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Research Article

Hen-Day Egg Production and Qualitative Egg Indices in Laying Hens Administered with Lycopene and Vitamin E during the Hot-Dry Season

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ABSTRACT

The aim of the study was to evaluate the ameliorative effects of lycopene and vitamin E, administered individually and in combination on laying hens during the hot-dry season. Dry- and wet-bulb temperatures were recorded daily from 06:00-18:00 h during the 5-week experimental period. Laying hens aged 41 weeks, divided into 4 groups of 100 hens each served as subjects: Group 1, lycopene+ vitamin E (30 mg/kg+250 mg/kg body weight, respectively); Group 2, lycopene (30 mg/kg body weight); Group 3, vitamin E (250 mg/kg body weight); and Group 4, controls. All administrations were performed orally by gavage daily for five weeks. Daily and weekly hen-day egg productions, egg weight, eggshell thickness and eggshell weight were determined using standard procedures. The dry-bulb temperature (23.0°C-39.0°C) and temperature-humidity index (24.4°C-35.0°C) recorded show that the hens were subjected to heat stress during the season. Egg production obtained in lycopene (62.4 ± 1.1 %), vitamin E (62.1 ± 1.2%) and lycopene+ vitamin E (62.7 ± 1.0 %) groups were higher (P<0.05) than in controls (56.0 ± 0.8%). Eggshell was thickest in lycopene+ vitamin E group (0.28 ± 0.02 mm), compared to lycopene (0.23 ± 0.02 mm) or vitamin E group (0.22 ± 0.02 mm). The thickness was lowest (P<0.05) in control hens (0.18 ± 0.02 mm) than any other group. Similarly, control laying hens recorded the least (P<0.05) eggshell weight (6.7 ± 0.02 g), compared to the weights recorded in lycopene+ vitamin E, lycopene and vitamin E groups (7.3 ± 0.24 g, 7.3 ± 0.3 g and 7.2 ± 0.3 g, respectively). In conclusion, lycopene and vitamin E, especially in combination, ameliorated the risk of adverse effects of heat stress by increasing hen-day production, eggshell weight and eggshell thickness during the hot-dry season.

Keywords: Hen-day egg production; Qualitative egg indices; Laying hens; Lycopene; Vitamin E; Hot-dry season

INTRODUCTION

Oxidative stress is a critical factor implicated in the initiation, development and progression of most ovarian dysfunctions, which may be exacerbated during the inclement hot-dry season. In poultry production, various environmentally-induced stresses, ranging from poor nutrition [1-6], social stress [6], and heat stress [7,8], exert remarkable depressive effects on poultry well-being and optimum productivity [8]. Heat stress results from outrages in environmental temperature, often associated with the zone during the hot-dry season. The severity of environmental temperature is aggravated by concurrent increase in relative humidity, which impairs performance and induces oxidative stress in poultry. In the tropical environment, heat stress constitutes a major debilitating factor to poultry production [9,10]. It results from a negative balance between the net amount of energy flowing from the laying hen's body to its surrounding environment and the amount of heat energy produced by the hen. This imbalance may be caused by salient environmental factors, including sunlight, thermal irradiation, air temperature, relative humidity, air movements, metabolic rate, and impaired thermoregulatory mechanism [7,8,11]. Lycopene is the predominant carotenoid in tomatoes and one of the major carotenoids in the serum and tissues [12,13]. When lycopene is incorporated in avian tissues, especially in egg yolk, it exhibits significant antioxidant activity [14]. Lycopene quenches Reactive Oxygen Species (ROS), including singlet oxygen and other oxidising species and, thus, protects the cells from oxidative damage, occurring in heat stress [2,15,16]. Vitamin E is an essential fat-soluble nutrient, often called tocopherol. Alpha-tocopherol is essentially the most predominant, having the highest biological activity in many species. It is a potent antioxidant involved in the prevention and management of infertility and other reproductive

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anomalies [17,18]. Domestic birds do not synthesize enough vitamin E and, consequently, they are dependent on dietary sources to meet the body requirements [3,19,20]. Therefore, vitamin E supplementation in poultry nutrition, through better protection against oxidative stress [3,21], improves fertility, hatchability and the qualitative post-hatch performance of avian chicks [18,22].

The aim of the study was to evaluate the effects of lycopene and vitamin E on hen-day egg production and qualitative egg indices in laying hens during the hot-dry season.

MATERIALS AND METHODS

Location of the study

The experiment was performed in a standard poultry farm in Zaria, located at latitude 11°N, 12/N and longitude 7 °E, 8/E, elevation of 650 m above sea level, and in the Northern Guinea Savannah zone of Nigeria. The zone has annual mean maximum and minimum temperatures of 31.8 ± 3.2°C and 18.0 ± 3.7°C, respectively. It is characterised by three seasons: Harmattan (cold-dry) occurring in November–February, rainy (June–October) and hot-dry seasons (March–May) [11,23]. The hot-dry season has been described as the most stressful to laying hens [24,25].

Thermal environmental data

A dry- and wet-bulb thermometer (Mason's Type Wet-and Dry-bulb hygrometer (GH Zeal Limited, London, England), positioned at the height of 2 m from the floor in the experimental poultry pen was used to record the dry- and wet-bulb temperatures daily every three hours, beginning from 06:00 h to 18:00 h, throughout the duration of the study that lasted for five weeks. The Temperature-Humidity Index (THI), used to determine the heat load in the laying hens, was calculated from the dry- and wet-bulb temperatures [26]:

THI=0.6 Tdb+0.4 Tdw

Where:

THI: Temperature-Humidity Index for the laying hen (°C)

Tdb: dry-bulb Temperature (°C)

Twb: wet-bulb Temperature (°C)

Flock management

During the peak of the hot-dry season in March and April, 400, apparently, healthy ISA Brown laying hens, aged 41 weeks with a mean live weight of 1.8 ± 0.5 kg were used for the study. They were maintained in deep litter in an open-sided standard poultry pen unit. The hens were divided by simple randomisation into four groups, comprising 100 group-penned laying hens each and maintained on layer mash (Vital Feeds Ltd., Jos, Nigeria). The feed had nutritive values of 16.50% crude protein, 6.5% crude fibre and 2650.0 kCal/kg metabolisable energy. The flock was given access to feed and water ad libitum. Standard routine vaccinations and periodic prophylactic medications were administered to the hens. The husbandry and the conduct of the experiments on the laying hens were performed in accordance with the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (Council of Europe No 123, Strasbourg 1985). All the experimental protocols described were approved by the Ethics Review Committee for Animal Experimentation of Ahmadu Bello University, Zaria, Nigeria.

Experimental design

The study was conducted on four different groups of laying hens in a laying pen, comprising 100 birds per group. Each pen was identified according to its experimental role. The lycopene-treated group was administered orally with 30 mg lycopene/kg body weight per day [27], while the control group was given the equivalent of water only. The lycopene+ vitamin E-treated hens were administered orally with 30 mg lycopene, combined with 250 mg vitamin E/kg body weight per day, while the vitamin E-penned layers received vitamin E only at a dose of 250 mg/kg body weight per day [28]. All administrations were performed orally, using a gavage between 7:00 h and 8:00 h daily for five weeks. Feeds and water were available to the hens ad libitum.

The hen-day egg production and mean egg weight in each pen were recorded daily as indices of egg production. The weekly eggshell weight and eggshell diameter were evaluated throughout the study period as described by Mack et al. [29].

Data analyses

The data obtained were expressed as mean ± Standard Error of the Mean (mean ± SEM). Variations in hen-day egg production and eggshell qualitative indices of the laying hens were analysed using repeated-measures Analysis of Variance (ANOVA), followed by Tukey's multiple comparison post-hoc test. Values of $P<0.05$ were considered significant. Data were analysed using GraphPad Prism, version 5.03 (GraphPad Software, San Diego, California, USA, www.graphpad.com).

RESULTS

Thermal environmental conditions

The thermal environmental conditions of DBT and THI data are presented in Tables 1 and 2. Weekly mean DBT values were significantly ($P<0.05$) lower during the morning hours between 6:00 h and 9:00 h than the values obtained at 12:00, 15:00 and 18:00 h. The lowest DBT (24.3 ± 0.5°C) was recorded at 6:00 h during the fourth week of the study, while the highest value (36.7 ± 0.6°C) was obtained at 9:00 h in the 3rd week of the study (Table 1). The DBT varied significantly ($P<0.05$) between 9:00 h and 12:00 h; thereafter, the variations were not significantly ($P>0.05$) different.

Temperature-humidity index

The THI was lowest at 0:600 h (23.1 ± 0.05°C), obtained at the 4th week of the study; while the highest ($P<0.05$) value (33.3 ± 0.4°C) was recorded at the 3rd week. The overall THI value (28.42 ± 0.42°C) was recorded at 0:600 h, 09:00 h, 12:00 h, 15:00 h and 18:00 h, respectively. The overall pattern of THI decreased significantly ($P<0.05$) with time of the day in the order: 18:00>15:00 h>12:00 h>09:00 h>06:00 h (Table 2). During the study period, the laying hens panted frequently; most often from 10:00 h of the day, and the intensity increased remarkably between 12:00 h and 18:00 h. Panting recorded shortly after 9:00 h was heightened between 15:00 h and 18:00 h of the day due to sustained heat load. In some cases during the study, the laying hens were visibly going-off their

Table 1: Weekly diurnal fluctuations in dry-bulb temperature (°C) during the hot-dry season.

Week	Time, h				
	06:00	09:00	12:00	15:00	18:00
1	26.0 ± 0.38[a]	27.3 ± 0.4[a]	32.6 ± 0.6[b]	35.43 ± 0.8[c]	36.71 ± 0.6[c]
	(25.0 - 27.0)*	(25.0 -28.0)	(30.0 -35.0)	(32.0 -39.0)	(35.0 -39.0)
2	25.3 ± 0.4[a]	27.6 ± 0.5[b]	32.3 ± 0.4[c]	34.71 ± 0.5[d]	34.71 ± 0.5[d]
	(24.0 - 27.0)	(26.0 -30.0)	(30.0 -33.0)	(33.0 - 36.0)	(33.0 -36.0)
3	25.71 ± 0.5[a]	29.43 ± 0.4[b]	33.14 ± 0.5[c]	35.0 ± 0.5d	36.57 ± 0.5[e]
	(24.0 - 27.0)	(28 -31.0)	(32.0 -35.0)	(33.0 -37.0)	(35.0 -39.0)
4	24.3 ± 0.5[a]	28.1 ± 0.7[b]	31.6 ± 0.6[c]	34.0 ± 0.3[d]	34.57 ± 0.3[d]
	(23.0-26.0)	(25.0 -31.0)	(28.0 -33.0)	(33.0 -35.0)	(33.0 -35.0)
5	26.3 ± 0.5[a]	28.1 ± 0.8[b]	31.4 ± 0.3[c]	32.6 ± 0.3[c]	33.0 ± 0.5[c]
	(24.0 - 27.0)	(25.0 -31.0)	(30.0 -32.0)	(31.0 -33.0)	(31 -35.0)
Overall mean ± SEM	25.5 ± 0.5	28.1 ± 0.6	32.2 ± 0.5	34.3 ± 0.5	35.0 ± 0.5
Range	4	6	7	8	4

Note: [a, b, c, d]=Means (± SEM) with different superscripts [a, b, c, d] are significantly (P<0.05) different. *Data in parentheses represent minimum and maximum dry-bulb temperature.

Table 2: Temperature-humidity index (°C) in poultry pen during the hot-dry season.

Week	Time, h				
	06:00	09:00	12:00	15:00	18:00
1	25.4 ± 0.4[a]	26.1 ± 0.3[a]	30.6 ± 0.4[b]	32.5 ± 0.7[c]	33.0 ± 0.5[d]
	(24.20-26.29)	(24.60-26.80)	(28.80-31.80)	(30.0-35.40)	(31.40-35.0)
2	24.5 ± 0.3[a]	26.4 ± 0.4[b]	30.1 ± 0.4[c]	32.0 ± 0.3[d]	31.8 ± 0.5d
	(23.20-25.80)	(24.80-28.0)	(28.40-31.0)	(31.0-32.80)	(30.20-33.60)
3	24.6 ± 0.8[a]	28.0 ± 1.7[b]	31.0 ± 0.4[c]	33.3 ± 0.4[c]	33.2 ± 0.6[d]
	(22.0-26.60)	(27.20-28.40)	(30.0-32.20)	(30.80-33.40)	(31.0-35.40)
4	23.1 ± 0.5[a]	27.0 ± 0.6[b]	29.2 ± 0.4[c]	31.0 ± 0.4[d]	31.7 ± 0.2[d]
	(21.80-24.80)	(24.20-29.0)	(26.80-30.40)	(30.20-32.60)	(30.80-32.60)
5	25.3 ± 0.5[a]	27.0 ± 0.7[b]	29.5 ± 0.3[c]	30.3 ± 0.2[d]	30.5 ± 0.4[d]
	(23.20-26.20)	(24.20-29.40)	(28.40-30.40)	(29.40-31.0)	(28.60-32.20)
6	24.6 ± 0.3[a]	26.1 ± 0.3[b]	28.5 ± 0.3[c]	29.3 ± 0.4[c]	29.4 ± 0.3[d]
Overall mean ± SEM	(23.20-25.20)	(24.80-26.80)	(26.80-29.40)	(27.40-30.20)	(28.0-30.60)
	24.58 ± 0.46	26.7 ± 60.6	29.66 ± 0.36	31.4 ± 0.4	31.6 ± 0.42

Note: [a, b, c, d]=Means (± SEM) values with different superscript letters [a, b,c,d] are significantly (P<0.05) different. *Data in parentheses represent minimum and maximum dry-bulb temperature.

feeders and concentrating activity around the drinkers, where they were observed to drink more intensively and rested under their feed augers. They also spent more time with their wings elevated, less time moving or walking, and more time resting.

Effect of lycopene and vitamin E on hen-day egg production

Supplemental administration of lycopene and vitamin E significantly (P<0.05) increased daily egg production, which resulted in a remarkable weekly egg output, when compared with the controls. Laying hens that received lycopene+ vitamin E had hen-day egg production, ranging from the lowest mean value (59.0 ± 1.2 %) to the highest hen-day (66.57 ± 1.2 %) during the 4th and 3rd week. The extreme minimum and extreme maximum values recorded in lycopene+ vitamin E laying hens were 56.0% and 72.0%, respectively. The overall mean value of hen-day egg production of 62.7 ± 1.0% was obtained in lycopene+ vitamin E laying hens (Table 3). In laying hens supplemented with vitamin E alone, weekly hen-day egg production ranged between 59.0 ± 1.9% and 65.3 ± 1.5% hen-day; and the overall mean hen-day (62.1 ± 1.2 %) was not significantly (P>0.05) different from that recorded in lycopene+ vitamin E laying hens (62.7 ± 1.0%). The overall mean hen-day for the control laying hens (56.0 ± 0.8 %) was the lowest (P<0.05), compared to the value recorded in any of the experimental groups (Table 3).

Relationship (r) between temperature-humidity index and hen-day egg production

The relationship between THI and hen-day egg production was positive in most of the weeks of recordings, particularly in vitamin E group, followed by the lycopene group (Table 4).

Effect of lycopene and vitamin E on eggshell diameter

The eggshell diameters (thickness) of the laying hens during the hot-dry season are presented in Table 5. Eggshell thickness was the lowest (P<0.05) in control laying hens, compared to all other

Table 3: Weekly hen-day egg production (%) in laying hens during the hot-dry season (n=100 per group).

Week	Layer group			
	L+VE	L	VE	CONTROL
1	60.57 ± 0.7[a]	59.14 ± 0.8[a]	59.0 ± 1.9[a]	57.29 ± 0.9[a]
	(58.0 - 68.0)*	(56.0 - 61.0)	(52.0 - 65.0)	(53.0-60.0)
2	65.30 ± 0.6[a]	62.86 ± 0.9[a]	64.43 ± 1.2[a]	56.70 ± 0.7[b]
	(63.0-68.0)	(59.0-66.0)	(61.0-70.0)	(54.0-59.0)
3	66.7 ± 1.5[a]	65.10 ± 1.3[a]	65.3 ± 1.5[a]	55.14 ± 0.5[b]
	(62.0-72.0)	(60.0 -69.0)	(58.0-70.0)	(53.0 -57.0)
4	59.0 ± 1.2[a]	62.40 ± 1.0[a]	59.43 ± 1.0[a]	52.8 ± 0.6[b]
	(56.0 - 65.0)	(59.0-66.0)	(56.0-62.0)	(50.0 - 55.0)
5	64.30 ± 0.9[a]	63.30 ± 0.7[a]	61.71 ± 0.9[a]	57.0 ± 1.2[b]
	(62.0 - 67.0)	(60.0 - 65.0)	(60.0 - 65.0)	(53.0-60.0)
6	60.60 ± 0.8[a]	61.30 ± 1.6[a]	59.90 ± 0.7[a]	56.71 ± 1.1[b]
	(58.0 - 63.0)	(54.0 - 65.0)	(57.0 - 62.0)	(52.0-60.0)
Overall mean ± SEM	62.7 ± 1.0	62.4 ± 1.1	62.1 ± 1.2	56.0 ± 0.8
Range	(56.0-72.0)	(54.0-69.0)	(52.0-70.0)	(50.0-60.0)
	16	15	18	10

Note: [a, b]=Means (± SEM) with different superscript [a] and [b] between layer groups are significantly (P<0.05) different. Data in parentheses represent minimum and maximum hen-day egg production. L +VE =Lycopene+Vitamin E, L=Lycopene only, E=vitamin E only and CONT=Control.

Table 4: Correlation co-efficients between temperature-humidity index and hen-day egg production during the hot-dry season.

Week	Laying hen group			
	L+VE	L	VE	CONT.
1	0.022	-0.029	0.513*	0.580*
2	-0.226	0.921***	0.622*	0.083
3	0.523*	0.164	0.600*	-0.097
4	0.587*	0.3	0.26	0.06
5	0.124	0.570*	0.500*	0.803**
6	0.580*	0.609*	0.760*	0.613*

Note: Correlation values with superscript * are significant (P<0.05); * =P<0.01, *** =P<0.001 L+VE=lycopene + vitamin E-administered hens; L=Lycopene-administered hens; VE=Vitamin E-administered hens; CONT=Control hens.

Table 5: Eggshell diameter (mm) in ISA Brown laying hens administered with lycopene and vitamin E during the hot-dry season (mean ± SEM; n=10 per group).

Group	Week				
	1	2	3	4	5
L+VE	0.33 ± 0.02[a]	0.25 ± 0.01[a]	0.30 ± 0.03[a]	0.30 ± 0.02[a]	0.24 ± 0.03[a]
L	0.24 ± 0.02[b]	0.26 ± 0.02[a]	0.23 ± 0.03[b]	0.32 ± 0.01[a]	0.23 ± 0.03[a]
VE	0.22 ± 0.03[b]	0.23 ± 0.02[a]	0.20 ± 0.02[b]	0.24 ± 0.02[b]	0.20 ± 0.02[a]
CONT	0.23 ± 0.02[b]	0.19 ± 0.02[b]	0.12 ± 0.02[c]	0.21 ± 0.01[b]	0.16 ± 0.02[b]

Note: [a, b, c] =Values with different superscript letters between layer groups are significantly (P<0.05) different.
L+VE=Lycopene + vitamin E-administered hens; L= Lycopene-administered hens; VE=Vitamin E-administered hens; CONT =Control hens.

groups. Overall, eggshell thickness was highest in lycopene+ vitamin E laying hens (0.28 ± 0.02 mm). The laying hens administered with vitamin E alone had the thickness of 0.22 ± 0.02 mm, which did not differ from that of control laying hens (0.18 ± 0.02 mm), but was significantly (P<0.05) lower than the values for the rest groups (Figure 1).

Effect of lycopene and vitamin E on eggshell weight

The eggshell weight in lycopene and/or vitamin E laying hens did not differ significantly at week 1, compared to the controls. However at week 2, all the antioxidant-treated groups recorded higher eggshell weights, compared to the controls. At week 3, although lycopene+ vitamin E and lycopene hens had eggshell weights that were higher than those of controls, the values did not differ from that recorded in vitamin E laying hens. At week 4, lycopene+ vitamin E and vitamin E laying hens recorded eggshell weights that were higher than those of lycopene hens, particularly in the controls. At week 5, only the lycopene+ vitamin E group recorded higher eggshell weight compared to the controls.

The control laying hens recorded the least overall eggshell weight (6.7 ± 0.02 g); which was significantly (P<0.05) lower than the values recorded in lycopene+ vitamin E, lycopene and vitamin E lay-

ing hens (7.3 ± 0.24 g, 7.3 ± 0.3 g and 7.2 ± 0.3 g, respectively) (Table 6 and Figure 2).

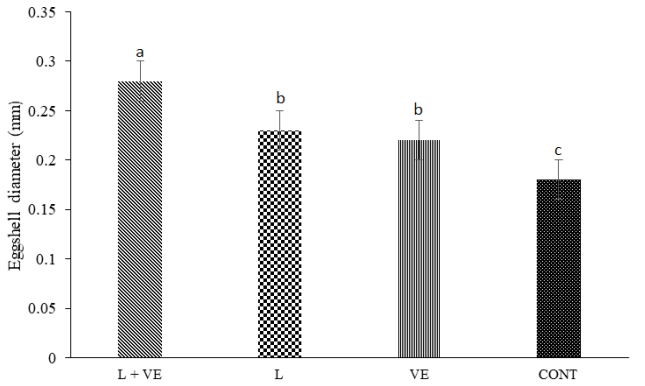

Figure 1: Overall mean eggshell diameter in ISA Brown laying hens during the hot-dry season a, b, c=Values with different superscript letters between layer groups are significantly (P<0.05) different. L+VE=lycopene + vitamin E-administered hens; L= lycopene-administered hens; VE=vitamin E-administered hens; CONT=control hens.

Table 6: Eggshell weight (g) of ISA Brown laying hens administered with lycopene and vitamin E during the hot-dry season (mean ± SEM; n=10 per group).

Group	Week				
	1	2	3	4	5
L+VE	7.4 ± 0.3	7.0 ± 0.3	7.4 ± 0.2	7.5 ± 0.2 [a]	7.1 ± 0.2 [a]
L	7.2 ± 0.2	7.6 ± 0.3	7.5 ± 0.3	7.1 ± 0.2	7.0 ± 0.5 [a]
VE	7.0 ± 0.3	7.7 ± 0.2	7.2 ± 0.4)	7.7 ± 0.3	6.6 ± 0.3[b]
CONT	7.0 ± 0.3	6.3 ± 0.2[b]	7.1 ± 0.2	6.5 ± 0.2[b]	6.5 ± 0.2[b]

Note: [a, b, c]=Values with different superscript letters between hen groups are significantly (P<0.05) different.
L+VE=Lycopene + vitamin E-administered birds; L=Lycopene-administered birds; VE=Vitamin E-administered layers; CONT=Control layers.

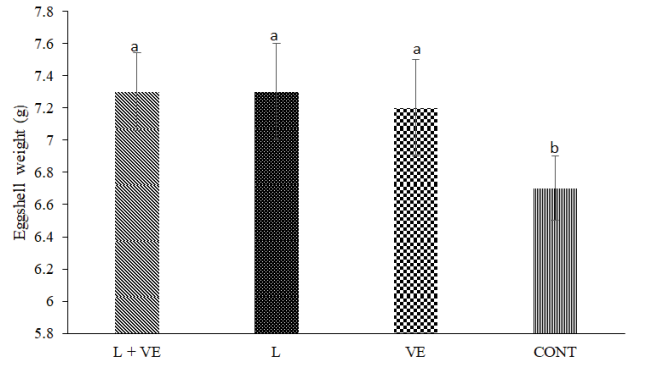

Figure 2: Overall mean eggshell weight in ISA Brown laying hens during the hot-dry season a, b, c=Values with different superscript letters between layer groups are significantly (P<0.05) different. L+VE=lycopene + vitamin E-administered hens; L= lycopene-administered hens; VE=vitamin E-administered hens; CONT=control hens.

DISCUSSION

The results show that during the hot-dry season, the afternoon and evening hours were most thermally stressful to the laying hens. The ambient temperatures and correspondingly the heat load rose progressively from daily nadirs (minimum) at early hours of the day, beginning from 06:00 h and attaining the peak (maximum) at the end of the day, at 18:00 h. Diurnal variations in DBT values show that the overriding environmental factor affecting the hens was the ambient temperature. The finding was similar to the reports of Vathana et al., [30-32] that ambient temperature is characterised by diurnal variations and it is the principal determinant of the metabolic parameters. The recorded trend in environmental temperature was similar to the finding of Dzenda et al., [11,23] that heat stress is prevalent during the hot-dry season in the zone.

The upper limit of DBT (36.71 ± 0.6°C), ranging from 35.0-39.0°C and recorded at 18:00 h and corresponding to THI of 33.0°C (31.40-35°C), shows that the value was remarkably higher than the DBT upper limit of 24-26°C of the thermoneutral (comfort) zone for poultry in the temperate environment [33,34]. The value was also outside the range of 18-26°C, reported for poultry, reared under tropical environmental conditions [32,35,36]. At 6:00 h the lowest DBT of 24.3 ± 0.5°C, corresponding to THI of 23.1°C, fell within the range of the upper limit reported for poultry, and it was the only DBT value recorded that was strictly within the comfort (thermoneutral) zone (Tables 2 and 3). Thus, the laying hens during the hot-dry season in the zone were reared under the DBT values that were predominantly outside the thermoneutral (comfort) zone, indicating that the thermoregulatory mechanisms of the laying hens may be overtasked in an attempt to ensure homeothermy [33,37]. Such impairment results in a down-turn in physiological and performance parameters of the laying hens, indicating that the ambient temperature may have negative influence on the well-being and productivity of the laying hens [38,39].

The heat stress observed from the study period corroborates the reports of Ayo et al. [31,40,41], who demonstrated the prevalence of heat stress in the zone during the hot-dry season. Oladele et al. [42] reported the deterrent effects of heat stress on biochemical parameters in avian species in the zone. Ayo et al. [43] documented some detrimental effects of heat stress on cloacal temperature and performance parameters of pullets in the zone. The present study shows that high ambient temperatures are inimical to egg production and supports the reports of Felva-Grant et al. [44], and Leinonen et al. [39], who demonstrated that high ambient temperature is a deterrent on fecundity in poultry. Obidi et al. [24,25] have demonstrated the deleterious effects of the hot-dry season on fertility and hatchability in breeder hens, and that the season depresses sperm concentration, motility and fertility in breeder cocks in the zone.

The observations on the panting behaviour of the laying hens corroborate the findings of Minka and Ayo [32] and Mack et al. [29,45], who reported panting in heat-exposed pullets and laying hens, respectively as a stressful behavioural response. The present study has shown that high ambient temperature, resulting in increase in thermal load in poultry, induced panting which was an indication of behavioural thermoregulatory response in the laying hens [44]. Such behavioural response to heat stress has been reported by Mack et al. [29,45], who demonstrated that laying hens

subjected to heat stress spend less time feeding, but more time drinking and panting.

The results of the present study show that supplemental co-administration or individual inclusion of lycopene and vitamin E significantly supported fecundity in hens during the hot-dry season, when heat stress was prevalent. Similar results were obtained by Sahin et al. [28], Olson et al. [14] and Turk et al. [46], who demonstrated that lycopene and vitamin E enhance ovarian function during heat stress. Although there was no significant difference between the treatment groups, the antioxidant-administered laying hens recorded a relatively hen-day egg production than the control hens. The result, for the first time, has provided evidence on the beneficial role of the carotenoid lycopene and α-tocopherol in avian ovarian function and fertility. Few studies have demonstrated the significant potential of lycopene in enhancing immunity and reproductive efficiency in poultry [14,46]. The co-supplementation of lycopene and vitamin E to laying hens during the hot-dry season resulted in the highest hen-day egg production throughout the experimental period. The result shows that lycopene- and/or vitamin E-treated laying hens maintained consistently hen-day production, amounting to over 6% weekly mean egg production, compared to the controls.

The results show that the rate of decline in hen-day egg production was mitigated in lycopene- and vitamin E-administered laying hens in comparison with the control hens. This was, apparently, irrespective of the deterrent associated with old age of the laying hens and the heat load acting on them during the hot-dry season. This finding supports the previous report on the antioxidant and/or antistress activities of vitamin E and corroborated by Vazquez et al. [47], Lewis et al. [22] and Liu et al. [48], who reported the antistress and antiinflammatory effects of vitamin E in hens exposed to heat stress-induced conditions. Olson et al. [14] and Yardibi and Turkay [49], demonstrated the ameliorative effects of vitamin E on egg production, egg quality and nutrient utilisation in laying hens exposed to heat stress, thereby improving fertility and fecundity. The present study was conducted on laying hens, aged 41 weeks at the beginning of the study, when vital indices of fertility, including the rate of egg production and quality in hens normally start to decline due to age-related gonadal dysfunction and metabolic alterations, mediated by oxidative stress [19,50,51]. Such age-related ovarian functional depreciation is significantly associated with stress-mediated compromise in mitochondrial function due to the susceptibility of the ovarian structural lipoproteins to oxidative stress [52-54].

The results show that lycopene ameliorated the effect of heat stress on laying hens and improved hen-day egg production. Although the mechanism of action of lycopene was not elucidated in the present study, the reports of [55,56] demonstrated lycopene's antioxidant activity in avian species and its beneficial biological intervention in stress-induced ovarian failure. Bakker et al. [55] showed the anti-inflammatory and antioxidative roles of a dietary mixture of vitamin E and lycopene. Since most physiological anomalies, including disease conditions and reproductive (gonadal) dysfunctions, are mediated by inflammatory and oxidative stress mechanisms, the findings of the present study on the role of lycopene and α-tocopherol in alleviating heat-induced stress and reproductive losses during the hot-dry season may also be due to their anti-inflamatory and, particularly, antioxidative properties [48,56].

The remarkable decrease in eggshell thickness and eggshell weight in control laying hens, suggests a decrease in calcium mobilisation and utilisation during the heat stress. The results corroborate previous reports [29,57-59] that heat-induced stress adversely affects qualitative indices of eggshell in laying hens. Eggshell quality is an important index of overall egg quality, associated with the efficiency of calcium mobilisation and deposition on eggshell in the process of egg formation. This physiological aptitude of the laying hens reduces during unfavuorable conditions, including excessive increase in environmental temperatures [18,60,61]. The results show that lycopene and vitamin E ameliorated the deleterious effects of heat stress on the laying hens in the zone, and that the antioxidants improved qualitative indices of the egg in the laying hens, exposed to environmental heat stress during the hot-dry season. The observation supports the reports of Olson et al. [14] and Sahin et al. [2,62] that lycopene supplementation alleviates heat-induced stress on performance parameters of domestic birds, including egg qualitative indices. Similar report by [63], demonstrated the beneficial effect of vitamin E on egg production, qualitative eggshell indices and integrity in breeder hens, subjected to high ambient temperature. The combined effect of vitamin E and lycopene in alleviation of stress indices in broiler chickens exposed to high oxidant conditions has been demonstrated by Lu et al. [64].

The results show that lycopene and/or vitamin E increased the eggshell weight starting from week 2 of administration and the increase was sustained at week 3 in lycopene+ vitamin E and lycopene groups; while at week 4 the increase occurred in all the antioxidant-treated groups, but higher in lycopene+ vitamin E, and vitamin E, compared to lycopene group. This result indicates that lycopene administration significantly increased eggshell weight compared to controls, but the increase was, apparently, more sustained in laying hens administered with vitamin E, followed by those given lycopene+ vitamin E, while the least occurred in lycopene group. The findings have shown that with increase in the duration of administration of antioxidants lasting five weeks, lycopene+ vitamin E exerted the most potent effect on the increase in eggshell weight, compared to lycopene or vitamin E group.

CONCLUSION

In conclusion, thermal environment conditions during the hot-dry season in the Northern Guinea Savannah zone induced heat stress, adversely affecting laying hens. The thermal environmental conditions exerted negative effects on the laying hens via impairment in egg qualitative indices. Lycopene and vitamin E, especially their combination, alleviated the risk of adverse effects of heat stress on their productivity during the hot-dry season by increasing hen-day egg production and improving eggshell qualitative indices.

ETHICS APPROVAL

The husbandry and the conduct of the experiments on the laying hens were performed in accordance with the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (Council of Europe No 123, Strasbourg 1985). All the experimental protocols described were approved

by the Ethics Review Committee for Animal Experimentation of Ahmadu Bello University, Zaria, Nigeria.

CONFLICTS OF INTEREST

There is no conflict of interest.

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