70, leptin and adiponectin in comparison with rabbit does on control diet that is without inclusions. Lower leptin and adiponectin could be accompanied with higher triiodothyronine to boost appetite in



herbal-supplemented groups and promote growth enhancement in does to mitigate the effects of heat stress. Increased level of leptin during heat stress has been reported to stimulate satiety signals or prevention of food intake (Schwartz et al., 2000). Similarly, administration of *M. oleifera* had been reported to ameliorate satiety signals and stimulate hunger (Abdel-Latif et al., 2018). Some studies reported decrease in serum leptin concentration after saponin administration (Yang et al., 2010). Also, Hypoadiponectinemia is a hallmark of fattened birds as it impedes satiety and enhances appetite (Decara et al., 2018). Increase adiponectin is associated with decrease blood glucose levels which culminates in increased insulin sensitivity (Elekofehinti et al., 2017). The expression of proinflammatory cytokines is impeded by HSP70 and the production of anti-inflammatory cytokines are also accelerated (Siddiqui et al., 2020). Inhibition of proinflammatory cytokine expression is caused by the upregulation of HSP70 under stress conditions preventing the transfer of nuclear factor- κ B into the nucleus (Pritts, 2000). Thus, elevated expression of HSPs during heat-stress conditions confer cytoprotection by preventing cytokine production and improving cell tolerance (Shehata et al., 2020). Similar to result obtained in does on control diets, of serum HSP-70 increased in poultry subjected to heat stress (Archana et al., 2017). The HSPs stimulates the immune system to encourage increased killing of pathogenic bacteria by neutrophils and macrophages and other innate immune cells against invading bacteria (Archana et al., 2017). These mechanisms could account for increased WBC in recorded in does fed on herbal inclusive diets diet in this study. The inclusion of the herbal inclusions in does diet in this study, ameliorated the effects of heat stress which led to reduction of HSP levels, and this could account for its lowered leucocytes and differential counts. Similarly, fermented herbal tea residues reduced serum HSP70 level in Holstein heifer under heat stress conditions (Baumgard & Rhoads, 2013). Contrariwise, HSP70 protein or mRNA expression during thermal stress is enhanced by glutamine supplementation (Hao et al., 2012). Immunity responses, reproductive performance and production under severe heat stress conditions might be enhanced by increase in HSP70 gene expression in rabbit does (Mousa et al., 2019). The exposure of the does for 12 weeks in this study suggests that the herbal inclusions could have restored the normal physiology of the animals hence its lowered HSP 70 and leucocytic indices. exposure to heat stress promote expression of genes related to survival (rapid expression of Heat Shock Factors and Heat Shock Protein) (De Nadal et al., 2011), while the stressors also promote none expression of fewer essential genes (Cedraz et al., 2017). Natural plant-derived compounds (antioxidant, detoxification and anti-inflammatory activities) have been reported to downregulate HSP expression through their biological and pharmacological activities during stress conditions (Abdel-Moneim et al., 2020; Naiel et al., 2020). HSP70 can force target proteins to maintain an adequate structure and retain normal function. Induced oxidative-stress conditions can decline HSP70 overexpression in mitochondrial permeability transition and the swelling of mitochondria, and in the inhibition of cell apoptosis (Wang et al., 2014). Also, Liu et al. (2014) reported that resveratrol

had positive effects on serum oxidative status, attenuated the heat stress induced over expression of HSP70, mRNA in the bursa of Fabricius and spleen and increased the low expression of HSP27 and HSP90 mRNA in the thymus upon heat stress (Akbarian et al., 2016).

In broilers (Mujahed et al., 2007), rabbit (Jimoh et al., 2017) and laying birds (Jimoh, Ihejirika, Balogun, Adelani, et al., 2018) environmental heat stress is associated with increase lipid peroxidation through arisen Thiobarbituric acid-reactive species (TBARS) and malondialdehyde (MDA) levels. TBARS and MDA are the major products of polyunsaturated fatty acid peroxidation (Belhadj Slimen et al., 2015). In biological systems, there are three line of antioxidant defense: first, radical detoxification by the major antioxidant enzymes; SOD, glutathione peroxidase and CAT; second, radical scavenging antioxidants of Vitamin E, Ascorbic acid, Glutathione, Uric acid in the cellular level; and the damaged molecule repair (Methionine sulfoxide reductase, Heat shock proteins and DNA-repairing enzymes) or removal (phospholipases, proteasomes) (Surai et al., 2019). During heat stress conditions according to our study, the herbal inclusions of *V. album* (MILM), *M. oleifera* (MOLM) and *P. amarus* (PHLM) leaf meals enhance oxidative stability of animals by lowering lipid peroxidation and enhancing total antioxidant and antioxidant enzymes activities. Results obtained showed that rabbit does fed *M. oleifera* supplemented diets had the most oxidative stability with the higher total antioxidant activity, SOD, CAT and the least lipid peroxidation than other treatments. Study done by Jimoh, Ayedun, et al. (2018) revealed that administration of soursop juice on heat-stressed bucks at 2.22 mlkg⁻¹ body weight offered optimum antioxidant defense against oxidative stress, reduced serum lipid peroxidation and demonstrated hypocholesterolemic effect in a dose-dependent manner throughout the study. In our study, decrease lipid peroxidation and oxidative stability might be attributed to the induction of these herbal plants supplement causing hypocholesterolemia on the rabbit does. In line with the report of Faremi et al. (2008) who reported that *P. amarus* can decreased the level of glutathione, SOD, CAT, rate of lipid peroxidation and increasing the antioxidant defense mechanism in rats. Naaz et al. (2007) also reported an enhancing effect of enzymatic and nonenzymatic antioxidant systems of *P. amarus* conferring hepatoprotective activity on mice. Research has shown that leaves of *M. oleifera* have high-level antioxidants like phenolic acids (gallic, chlorogenic, ellagic and ferulic acid), flavonoids (kaempferol, quercetin and rutin) and glucosinolates (Mbikay, 2012). Also, Leaves of *M. oleifera* have been reported to have a lot of β -carotene (precursor of vitamin A) and other vitamins like B-complex, C, D and K (Abd El-Hack et al., 2020). Thus, these findings confirm that antioxidant enrichment of the herbs and improving oxidative stability on the rabbit does. Similarly, Daramola et al. (2018) observed that *M. oleifera* enhances SOD and glutathione activities on laying pullets and led to a reduction in serum malonaldehyde. Oxidative stability could influence the immune status and productivity of animals like rabbits. When animals are at thermal comfort of oxidative stress due to hyperthermia, there is reduction in the activity of antioxidant enzymes (Jimoh & Ewuola, 2019). Thus, improved oxidative stability

obtained in herbal-supplemented diets of our study could be an indication of enhanced productivity and most likely promote performance in rabbit does.

5 | CONCLUSION

This study revealed that dietary inclusion of *M. oleifera* to female rabbits exposed to heat stress, enhanced PCV and haemoglobin, increased SOD, CAT and total antioxidant activities, lowered lipid peroxidation, interleukin 1 β and Interferon γ , suppressed HSP70 and leptin. *V. album* lowered neutrophil/lymphocyte ratio, depressed interleukin 1 β , TNF- α and leptin, enhanced SOD and glutathione peroxidase activities. The inclusion of *P. amarus* in rabbit does diet, mitigated effect of heat stress by lowering lymphocytes, suppressed IL-6 and adiponectin. It can be concluded that any of the three-leaf meals (*M. oleifera*, *P. amarus* and *V. album*) can be incorporate to rabbit does diet to ameliorate effects of heat stress.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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REFERENCES

- Abd El-Hack, M. E., Abdelnour, S. A., Taha, A. E., Khafaga, A. F., Arif, M., Ayasan, T., Swelum, A. A., Abukhalil, M. H., Alkahtani, S., Aleya, L., & Abdel-Daim, M. M. (2020). Herbs as thermoregulatory agents in poultry: An overview. *Science of the Total Environment*, 703, 1–7. <https://doi.org/10.1016/j.scitotenv.2019.134399>
- Abdel-Latif, M., Sakran, T., Badawi, Y. K., & Abdel-Hady, D. S. (2018). Influence of *Moringa oleifera* extract, vitamin C, and sodium bicarbonate on heat stress-induced HSP70 expression and cellular immune response in rabbits. *Cell Stress and Chaperones*, 23, 975–984. <https://doi.org/10.1007/s12192-018-0906-1>
- Abdelnour, S. A., Al-Gabri, N. A., Hashem, N. M., & Gonzalez-Bulnes, A. (2021). Supplementation with proline improves haemato-biochemical and reproductive indicators in male rabbits affected by environmental heat-stress. *Animals: An Open Access Journal from MDPI*, 11, 373. <https://doi.org/10.3390/ani11020373>
- Abdelnour, S. A., El-Saadony, M. T., Saghir, S. A. M., Abd El-Hack, M. E., Al-shargi, O. Y. A., Al-Gabri, N., & Salama, A. (2020). Mitigating negative impacts of heat stress in growing rabbits via dietary prodigiosin supplementation. *Livestock Science*, 240(104220), 104220.
- Abdel-Moneim, A. M. E., Shehata, A. M., Alzahrani, S. O., Shafi, M. E., Mesalam, N. M., Taha, A. E., Swelum, A. A., Arif, M., Fayyaz, M., & Abd El-Hack, M. E. (2020). The role of polyphenols in poultry nutrition. *Journal of Animal Physiology and Animal Nutrition*, 104, 1851–1866.
- Akbadian, A., Michiels, J., Degroote, J., Majdeddin, M., Golian, A., & De Smet, S. (2016). Association between heat stress and oxidative stress in poultry; mitochondrial dysfunction and dietary interventions with phytochemicals. *Journal of Animal Science and Biotechnology*, 7(37), 37. <https://doi.org/10.1186/s40104-016-0097-5>
- Al-Braich, M. S., Al-Husaini, N. K., Saleh, S. H. M., & Awn, M. F. (2014). Effect of adiponectin level in type ii diabetic postmenopausal women compared to healthy women. *International Journal of Science and Nature*, 5(2), 287–289.
- Archana, P. R., Aleena, J., Pragna, P., Vidya, M. K., Abdul Niyas, P. A., Bagath, M., Krishnan, G., Manimaran, A., Beena, V., Kurien, E. K., Sejian, V., & Bhatta, R. (2017). Role of heat shock proteins in livestock adaptation to heat stress. *Journal of Dairy, Veterinary & Animal Research*, 5(1), 13–19. <https://doi.org/10.15406/jdvar.2017.05.00127>
- Baumgard, L. H., & Rhoads, R. P. (2013). Effects of heat stress on postabsorptive metabolism and energetics. *Annual Review of Animal Biosciences*, 1, 311–337.
- Belhadj Slimen, I., Najar, T., Ghram, A., & Abdrrabba, M. (2015). Heat stress effects on livestock: Molecular, cellular and metabolic aspects, a review. *Journal of Animal Physiology and Animal Nutrition*, 100, 401–412. <https://doi.org/10.1111/jpn.12379>
- Cedraz, H., Gromboni, J. G. G., Garcia, A. A. P., Farias Filho, R. V., Souza, T. M., Oliveira, E. R., Oliveira, E. B., Nascimento, C. S., Meneghetti, C., & Wenceslau, A. A. (2017). Heat stress induces expression of HSP genes in genetically divergent chickens. *PLoS One*, 12(10), e0186083. <https://doi.org/10.1371/journal.pone.0186083>
- Daramola, O., Jimoh, A., Oloruntola, O., & Ayodele, S. (2018). Effect of herbal supplement on the laying performance and antioxidant status of serum and egg yolk of laying birds. *Biotechnology Journal International*, 21(3), 1–9.
- Decara, J., Serrano, A., Pavón, F. J., Rivera, P., Arco, R., Gavito, A., Vargas, A., Navarro, J. A., Tovar, R., Lopez-Gamero, A. J., Martínez, A., Suárez, J., Rodríguez de Fonseca, F., & Baixeras, E. (2018). The adiponectin promoter activator NP-1 induces high levels of circulating TNF α and weight loss in obese (fa/fa) Zucker rats. *Scientific Reports*, 8, 9858. <https://doi.org/10.1038/s41598-018-27871-7>
- Elekofehinti, O. O., Ejelolu, O. C., Kamdem, J. P., Akinlosotu, O. B., & Adanlawo, I. G. (2017). Saponins as adipokines modulator: A possible therapeutic intervention for type 2 diabetes. *World Journal of Diabetes*, 8(7), 337–345.
- Ewuola, E. O., Jimoh, O. A., Atuma, O. V., & Soipe, O. D. (2012). "Haematological and Serum Biochemical Response of Growing Rabbits Fed Graded Levels of leaf meal. World Rabbit Science Association." In *Proceedings of the 10th World Rabbit Congress*, September 3–6, 2012. 679–683. Sharm El-Sheikh, Egypt.
- Faremi, T. Y., Suru, S. M., Fafunso, M. A., & Obioha, U. E. (2008). Hepatoprotective potentials of *Phyllanthus amarus* against ethanol-induced oxidative stress in rats. *Food and Chemical Toxicology*, 46(8), 2658–2664. <https://doi.org/10.1016/j.fct.2008.04.022>
- Hao, Y., Gu, X. H., & Wang, X. L. (2012). Overexpression of heat shock protein 70 and its relationship to intestine under acute heat stress in broilers: 1. Intestinal structure and digestive function. *Poultry Science*, 91(4), 781–789.
- Harikrishnan, H., Jantan, I., Haque, M. A., & Kumolosasi, E. (2018). Anti-inflammatory effects of *Phyllanthus amarus* Schum. & Thonn. through inhibition of NF- κ B, MAPK, and PI3K-Akt signaling pathways in LPS-induced human macrophages. *BMC Complementary and*

- Alternative Medicine*, 18(1), 224. <https://doi.org/10.1186/s12906-018-2289-3>
- Hegde, P., Maddur, M. S., Friboulet, A., Bayry, J., & Kaveri, S. V. (2011). *Viscum album* exerts anti-inflammatory effect by selectively inhibiting cytokine-induced expression of cyclooxygenase-2. *PLoS One*, 6(10), e26312. <https://doi.org/10.1371/journal.pone.0026312>
- Hirakawa, R., Nurjanah, S., Furukawa, K., Murai, A., Kikusato, M., Nochi, T., & Toyomizu, M. (2020). Heat stress causes immune abnormalities via massive damage to effect proliferation and differentiation of lymphocytes in broiler chickens. *Frontiers in Veterinary Science*, 7(7), 46. <https://doi.org/10.3389/fvets.2020.00046>
- Hu, R., He, Y., Arowolo, M., Wu, S., & He, J. (2019). Polyphenols as potential attenuators of heat stress in poultry production. *Antioxidants*, 8(3), 67.
- Huang, C., Jiao, H., Song, Z., Zhao, J., Wang, X., & Lin, H. (2015). Heat stress impairs mitochondria functions and induces oxidative injury in broiler chickens. *Journal of Animal Science*, 93, 2144–2153.
- Jang, I. S., Ko, Y. H., Moon, Y. S., & Sohn, S. H. (2014). Effects of vitamin C or E on the pro-inflammatory cytokines, heat shock protein 70 and antioxidant status in broiler chicks under summer conditions. *Asian-Australasian Journal of Animal Sciences*, 27(5), 749–756. <https://doi.org/10.5713/ajas.2013.13852>
- Jiang, S., Mohammed, A. A., Jacobs, J. A., Cramer, T. A., & Cheng, H. W. (2020). Effect of synbiotics on thyroid hormones, intestinal histomorphology, and heat shock protein 70 expression in broiler chickens reared under cyclic heat stress. *Poultry Science*, 99, 142–150. <https://doi.org/10.3382/ps/pez571>
- Jimoh, O., Ewuola, E., & Balogun, A. (2017). Oxidative stress markers in exotic breeds of rabbit during peak of heat stress in Ibadan, Nigeria. *Journal of Advances in Biology & Biotechnology*, 12(1), 1–9. <https://doi.org/10.9734/JABB/2017/30437>
- Jimoh, O. A. (2019). Oxidative stress indicators of rabbit breeds in Ibadan, Southwest Nigeria. *Bulletin of the National Research Centre*, 43(62), 1–7. <https://doi.org/10.1186/s42269-019-0104-z>
- Jimoh, O. A., Ayedun, E. S., Daramola, O. T., Oloruntola, O. D., Ayodele, S. O., & Okin-Aminu, H. O. (2020). Growth and haematological response of growing rabbits fed *Phyllanthus amarus* leaf meal supplemented diets. *Livestock Research for Rural Development*, 32(2), 1–5. <http://www.lrrd.org/lrrd32/1/abuba32020.html>
- Jimoh, O. A., Ayedun, E. S., Oyelade, W. A., Oloruntola, O. D., Daramola, O. T., Ayodele, S. O., & Omoniyi, I. S. (2018). Protective effect of soursop (*Annona muricata* linn.) juice on oxidative stress in heat stressed rabbits. *Journal of Animal Science and Technology*, 60(28), 1–6. <https://doi.org/10.1186/s40781-018-0186-4>
- Jimoh, O. A., & Ewuola, E. O. (2016). Thermoregulatory response of exotic rabbit breeds during peak temperature humidity index of Ibadan. *Tropical Animal Production Investigation*, 19(1), p 41–47.
- Jimoh, O. A., & Ewuola, E. O. (2018). Semen characteristics, seminal biochemical and oxidative stress markers in rabbits during heat stress. *Journal of Veterinary Andrology*, 3(2), 35–44.
- Jimoh, O. A., & Ewuola, E. O. (2019). Semen characteristics and seminal oxidative status of four breeds of rabbit in Southwest, Nigeria. *The Journal of Basic and Applied Zoology*, 80(35), 1–9. <https://doi.org/10.1186/s41936-019-0105-3>
- Jimoh, O. A., Ihejirika, U. G., Balogun, A. S., Adelani, S. A., & Okanlawon, O. O. (2018). Antioxidant status and serology of laying pullets fed diets supplemented with mistletoe leaf meal. *Nigerian Journal of Animal Science*, 20(1), 52–60.
- Jimoh, O. A., Ihejirika, U. G., Balogun, A. S., & Uwaeziozi, U. C. (2018). Antioxidative effect of mistletoe leaf meal supplemented diets in laying pullets. *Archivos de Zootecnia*, 67(260), 526–530. <https://www.uco.es/ucopress/az/index.php/az/>
- Jimoh, O. A., Oyeyemi, B. F., & Oyeyemi, W. A. (2021). Soursop juice enhanced seminal antioxidant defence and semen quality of rabbit bucks in extremely dry climatic condition of Southwestern Nigeria. *Journal of Thermal Biology*, 100, 103034. <https://doi.org/10.1016/j.jtherbio.2021.103034>
- Jimoh, O. A., Oyeyemi, W. A., Okin-Aminu, H. O., & Oyeyemi, B. F. (2021). Reproductive characteristics, semen quality, seminal oxidative status, steroid hormones, sperm production efficiency of rabbits fed herbal inclusions. *Theriogenology*, 168, 41–49. <https://doi.org/10.1016/j.theriogenology.2021.03.020>
- Kooltheat, N., Sranujit, R., Chumark, P., Potup, P., Laytragoon-Lewin, N., & Usuwanthim, K. (2014). An ethyl acetate fraction of *Moringa oleifera* Lam. Inhibits human macrophage cytokine production induced by cigarette smoke. *Nutrients*, 6, 697–710.
- Kou, X., Li, B., Olayanju, J., Drake, J., & Chen, N. (2018). Nutraceutical or Pharmacological Potential of *Moringa oleifera* Lam. *Nutrients*, 10, 343. <https://doi.org/10.3390/nu10030343>
- Liu, L. L., He, J. H., Xie, H. B., Yang, Y. S., Li, J. C., & Zou, Y. (2014). Resveratrol induces antioxidant and heat shock protein mRNA expression in response to heat stress in black-boned chickens. *Poultry Science*, 93, 54–62.
- Makarov, S. S. (2000). NF- κ B as a therapeutic target in chronic inflammation: Recent advances. *Molecular Medicine Today*, 6(11), 441–448.
- Mbakay, M. (2012). Therapeutic potential of *Moringa oleifera* leaves in chronic hyperglycemia and dyslipidemia: A review. *Frontiers in Pharmacology*, 3:24.
- Mehaisen, G. M. K., Ibrahim, R. M., Desoky, A. A., Safaa, H. M., El-Sayed, O. A., & Abass, A. O. (2017). The importance of propolis in alleviating the negative physiological effects of heat stress in quail chicks. *PLoS One*, 12(10), e0186907. <https://doi.org/10.1371/journal.pone.0186907>
- Mousa, B. H., Emam, K. R. S., Morsy, A. S., Ahmed, N. A. E. H., & Sakr, O. G. (2019). Effect of early heat shock exposure on physiological responses and reproduction of rabbits under hot desert conditions. *Journal of World's Poultry Research*, 9(2), 90–101.
- Mueller, M., Hobiger, S., & Jungbauer, A. (2010). Anti-inflammatory activity of extracts from fruits, herbs and spices. *Food Chemistry*, 122, 987–996.
- Mujahid, A., Pumford, N. R., Bottje, W., Nakagawa, K., Miyazawa, T., Akiba, Y., & Toyomizu, M. (2007). Mitochondrial oxidative damage in chicken skeletal muscle induced by acute heat stress. *The Journal of Poultry Science*, 44, 439–445.
- Naaz, F., Javed, S., & Abdin, M. Z. (2007). Hepatoprotective effect of ethanolic extract of *Phyllanthus amarus* Schum. et Thonn. on aflatoxin B1-induced liver damage in mice. *Journal of Ethnopharmacology*, 113(3), 503–509.
- De Nadal, E., Ammerer, G., & Posas, F. (2011). Controlling gene expression in response to stress. *Nature Reviews Genetics*, 12, 833–845. <https://doi.org/10.1038/nrg3055>
- Naiei, M. A. E., Shehata, A. M., Negm, S. S., Abd El-Hack, M. E., Amer, M. S., Khafaga, A. F., Bin-Jumah, M., & Allam, A. A. (2020). The new aspects of using some safe feed additives on alleviated imidacloprid toxicity in farmed fish: A review. *Reviews in Aquaculture*, 12, 2250–2267.
- Pritts, T. A. (2000). Induction of the stress response in vivo decreases nuclear factor- κ B activity in jejunal mucosa of endotoxemic mice. *Archives of Surgery*, 135, 860–866.
- Schwartz, M. W., Woods, S. C., Porte, Jr. D., Seeley, R. J., & Baskin, D. G. (2000). Central nervous system control of food intake. *Nature*, 404(6778), 661–671.
- Shawki, A., & McCole, D. F. (2017). Mechanisms of intestinal epithelial barrier dysfunction by adherent invasive *Escherichia coli*. *Cellular and Molecular Gastroenterology and Hepatology*, 3, 41–50.
- Shehata, A. M., Saadeldin, I. M., Tukur, H. A., & Habashy, W. S. (2020). Modulation of heat-shock proteins mediates chicken cell survival against thermal stress. *Animals: An Open Access Journal from MDPI*, 10(2407), 2407. <https://doi.org/10.3390/ani10122407>

- Sheiha, A. M., Abdelnour, S. A., Abd El-Hack, M. E., Khafaga, A. F., Metwally, K. A., Ajarem, J. S., Maodaa, S. N., Allam, A. A., & El-Saadony, M. T. (2020). Effects of dietary biological or chemical-synthesized nano-selenium supplementation on growing rabbits exposed to thermal stress. *Animals: An Open Access Journal from MDPI*, 10, 430.
- Siddiqui, S. H., Kang, D., Park, J., Khan, M., & Shim, K. (2020). Chronic heat stress regulates the relation between heat shock protein and immunity in broiler small intestine. *Scientific Reports*, 10, 18872. <https://doi.org/10.1038/s41598-020-75885-x>
- Surai, P. F., Kochish, I. I., Fisinin, V. I., & Kidd, M. T. (2019). Antioxidant defence systems and oxidative stress in poultry biology: An update. *Antioxidants*, 8, 235. <https://doi.org/10.3390/antiox8070235>
- Wang, X., Yuan, B., Dong, W., Yang, B., Yang, Y., Lin, X., & Gong, G. (2014). Induction of heat-shock protein 70 expression by geranylgeranylacetone shows cytoprotective effects in cardiomyocytes of mice under humid heat stress. *PLoS One*, 9(4), e93536. <https://doi.org/10.1371/journal.pone.0093536>
- Yang, C., Wang, J., Zhao, Y., Shen, L., Jiang, X., Xie, Z., Liang, N., Zhang, L., & Chen, Z. (2010). Anti-diabetic effects of *Panax notoginseng* saponins and its major anti-hyperglycemic components. *Journal of Ethnopharmacology*, 130, 231–236. <https://doi.org/10.1016/j.jep.2010.04.039>

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