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Reducing Sharp Fluctuations in Body Temperature and Optimizing Production Index of Broilers Using Dietary Electrolytes

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Abstract

A degree centigrade fall or rise in body temperature of broiler chickens is sufficient to reduce performance, alter sound physiological state and divert nutritional metabolism in quest for ensuring thermal balance. Thermoregulatory mechanisms of newly hatched chicks are poorly developed, and fluctuations in brooding temperature coupled with severe environmental temperatures in the tropics could threaten the survivability, production and economic integrity of fast-growing strains of broilers. However, information on the effect of sharp fluctuations in body temperature on nutrient intake and European production index (EPI) of broilers fed dietary electrolytes is scanty and thus investigated. Using a total of 300, one-day-old unsexed broiler chicks (Arbor Acre) that were randomly allotted to six dietary treatments (T1-210, T2-240, T3270, T4-300, T5-330 and T6-360 mEq/kg electrolyte balance), data on performance characteristics and their correlations with body temperature and EPI at prestarter, starter and finisher phases were determined using standard procedures. Data were analysed using descriptive statistics and ANOVA at $\alpha = 0.05$. At prestarter phase, feed intake (FI) had a strong and positive relationship with protein intake ($r = 1.00$; $p < 0.01$), EPI ($r = 0.96$; $p < 0.01$) and potassium (K) intake ($r = 0.66$; $p < 0.01$), but was negatively correlated with temperature change ($r = -0.39$; $p < 0.05$). However, FI was not significantly correlated with body weight (BW), body weight gain (BWG), sodium (Na) and water intake. At starter phase, EPI was positively correlated to K intake ($r = 0.38$; $p < 0.05$), but not Na and chloride (Cl) intake. European production index of starter chicks could be enhanced by increasing the level of K intake through dietary supplementation up to 1.02%. Weight gain was adversely affected by sharp changes in temperature at finisher phase. Increase in water intake may not be a remedial tool in lowering sharp fluctuations in body temperature. However, sharp fluctuation in body temperature of broilers was reduced with DEB of 330, 270 and 240 mEq/kg at prestarter, starter and finisher phases, respectively.

Keywords

Temperature Change, Broilers, European Production Index,
Dietary Electrolyte Balance, Heat Stress

1. Introduction

Rectal temperature has been a good indicator of body temperature of birds as it is the body temperature measured per rectum and it is accurate for measuring internal body temperature. De Rensis and Scaramuzzi (2003) [1] also noted that rectal temperature is an excellent indicator of the physiological state and is reliable in evaluating thermal balance of the body, however, homeostasis mechanisms can prevent a rise in rectal temperature. Perissinotto *et al*., (2007) [2] reported that body temperature is determined by the balance between heat loss and gain, and its value is obtained by measuring the rectal temperature. The thermoregulatory characteristics of poultry differ to some extent from those of mammals due to their high rate of metabolism and more intensive heat production relative to their lowered dissipating capacity of heat, as affected by feathers and absence of sweat glands. Evaporative cooling is therefore achieved exclusively by panting. Daghir (2009) [3] reported that after feathering, birds prefer mean ambient temperatures between 18˚C to 22˚C for growth and egg production, although the optimal temperature for feed efficiency is higher. The author noted further that the crucial temperature for poultry is 30˚C, because birds are still able to compensate for energy loss caused by lower feed intake through a relatively better feed conversion ratio and lowered basal metabolic rate. However, above 30˚C, nutrient intake declines such that birds are no longer able to compensate for it, and a showcase of rapid decline in production becomes vivid. Birds are homoeothermic like mammals, and they have to maintain a relatively constant temperature of their vital organs. Therefore, it becomes essential that heat be lost or conserved in response to changes in the environment. Athira *et al.* (2017) [4] noted that climate change has led to environmental stresses that affect efficient livestock production. A significant decrease in productive potential and an increase in physiological responses are observed in animals which are exposed to hot climates. According to Borges *et al.* (2003) [5], newly hatched chicks have body temperatures approximately 2.5˚C below that of the adult bird, and it takes about a week post-hatch before the adult body temperature can be reached. This increase is related to feather cover and the increase in metabolic activities associated with growth. However, Borges *et al.* (2003) [5] stated that the use of dietary electrolytes could enhance broiler performance under heat stress, and noted further that regardless of ambient temperatures, increasing DEB in broiler rations stimulated feed intake, which may possibly be due to increasing Na^+ levels in diets (0.15% to 0.45%). Mongin (1981) [6] reported that optimal chick growth performance, when fed purified diets, was achieved using DEB of around 250 mEq/kg, and an optimal electrolyte balance was found for feeds containing from 250 to 300 mEq/kg. Murakami *et al.* (2001) [7] established with modern broiler strains and practical diets, an optimal DEB for starter phase to be between 246 and 315 mEq/kg, showcasing the efficacy of dietary electrolyte balance for enhancing performance of broiler chickens. However, information on the effect of DEB on body temperature change and production index of fast growing strains of broiler chickens reared under severe heat stress condition is scanty. Therefore, this study was conducted to investigate the effect of sharp fluctuations in body temperature on nutrient intake and European production index (EPI) of broilers fed dietary electrolytes and also to determine the association between core performance parameters, body temperature and EPI of broilers under tropical conditions at prestarter, starter and finisher phases.

2. Materials and Methods

The study was carried out at the Teaching and Research Farm, University of Ibadan, Nigeria, after the experimental protocol was reviewed and approved by the Institutional Animal Care and Use Committee; and the Agricultural Biochemistry and Nutrition Unit of the Department of Animal Science. A total of 300, one-day old unsexed Arbor Acre broiler chicks were randomly allotted to six dietary treatments (mEq/kg: 210, 240, 270, 300, 330, 360 DEB) with five replicate groups in a Completely Randomized Design (CRD). Feed grade potassium chloride and sodium bicarbonate, and the inherent potassium, sodium and chloride ions in feed ingredients were the electrolyte sources computed for determining the aggregate DEB using the equations derived by Popoola and Iyayi (2018) [8]. The derived equations were based on assumptions opined by Popoola *et al.* (2020) [9] for an ideal DEB, affirming that not more than 30 to 140 mEq/kg DEB are required from mineral sources, with about 115 to 210 mEq/kg DEB obtainable from feed ingredients.

The derived equation of DEB is $\sum \text{DEB} = \sum\left(\text{Na}^+ + \text{K}^+\right) - \sum \text{Cl}^- \cdots [\text{y}][\text{c}]$ (1)

where [y] = mineral sources, and [c] = other macro ions (Ca, Mg, P, S etc) held constant.

$$\sum \text{DEB} = \iota\text{DEB} + \varepsilon\text{DEB} \quad (2)$$

where $\sum$DEB = Aggregate DEB; ιDEB = Inherent DEB in rations and εDEB = DEB in Electrolyte sources.

Feed intake was determined by giving a known quantity of feed to the birds and subtracting the left over for a given period from the quantity supplied. This difference was divided by the number of birds in a replicate group to estimate the feed intake per bird. Body weight gain of birds was determined by subtracting the initial weight for each week from the final weights with the aid of sensitive weighing scale. Drinking water was supplied to broilers as described by Popoola *et al.* (2019) [10]. European production index (EPI) was calculated using the formula

$$\text{EPI} = \frac{\text{Liveability}(\%) \times \text{Body weight}(\text{kg})}{\text{Age}(\text{d}) \times \text{FCR}(\text{kg feed/kg gain})} \times 100$$

Maximum and minimum average ambient temperature and relative humidity were monitored on a daily basis using a digital hygro-thermometer. Rectal temperature was measured in the morning (06:00-08:00 h) and afternoon (13:00-15:00 h), with the use of a digital rectal probe. Two birds per pen with body weight closest to the class mean weight were identified for body temperature measurement. Assay was conducted for sodium and potassium (Flame spectrophotometer), and chloride (titration) in diets fed to broiler chickens at different phases of growth (Lacroix *et al*., 1970) [11]. Data obtained were subjected to descriptive statistics and analysis of variance using SAS package (2012) [12]. Means for treatments in the analysis of variance were compared using Duncan Multiple range test and all statement of significance were based on probability level of 0.05.

3. Results

The chemical composition of dietary treatments fed to broiler chickens at starter and finisher phases is shown in **Table 1**. **Table 2** shows the growth performance, European production index and body temperature of broilers fed dietary electrolytes at prestarter phase. Feed intake (FI) of birds on 270 mEq/kg DEB was significantly ($p < 0.05$) lower compared to 330 mEq/kg DEB. However, body weight (BW) and body weight gain (BWG) of birds were not affected by aggregate DEB treatments. Protein intake (PI) was observed to be lower in birds on 270 mEq/kg DEB. The European production index (EPI) observed in broilers on 270 mEq/kg (328.30) and 360 mEq/kg (338.86) were significantly ($p < 0.05$) lower compared to 330 mEq/kg (369.39) DEB at prestarter phase. Na intake was lowest ($p < 0.05$) in birds on 210 mEq/kg (0.62 g) and highest in those on 360 mEq/kg (2.20 g) DEB. K intake in birds on 330 mEq/kg (4.70 g) and 360 mEq/kg (4.62) was significantly ($p < 0.05$) higher compared to other treatments. Cl intake observed in birds on 240 mEq/kg (1.22 g) and 270 mEq/kg (1.35 g) were similar and significantly ($p < 0.05$) lower compared to 300 (1.62 g), 330 (1.98 g), and 360 mEq/kg (2.07 g) DEB. Water intake (WI) values of birds on 210, 240, and 300 mEq/kg DEB were similar and significantly ($p < 0.05$) lower compared to 360 mEq/kg DEB. The lowest ($p < 0.05$) morning and afternoon rectal temperature (RT) was observed in birds on 270 mEq/kg. However, temperature change (TC) in broilers on 330 mEq/kg (0.35˚C) DEB was significantly ($p < 0.05$) lower compared to other treatments. At starter phase (**Table 3**), FI was not significantly ($p > 0.05$) affected by dietary treatments. However, BW was significantly higher in birds on 330 mEq/kg (679.68 g) DEB compared to other treatments except 270 mEq/kg (673.44 g). The PI, BWG, and EPI were not significantly ($p > 0.05$) affected by DEB treatments

Table 1. Chemical composition of diets fed to broilers at starter and finisher phases.

Phase	Nutrients (%)	T1	T2	T3	T4	T5	T6
Starter	Crude protein	22.90	22.95	23.10	22.93	22.79	22.89
	Crude fat	5.29	5.26	5.44	5.54	5.46	5.66
	Calcium	1.01	1.02	1.04	1.01	1.02	1.03
	Phosphorus	0.82	0.83	0.89	0.81	0.83	0.82
	Sodium	0.14	0.22	0.29	0.36	0.43	0.51
	Potassium	0.82	0.87	0.92	0.97	1.02	1.07
	Chloride	0.23	0.28	0.33	0.38	0.43	0.48
Finisher	Crude protein	21.78	21.67	21.84	21.79	21.66	21.85
	Crude fat	4.24	4.20	4.15	4.11	4.21	4.09
	Calcium	1.03	0.94	0.94	0.95	0.96	0.96
	Phosphorus	0.78	0.77	0.78	0.78	0.78	0.78
	Sodium	0.16	0.23	0.29	0.37	0.44	0.52
	Potassium	0.83	0.85	0.89	0.95	0.99	1.04
	Chloride	0.25	0.27	0.32	0.37	0.42	0.47

T1—210 mEq/kg, T2—240 mEq/kg, T3—270 mEq/kg, T4—300 mEq/kg, T5—330 mEq/kg, T6—360 mEq/kg, DEB—Dietary electrolyte balance.

Table 2. Growth performance, production index and body temperatures of heat-stressed broilers at prestarter phase.

Parameters	Dietary electrolyte balance (mEq/kg)							
	210	240	270	300	330	360	SEM	p value
FI (g/bird)	443.16^{ab}	437.20^{ab}	409.28^{b}	426.17^{ab}	460.82^{a}	431.66^{ab}	13.72	0.20
BW (g/bird)	319.60	331.24	332.16	339.39	333.40	320.14	10.99	0.77
BWG (g/bird)	283.40	294.66	295.80	303.17	297.10	284.54	10.96	0.78
PI (g/bird)	101.93^{ab}	100.56^{ab}	94.13^{b}	98.02^{ab}	105.99^{a}	99.28^{ab}	3.16	0.20
EPI	357.00^{ab}	351.04^{ab}	328.30^{b}	341.45^{ab}	369.39^{a}	338.86^{b}	9.44	0.06
Na intake (g/bird)	0.62^{f}	0.96^{e}	1.19^{d}	1.53^{c}	1.98^{b}	2.20^{a}	0.05	<0.0001
K intake (g/bird)	3.63^{c}	3.80^{bc}	3.77^{bc}	4.13^{b}	4.70^{a}	4.62^{a}	0.13	<0.0001
Cl intake (g/bird)	1.02^{d}	1.22^{c}	1.35^{c}	1.62^{b}	1.98^{a}	2.07^{a}	0.05	<0.0001
Water intake (mL/bird/d)	235.63^{c}	261.93^{b}	265.18^{b}	265.69^{b}	280.67^{ab}	297.16^{a}	7.67	<0.0001
Morning RT (˚C)	40.96^{a}	40.84^{a}	40.12^{c}	40.78^{a}	40.54^{b}	40.96^{a}	0.06	<0.0001
Afternoon RT (˚C)	41.41^{a}	41.45^{a}	40.69^{c}	41.37^{a}	40.89^{b}	41.47^{a}	0.05	<0.0001
TC (˚C)	0.46^{ab}	0.61^{a}	0.58^{a}	0.59^{a}	0.35^{b}	0.51^{ab}	0.06	0.03

^{abcdef}Means of treatments along a row with different superscripts differed significantly ($p < 0.05$) using DMRT. FI—Feed intake, BW—Body weight, BWG—Body weight gain, PI—Protein intake, EPI—European production index, Na—Sodium, K—Potassium, Cl—Chloride, RT—Rectal temperature, TC—Temperature change.

Table 3. Growth performance, production index and body temperatures of heat-stressed broilers at starter phase.

Parameters	Dietary electrolyte balance (mEq/kg)							
	210	240	270	300	330	360	SEM	p value
FI (g/bird)	424.00	420.70	441.00	445.89	419.00	423.00	3.97	0.53
BW (g/bird)	629.14^{bc}	659.80^{b}	673.44^{ab}	656.50^{b}	679.68^{a}	625.78^{c}	14.67	0.07
BWG (g/bird)	309.54	328.56	341.28	317.11	346.28	304.64	14.43	0.26
PI (g/bird)	97.52	96.76	101.43	102.55	96.37	97.29	2.87	0.53
EPI	411.90	403.24	414.87	448.38	391.68	416.17	19.74	0.48
Na intake (g/bird)	0.59^{f}	0.93^{e}	1.28^{d}	1.61^{c}	1.80^{b}	2.16^{a}	0.05	<0.0001
K intake (g/bird)	3.48^{c}	3.66^{c}	4.06^{b}	4.33^{ab}	4.27^{ab}	4.53^{a}	0.12	<0.0001
Cl intake (g/bird)	0.98^{e}	1.18^{d}	1.46^{c}	1.69^{b}	1.80^{b}	2.03^{a}	0.05	<0.0001
Water intake (mL/bird/d)	449.32^{b}	498.95^{a}	501.98^{a}	507.48^{a}	506.55^{a}	524.72^{a}	10.51	<0.0001
Morning RT (˚C)	40.72^{a}	40.63^{a}	40.36^{b}	40.70^{a}	40.63^{a}	40.67^{a}	0.04	<0.0001
Afternoon RT (˚C)	41.71^{a}	41.69^{a}	40.90^{c}	41.69^{a}	41.43^{b}	41.65^{a}	0.03	<0.0001
TC (˚C)	0.99^{a}	1.05^{c}	0.54^{c}	0.99^{a}	0.79^{b}	0.98^{a}	0.04	<0.0001

^{abcdef}Means of treatments along a row with different superscripts differed significantly (p < 0.05) using DMRT. FI—Feed intake, BW—Body weight, BWG—Body weight gain, PI—Protein intake, EPI—European production index, Na—Sodium, K—Potassium, Cl—Chloride, RT—Rectal temperature, TC—Temperature change.

at starter phase. However, Na, K, and Cl intake were significantly ($p < 0.05$) higher in birds on 360 mEq/kg DEB. Similar WI values were observed in birds on 240 (498.95), 270 (501.98), 300 (507.48), 330 (506.55) and 360 DEB (524.72 mL/bird/d). However, birds on 270 mEq/kg DEB had the lowest ($p < 0.05$) TC of 0.54˚C.

At finisher phase (Table 4), FI was not significantly influenced by dietary treatments. However, BW observed in birds on 210 mEq/kg (1310.00) was significantly ($p < 0.05$) lower compared to 240, 270, and 300 mEq/kg DEB. Similar values of BWG were observed in birds on 210 DEB (680.86 g) and 330 (676.72 g). The EPI was not significantly ($p > 0.05$) affected by DEB treatments at finisher phase. However, Na, K, and Cl intake values were significantly ($p < 0.05$) lower in birds on 210 mEq/kg DEB compared to other treatments. WI was lower ($p < 0.05$) in 210 (1042.79), 240 (1068.70), and 300 (1052.86) compared to 360 (1203.71 mL). Morning and afternoon RT were highest ($p < 0.05$) in birds on 210 mEq/kg. However, 240 mEq/kg DEB resulted in significantly ($p < 0.05$) lower TC (0.89) compared to other treatments.

Table 5 shows the correlation between performance parameters and sharp fluctuations in body temperature of heat-stressed broilers at prestarter phase. Feed intake (FI) had a strong and positive relationship with protein intake ($r = 1.00$; $p < 0.01$), production index ($r = 0.96$; $p < 0.01$) and potassium intake ($r = 0.66$; $p < 0.01$). However, FI was negatively correlated with temperature change ($r = -0.39$; $p < 0.05$). It was observed that FI was not significantly ($p > 0.05$) correlated with

Table 4. Growth performance, production index and body temperatures of heat-stressed broilers at finisher phase.

Parameters	Dietary electrolyte balance (mEq/kg)							
	210	240	270	300	330	360	SEM	p value
FI (g/bird)	1531.80	1572.00	1543.00	1481.89	1528.00	1487.00	36.02	0.49
BW (g/bird)	1310.00^{c}	1485.12^{a}	1454.16^{ab}	1382.75^{b}	1356.40^{bc}	1344.91^{bc}	39.27	0.03
BWG (g/bird)	680.86^{b}	825.32^{a}	780.72^{ab}	726.26^{ab}	676.72^{b}	719.13^{ab}	35.82	0.04
PI (g/bird)	337.00	345.84	339.46	326.02	336.16	327.14	7.93	0.49
EPI	849.82	812.81	822.05	809.29	875.85	798.05	27.82	0.38
Na intake (g/bird)	2.45^{f}	3.62^{e}	4.47^{d}	5.48^{c}	6.72^{b}	7.73^{a}	0.14	<0.0001
K intake (g/bird)	12.71^{c}	13.36^{bc}	13.73^{bc}	14.08^{b}	15.13^{a}	15.46^{a}	0.34	<0.0001
Cl intake (g/bird)	3.83^{f}	4.24^{e}	4.94^{d}	5.48^{c}	6.42^{b}	6.99^{a}	0.13	<0.0001
Water intake (mL/bird/d)	1042.79^{b}	1068.70^{b}	1103.73^{ab}	1052.86^{b}	1133.11^{ab}	1203.71^{a}	33.04	0.02
Morning RT (˚C)	41.01^{a}	40.48^{d}	40.74^{c}	40.83^{b}	40.94^{a}	40.85^{b}	0.03	<0.0001
Afternoon RT (˚C)	42.02^{a}	41.36^{d}	41.72^{c}	41.87^{b}	41.91^{b}	41.89^{b}	0.03	<0.0001
TC (˚C)	1.01^{a}	0.89^{b}	0.98^{ab}	1.04^{a}	0.96^{ab}	1.05^{a}	0.04	0.07

^{abcdef}Means of treatments along a row with different superscripts differed significantly ($p < 0.05$) using DMRT. FI—Feed intake, BW—Body weight, BWG—Body weight gain, PI—Protein intake, EPI—European production index, Na—Sodium, K—Potassium, Cl—Chloride, RT—Rectal temperature, TC—Temperature change.

Table 5. Correlation between performance parameters and sharp flunctuations in body temperature of heat-stressed broilers at prestarter phase.

Parameters	FI	BW	BWG	PI	Prod. index	Na intake	K intake	Cl intake	Water intake	Morning RT	Afternoon RT	TC
FI		0.29 ^{ns}	0.29 ^{ns}	1.00**	0.96**	0.25^{ns}	0.66**	0.35^{ns}	0.01^{ns}	0.20^{ns}	0.08^{ns}	−0.39*
BW	0.29^{ns}		0.99**	0.29^{ns}	0.23^{ns}	0.10^{ns}	0.22^{ns}	0.13^{ns}	0.02	−0.15^{ns}	−0.12^{ns}	0.09^{ns}
BWG	0.29^{ns}	0.99**		0.29^{ns}	0.22^{ns}	0.11^{ns}	0.22^{ns}	0.14^{ns}	0.03^{ns}	−0.15^{ns}	−0.12^{ns}	0.09^{ns}
PI	1.00**	0.29^{ns}	0.29^{ns}		0.96**	0.25^{ns}	0.66**	0.35^{ns}	0.01^{ns}	0.20^{ns}	0.08^{ns}	−0.39*
Prod. index	0.96**	0.23^{ns}	0.22^{ns}	0.96**		0.19^{ns}	0.59**	0.29^{ns}	−0.39^{ns}	0.25^{ns}	0.15^{ns}	−0.31^{ns}
Na intake	0.25^{ns}	0.10^{ns}	0.11^{ns}	0.25^{ns}	0.19^{ns}		0.89**	0.99**	0.93**	−0.02^{ns}	−0.10^{ns}	−0.30^{ns}
K intake	0.66**	0.22^{ns}	0.22^{ns}	0.66**	0.59**	0.89**		0.94**	0.72**	0.08^{ns}	−0.05^{ns}	−0.43*
Cl intake	0.35^{ns}	0.13^{ns}	0.14^{ns}	0.35^{ns}	0.29^{ns}	0.99**	0.94**		0.89**	0.01^{ns}	−0.09^{ns}	−0.35^{ns}
Water intake	0.01^{ns}	0.02^{ns}	0.03^{ns}	0.01^{ns}	−0.04^{ns}	0.93**	0.72**	0.89**		−0.07^{ns}	−0.09^{ns}	−0.10^{ns}
Morning RT	0.20^{ns}	−0.15^{ns}	−0.15^{ns}	0.20^{ns}	0.25^{ns}	−0.02^{ns}	0.08^{ns}	0.01^{ns}	−0.07^{ns}		0.96**	−0.03^{ns}
Afternoon RT	0.08^{ns}	−0.12^{ns}	−0.12^{ns}	0.08^{ns}	0.15^{ns}	−0.10^{ns}	−0.05^{ns}	−0.09^{ns}	−0.09^{ns}	0.96**		0.27^{ns}
TC	−0.39*	0.09^{ns}	0.09^{ns}	−0.39*	−0.31^{ns}	−0.30^{ns}	−0.43*	−0.35^{ns}	−0.10^{ns}	−0.03^{ns}	0.27^{ns}	

**$p < 0.01$, *$p < 0.05$, ns = not significant. FI—feed intake, BW—body weight, BWG—body weight gain, PI—Protein intake, Prod.—production, Na—sodium, K—potassium, Cl—chloride, RT—rectal temperature, TC—temperature change.

BW, BWG, Na intake, water intake, morning and afternoon RT. The BW observed in broilers at prestarter phase was not significantly ($p > 0.05$) correlated with Na, K, and Cl intake. Protein intake had a strong and positive relationship with production index ($r = 0.96$; $p < 0.01$) and K intake ($r = 0.66$; $p < 0.01$), but was negatively correlated to TC ($r = -0.39$; $p < 0.05$). The Na ($r = 0.93$; $p < 0.01$), K ($r = 0.72$; $p < 0.01$), and Cl ($r = 0.89$; $p < 0.01$) had a strong and positive relationship with water intake of heat-stressed birds at prestarter phase. Temperature change was negatively correlated to potassium intake ($r = -0.43$; $p < 0.05$).

Table 6 shows the correlation between performance parameters and sharp fluctuations in body temperature of heat-stressed broilers at starter phase. The FI was positively correlated with BW ($r = 0.52$; $p < 0.01$), protein intake ($r = 1.00$; $p < 0.01$), production index ($r = 0.59$; $p < 0.01$) and K intake ($r = 0.58$; $p < 0.01$). The BW was not significantly ($p > 0.05$) correlated to morning or afternoon rectal temperature and temperature change. Production index was positively correlated to K intake ($r = 0.38$; $p < 0.05$), but not Na and Cl intake. Water intake had a strong and positive relationship with Na ($r = 0.85$; $p < 0.01$), K ($r = 0.72$; $p < 0.01$) and Cl ($r = 0.83$; $p < 0.01$) intake at starter phase. Table 7 shows the correlation between performance parameters and sharp fluctuations in body temperature of heat-stressed broilers at finisher phase. Feed intake was negatively correlated with temperature change ($r = -0.36$; $p < 0.05$), but had a strong and positive relationship with production index ($r = 0.60$; $p < 0.01$). The BW was negatively correlated to morning temperature ($r = -0.57$; $p < 0.01$), afternoon temperature ($r = -0.57$; $p < 0.01$) and temperature change ($r = -0.45$, $p < 0.05$). A strong, but negative correlation existed between body weight gain and temperature change ($r = -0.39$; $p < 0.05$) in heat-stressed birds at finisher phase. Sodium intake had a strong and positive relationship with temperature change ($r = 0.39$; $p < 0.05$).

Table 6. Correlation between performance parameters and sharp flunctuations in body temperature of heat-stressed broilers at starter phase.

Parameters	FI	BW	BWG	PI	Prod. index	Na intake	K intake	Cl intake	Water intake	Morning RT	Afternoon RT	TC
FI		0.52**	0.31^{ns}	1.00**	0.59**	0.17^{ns}	0.58**	0.26^{ns}	0.05^{ns}	-0.15^{ns}	-0.15^{ns}	-0.14^{ns}
BW	0.52**		0.78**	0.52**	0.09^{ns}	0.12^{ns}	0.33^{ns}	0.17^{ns}	-0.16^{ns}	-0.32^{ns}	-0.34^{ns}	-0.34^{ns}
BWG	0.31^{ns}	0.78**		0.31^{ns}	−0.47**	0.04^{ns}	0.17^{ns}	0.07^{ns}	0.08^{ns}	-0.29^{ns}	-0.32^{ns}	-0.32^{ns}
PI	1.00**	0.52**	0.31		0.59**	0.17^{ns}	0.58^{ns}	0.26^{ns}	0.05^{ns}	-0.15^{ns}	-0.15^{ns}	-0.14^{ns}
Prod. index	0.59**	0.09^{ns}	−0.47**	0.59**		0.14^{ns}	0.38*	0.19^{ns}	0.05^{ns}	0.06^{ns}	0.07^{ns}	0.07^{ns}
Na intake	0.17^{ns}	0.12^{ns}	0.04^{ns}	0.17^{ns}	0.14^{ns}		0.90**	0.99**	0.85**	0.01^{ns}	-0.07^{ns}	-0.12^{ns}
K intake	0.58**	0.33^{ns}	0.17^{ns}	0.58**	0.38**	0.90**		0.94**	0.72**	-0.05^{ns}	-0.12^{ns}	-0.16^{ns}
Cl intake	0.26^{ns}	0.17^{ns}	0.07^{ns}	0.26^{ns}	0.19^{ns}	0.99**	0.94**		0.83**	0.003^{ns}	-0.08^{ns}	-0.13^{ns}
Water intake	0.05^{ns}	0.16^{ns}	0.08^{ns}	0.05^{ns}	0.05^{ns}	0.85**	0.72**	0.83**		-0.22^{ns}	-0.18^{ns}	-0.14^{ns}
Morning RT	-0.15^{ns}	-0.32^{ns}	-0.29^{ns}	-0.15^{ns}	0.06^{ns}	0.01^{ns}	-0.05^{ns}	0.003^{ns}	-0.22^{ns}		0.96**	0.89**
Afternoon RT	-0.15^{ns}	-0.34^{ns}	-0.32^{ns}	-0.15^{ns}	0.07^{ns}	-0.07^{ns}	-0.12^{ns}	-0.08^{ns}	-0.18^{ns}	0.96**		0.98**
TC	-0.14^{ns}	-0.34^{ns}	-0.32^{ns}	-0.14^{ns}	0.07^{ns}	-0.12^{ns}	-0.16^{ns}	-0.13^{ns}	-0.14^{ns}	0.89**	0.98**	

**$p < 0.01$, *$p < 0.05$, ns = not significant. FI—feed intake, BW—body weight, BWG—body weight gain, PI—Protein intake, Prod.—production, Na—sodium, K—potassium, Cl—chloride, RT—rectal temperature, TC—temperature change.

Table 7. Correlation between performance parameters and sharp flunctuations in body temperature of heat-stressed broilers at finisher phase.

Parameters	FI	BW	BWG	PI	Prod. index	Na intake	K intake	Cl intake	Water intake	Morning RT	Afternoon RT	TC
FI		0.45*	0.33^{ns}	1.00**	0.60**	-0.12^{ns}	0.35^{ns}	-0.04^{ns}	-0.14^{ns}	-0.22^{ns}	−0.27	−0.36*
BW	0.45*		0.94**	0.45*	-0.24^{ns}	-0.09^{ns}	0.08^{ns}	-0.10^{ns}	-0.11^{ns}	−0.57**	−0.57**	−0.45*
BWG	0.33^{ns}	0.94**		0.33^{ns}	−0.49**	-0.13^{ns}	-0.01^{ns}	-0.15^{ns}	-0.09^{ns}	−0.58**	−0.56**	−0.39*
PI	1.00**	0.45*	0.33^{ns}		0.60**	-0.12^{ns}	0.35^{ns}	-0.04^{ns}	-0.14^{ns}	-0.22^{ns}	-0.27^{ns}	−0.36*
Prod. index	0.60**	-0.24^{ns}	−0.49**	0.60**		0.02^{ns}	0.32^{ns}	0.09^{ns}	-0.07^{ns}	0.23^{ns}	0.17^{ns}	-0.06^{ns}
Na intake	-0.12^{ns}	-0.09^{ns}	-0.13^{ns}	-0.12^{ns}	0.02^{ns}		0.89**	0.99**	0.84**	0.18^{ns}	0.24^{ns}	0.39*
K intake	0.35^{ns}	0.08^{ns}	-0.01^{ns}	0.35^{ns}	0.32^{ns}	0.89**		0.92**	0.71**	0.15^{ns}	0.19^{ns}	0.27^{ns}
Cl intake	-0.04^{ns}	-0.10^{ns}	-0.15^{ns}	-0.04^{ns}	0.09^{ns}	0.99**	0.92**		0.84**	0.25^{ns}	0.31^{ns}	0.43*
Water intake	-0.14^{ns}	-0.11^{ns}	-0.09^{ns}	-0.14^{ns}	-0.07^{ns}	0.84**	0.71**	0.84**		0.11^{ns}	0.15^{ns}	0.25^{ns}
Morning RT	-0.22^{ns}	−0.57**	−0.58**	-0.22^{ns}	0.23^{ns}	0.18^{ns}	0.15^{ns}	0.25^{ns}	0.11^{ns}		0.99**	0.74**
Afternoon RT	-0.27^{ns}	−0.57**	−0.56**	-0.27^{ns}	0.17^{ns}	0.24^{ns}	0.19^{ns}	0.31^{ns}	0.15^{ns}	0.99**		0.85**
TC	−0.36*	−0.45*	−0.39*	-0.36^{ns}	-0.06^{ns}	0.39*	0.27^{ns}	0.43*	0.25^{ns}	0.74**	0.85**	

**p < 0.01, *p < 0.05, ns = not significant. FI—feed intake, BW—body weight, BWG—body weight gain, PI—Protein intake, Prod.—production, Na—sodium, K—potassium, Cl—chloride, RT—rectal temperature, TC—temperature change.

Also, Cl intake was positively correlated to temperature change ($r = 0.43$; $p < 0.01$) at finisher phase. However, K intake had no significant ($p > 0.05$) relationship with temperature change at finisher phase. Water intake was not significantly ($p > 0.05$) correlated to changes in body temperature in heat-stressed broilers at finisher phase, but had a strong relationship with intake of Na ($r = 0.84$; $p < 0.01$), K ($r = 0.71$; $p < 0.01$) and Cl ($r = 0.84$; $p < 0.01$).

4. Discussion

The results obtained from current study were consistent with the report of Yalçin *et al.* (2001) [13] who observed that birds reared under high ambient temperatures tend to reduce feed consumption and increase water consumption; and this behavioral mechanism have been found to be more prominent in birds with higher body weight and growth rate (Deep and Cahaner, 2001) [14]. Thermoregulation is the ability of an animal to maintain body temperature in cold or hot environments, without affecting energy metabolism. Under cold climate, the body burns more nutrients and increase the rate of heat production to compensate for higher heat loss caused by the lower ambient temperatures. The results of present study agree with the observations of Plavnik and Yahav (1998) [15] who noted that for younger chicks with poorly developed thermoregulatory mechanism, higher ambient temperatures in the tropics as well as higher DEB can be beneficial to the survival of chicks at an early stage of growth. However, Temperatures comfortable for broiler chicks at early stage of life ranges from 33˚C to 35˚C, and temperatures higher than these may induce a condition known as hyperthermia, coupled with dehydration, lower feed consumption and retarded growth. On the other hand, lower environmental temperatures induce hypothermia and often result in pulmonary hypertension in broilers. Sejian *et al.* (2012) [16] reported that environmental factors such as temperature, relative humidity and solar radiation has both direct and indirect effects on livestock production. The results of present study corroborate the assertions of Borges *et al.* (2003) [5], who noted that increase in body temperature of broiler chickens at finisher phase is related to feather cover and an increase in metabolic activities associated with growth, compared to prestarter chicks with body temperatures approximately 2.5˚C lower than that of the adult bird. The results of current study indicated EPI values that showcased uniformity in body weight gain and healthy state of flock, confirming the assertions of Bhamare *et al.* (2016) [17]. From current study, an ionic imbalance could result in increased body temperature and alienation in blood chemistry. Similar findings were observed for afternoon rectal temperature and temperature change at starter phase. An ideal DEB is that which could limit the fluctuations in body or rectal temperature caused by environmental pressure. These results contradict the findings of Borges *et al.* (2003) [5] who noted that the internal body temperature of heat-stressed broiler chickens decreased linearly as the DEB increased, and that birds fed 240 and 360 mEq/kg DEB had the lowest temperature and smallest body heat variation from morning to afternoon during summer conditions (Max: 31˚C, Min: 23˚C; RH, 75.5%). Although, this was attributed to increased water consumption by these birds and presumably heat dissipation and the efficiency in heat evaporative heat loss also increased with increased water intake.

From current study, Na intake was lowest in birds on 210 mEq/kg and highest in those on 360 mEq/kg DEB. K intake in birds on 330 mEq/kg and 360 mEq/kg was significantly higher compared to other DEB treatments. The mechanism behind this uptake could be linked to the regulatory process of the sodium-potassium pump. The sodium-potassium pump bounds ATP and 3 intracellular Na^+ ions. The phosphorylation of the pump occurs after the hydrolysis of ATP at a highly conserved aspartate residue to release of ADP. An electric potential results from the lowered permeability of sodium to plasma membrane than it is to potassium ions. The electrical and concentration gradient established by the sodium-potassium ATPase supports not only the cell resting potential but the action potentials of nerves and muscles. Export of Na from the cell allows for several transporters, which import glucose, amino acids and other nutrients into the cell. An osmotic gradient that drives the absorption of water is created by the translocation of Na from one side to the other of an epithelium. In the gut, sodium is transported out of the resorbing cell on the blood side via the Na^+-K^+ pump, whereas, on the resorbing side, the Na^+-Glucose symporter uses the created Na^+ gradient as a source of energy to import both Na^+ and glucose, which is far more efficient than simple diffusion (Chatterjea and Shinde, 2008) [18]. Absorption of chloride takes place in small intestines. The mechanism of chloride uptake appears to depend on an exchange process with the HCO_3, and is important in the production of hydrogen chloride in the gastric juice and in chloride shift during respiration (Harper, 2003) [19].

5. Conclusion

European production index of starter chicks could be enhanced by increasing the level of K intake through dietary supplementation up to 1.02%. Weight gain is adversely affected by sharp changes in temperature as a negative correlation existed between these parameters at finisher phase. Increase in water intake may not be a remedial tool in lowering sharp fluctuations in body temperature as no significant correlation existed between these parameters. However, sharp fluctuation in body temperature of broilers was reduced with DEB of 330, 270 and 240 mEq/kg at prestarter, starter and finisher phases, respectively.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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