Growth Performance, Carcass Traits and Serum Mineral Chemistry as Affected by Dietary Sodium and Sodium Salts Fed to Broiler Chickens Reared under Phase Feeding System

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ABSTRACT: A basal diet (0.8 g/kg dNa) was formulated in which each of the two sources ($NaHCO_3$ and Na_2SO_4) were supplemented in such a way to attain four levels (1.7, 2.6, 3.5, and 4.4 g/kg) of total dNa, respectively, under 4×2 factorial arrangement. Eight dietary treatments were replicated four times, with 40 birds in each replicate (n = 1,280). The diets supplemented with Na_2SO_4 to attain higher levels of dNa showed highest BW gain and feed intake (FI) during d 1 to 10 (interaction effects) while 2.6 g/kg dNa exhibited improved BW gain and gain:feed (FG) during d 11 to 20. Linear rise in daily water intake (DWI) was associated with diets containing increasing dNa during d 1 to 42 ($p \leq 0.036$). During the first 10 d, DWI:FI was found highest in $NaHCO_3$ diets while Na_2SO_4 diets showed highest DWI:FI during last 10 d of the experiment ($p \leq 0.036$). Increasing dNa and changing Na_2SO_4 with $NaHCO_3$ salt increased pH and resulted in poor growth performance. Dressing weight ($p \leq 0.001$) and abdominal fat ($p \leq 0.001$; quadratic effect) were reduced, whereas breast ($p \leq 0.001$) and thigh ($p < 0.001$) weights were aggravated with increasing dNa (linear effects). Present findings suggested higher levels of dNa from Na_2SO_4 as the supplemental salt in broiler diets would produce better growth performance, especially in first ten days of life, and improve carcass and body organ characteristics. (**Key Words:** Broiler, Growth and Carcass Responses, Phase Feeding Program, Serum Mineral Chemistry, Sodium)

INTRODUCTION

Sodium (Na), the principal cation of extracellular fluid, is known to involve in a number of physiological functions like regulation of extracellular fluid volume, acid base balance, and membrane potential of cells. The concentration of Na in the extracellular fluid is maintained through

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Submitted May 15, 2013; Accepted Jul. 11, 2013; Revised Aug. 8, 2013

Na^+/K^+-ATPase pump, which expels Na from the cell (Leeson and Summers, 2001). It is anticipated that the addition of dietary cations (Na/K) could be used to compensate depressed growth in chickens caused by high levels of dietary anions (Cl/HCO_3) and vice versa. In our previous study, we observed better weight gain and gain:feed in 0.31% chloride diets supplemented with 0.30% Na (Mushtaq et al., 2013).

Mongin (1980) described the effect and interrelationship of Na, K and Cl into an equation, called dietary electrolyte balance (DEB $\leq$ Na+K-Cl, mEq/kg diet), and different researchers (Murakami et al., 2000, 2001; Rondon et al., 2001; Borges et al., 2003a, 2003b, 2004a,; 2004b; Mushtaq et al., 2005, 2007; Ahmad et al., 2005, 2009) recommended different DEB for broilers at different ages, ranging from 150 to 350 mEq/kg with various combinations of dietary Na (dNa), K and Cl. Mushtaq et al. (2005 and 2007) reported that different ions acted differently on a similar DEB of 250 mEq/kg.

The supplementation of various salts is anticipated to change the bird's osmotic balance and this change is mainly

influenced by the contributing electrolytes and ultimately leads to alter water consumption and excretion (Smith and Teeter, 1989; Borges et al., 2004a, 2004b). Sodium bicarbonate ($NaHCO_3$) is considered as the first-rated supplemental salt as a source of Na and HCO_3 when compared with other salts (Johnson and Karunajeewa, 1985; Gorman and Balnave, 1994; Ahmad et al., 2005). Sodium sulphate (Na_2SO_4) is known to induce blood acidosis with great severity when compared with other sulphate sources hence acidic properties of sulphates is directly linked with the supplemental salt (Ruiz-Lopez and Austic, 1993; Ahmad et al., 2005). Genetics and nutrient requirements of today's broilers are changing with respect to varying growing potential on a daily basis, hence there is a need to reconsider the requirements of dNa, DEB and sodium salts for broilers raised under phase feeding.

The present study was, therefore, envisaged to evaluate the effect of supplementation of dNa with the applicability of the DEB using different sodium salts on growth and carcass traits, body physiological responses, water intake, litter condition and serum mineral chemistry of the modern broiler strain fed under the phase feeding program.

MATERIALS AND METHODS

All the experimental procedure was approved by Advanced Study and Research Board, University of Veterinary and Animal Sciences, Lahore-Pakistan.

Housing and management

A total of 1,280 one-d-old (42.1±0.8 g) straight-run Hubbard broiler chicks (Hubbard×Hubbard) were randomly allocated to eight dietary treatments replicated four times in such a way that each replicate had 40 birds. Each replicate pen was equipped with separate overhead, transparent and volume-graduated twenty liters (20 L) water bottles linked to nipple drinker line. Water bottles were cleaned and filled with fresh water after measuring the water consumption on a daily basis. One flat bottom round feeder was provided for each experimental pen. Birds were housed in environmentally controlled systems where variation in temperature and relative humidity were recorded and maintained according to the production manual. Continuous light was provided 24 h for first 3 d and then 23L:1D light pattern was adopted for the rest of the experimental period. A 7.5 cm deep fresh sawdust was used as litter material over a concrete floor. For the first 3 d, house temperature was maintained at 32°C and thereafter reduced by 0.5°C per day until 24°C was attained at d 19.

Birds were vaccinated against Newcastle Disease (ND) plus Infectious Bronchitis viruses at 4 d, Infectious Bursal Disease virus at 8 d and again at 14 d; Hydropericardium Syndrome virus at 18 d and ND-Lasota strain at 22 d following the locally designed vaccination schedule.

Dietary plan

A basal diet having dNa, K and Cl as 0.8, 7.1 and 2.0 g/kg, respectively with a DEB value of 160 mEq/kg (Table 1) was formulated on least-cost basis. Afterwards, four levels of dNa (1.7, 2.6, 3.5 and 4.4 g/kg) were attained from the basal diet (0.8 g/kg) by using either feed-grade $NaHCO_3$ or Na_2SO_4, which corresponded to DEB values of 200, 240, 280 and 320 mEq/kg, respectively. For this purpose, a large batch of basal diet was prepared for each phase and then each of the experimental diets (i.e. eight) was prepared according to research plan using the basal diet. The experimental period was divided into four phases i.e., pre-starter (d 1 to 10), starter (d 11 to 20), grower (d 21 to 33) and finisher (d 34 to 42), which met or exceeded the nutrient specifications recommended by the Hubbard management guide (Hubbard, 2004; Table 1).

Dietary analyses

All the ingredients were assayed for their proximate composition (AOAC, 2005) prior to diet formulation and actual values were used in the formulation. The Na and K contents of each diet were analyzed by flame photometer (AOAC, 2005) and Cl by titration with silver nitrate (Lacroix et al., 1970). The Na, K and Cl contents of the final diets were again verified prior to start of the experiment. The ME of each ingredient was calculated by the appropriate regression equation suggested by the NRC (1994). Amino acid composition of each ingredient was calculated using AminoDat 3.0 Platinum (Degussa AG Feed Additives, 2006) based on the DM and CP contents of each ingredient. The amino acid composition of each diet met or exceeded the ideal amino acid ratio suggested by Han and Baker (1994). The experiment lasted for 42 d of age, offering mash diets throughout the experimental period.

Live performance

Data on feed intake (FI), BW gain (BWG) and feed-to-gain ratio (FG) was recorded for each phase. The feed was withheld for 6 h before weighing the birds at the end of each phase to ensure the emptying of the digestive tract of the bird (Table 2). Mortality was recorded on a daily basis and dead bird was weighed prior to removal to correct FG.

Water intake

Daily Water intake (DWI) was recorded from each replicate and a ratio between DWI and FI (DWI:FI) was also calculated for each phase (Table 3).

Litter moisture

Litter was collected at the end of each phase to

Table 1. Ingredient and nutrient composition of the basal diets fed four levels of sodium with two sources of sodium salts at different stages of growth in broilers[1]

	Pre-starter (d 1 to 10)	Starter (d 11 to 20)	Grower (d 21 to33)	Finisher (d 34 to 42)
Ingredients (g/kg)				
Corn	469.3	475.4	674.6	679.4
Broken rice	134.6	161.6	0.7	-
Soybean meal (CP: 44.1%)	276.3	291.1	269.3	244.7
Canola meal (CP: 37.3%)	63.9	12.4	-	-
Oil	16.2	22.1	18.8	39.4
Dicalcium phosphate	21.6	20.2	18.9	16.0
Limestone	10.4	9.4	10.5	11.0
L-lysine HCl	2.3	2.2	2.0	-
L-lysine sulphate	-	-	-	3.4
NaCl	1.5	1.6	1.6	1.6
KCl	0.4	0.3	0.5	1.4
DL-methionine	2.0	2.0	1.7	1.7
L-threonine	0.5	0.7	0.3	0.4
Premix[2]	1.0	1.0	1.0	1.0
Nutrients (g/kg or otherwise stated; Analysis results)				
ME (kcal/kg) [3]	2,903	3,010	3,102	3,155
Crude protein	211.0	202.0	189.0	182.0
Calcium	10.0	9.0	9.0	8.5
Available Phos.	4.5	4.2	4.0	3.5
Sodium	0.8	0.8	0.8	0.8
Potassium	7.1	7.1	7.1	7.1
Chloride	2.0	2.0	2.0	2.0
DEB (mEq/kg)[4]	160	160	160	160
Dig lys	11.0	10.5	9.7	9.3

[1] All the diets were supplemented with 4 levels of either $NaHCO_3$ (3.3, 6.6, 9.9, or 13.2 g/kg) or Na_2SO_4 (2.8, 5.6, 8.4, or 11.2 g/kg) to make final dNa concentrations of 1.7, 2.6, 3.5, or 4.4 g/kg, respectively. The basal diet has 0.8 g/kg dNa in it.

[2] Provides per kg of finished diet: vitamin A, 12 mg; vitamin D_3, 7 mg; vitamin E, 100 mg; vitamin K_3 (50% as menadione nicotinamide bisulfite), 3 mg; vitamin B_1 (98%), 3 mg; vitamin B_2 (800,000 mg), 12 mg; vitamin B_3 (niacin; 99%), 600 mg; vitamin B_6 (98%), 4 mg; vitamin B_9 (folic acid; 95%), 2 mg; vitamin B_{12} (0.10%), 20 mg; Biotin (0.10%), 5 mg; Ca-Pentothenate (98%), 12 mg; choline (70% as choline sodium), 1 g; MnO (60%), 169 mg; $FeSO_4$ (21%), 200 mg; $ZnSO_4$ (36%), 150 mg; $CuSO_4$ (25%), 40 mg; Se (sodium selenite 0.40%), 100 mg; KI (68%), 2 mg; Salinomycin, 60 mg; Zinc bacitracin (as Albac 10%), 50 mg.

[3] Calculated values (NRC, 1994). [4] Dietary electrolyte balance = (% Na×10,000/23)+(% K×10,000/39.1) − (% Cl×10,000/35.5).

determine its moisture (LM). For this purpose, about 500 g litter sample was randomly collected from different locations in each replicate pen. Each sample was homogenized and a representative sample of 100 g was taken and oven dried at 105°C for 24 h (AOAC, 2005) to determine moisture contents.

Water analysis

Water characteristics were also recorded twice (morning and noon) daily to check pH by pH metre (LT-Lutron pH-207 Taiwan), dissolved oxygen (DO) by DO metre (YSI 55 Incorporated, Yellow Springs, Ohio, 4387, USA). Moreover, temperature, electrical conductivity (EC), total dissolved solids (TDS) and salinity were recorded by Combo metre (H M Digital, Inc. CA 90230). These observations were recorded randomly from different replicates.

Blood pH, carcass traits and serum mineral chemistry

At the end of 42 d, two birds were randomly selected from each replicate for carcass and blood responses (Tables 4 and 5). Blood was collected from wing vein in EDTA-coated vacutainer for immediate pH monitoring. The same birds were killed by severing neck vein and blood samples were collected. Blood serum was separated by centrifugation of blood samples at 2,000×g for 15 min (Hayat et al., 1999; Ahmad et al., 2005) and was analyzed for minerals (Na, K, Cl, Ca, P, Mg, HCO_3, Table 6) contents. The same birds were further used for evaluation of carcass characteristics. Carcass responses were evaluated in terms of dressing, breast, thigh, abdominal fat, gizzard, proventriculus, heart, liver, kidney, spleen, pancreas, bursa, gallbladder, intestine and lung weights, and shank and intestine lengths and were presented as percent of dressing weight.

Statistical analysis

The experiment was executed under completely randomized design with factorial arrangement using four (4) levels of dNa from two (2) sources of salt. The replicate was an experimental unit. The data obtained at the end of each phase was subjected to ANOVA technique using GLM of Minitab 16.1 (Minitab, 2010). While the data collected at the end of the experiment, two-way ANOVA with level of dNa and source of salt as fixed effects and their interactions was applied. Linear and quadratic effects were studied in

Table 2. i) Effect of dietary sodium and sodium salts on body weight gain, feed intake and gain:feed of broilers during various phases of the experiment (Continued)

		d 1 to 10	d 11 to 20	d 21 to 33	d 34 to 42	d 1 to 42
Main effects (dNa/Salt)		---------------------------------- Body weight gain (g/bird) ----------------------------------				
dNa (g/kg)	1.7	149	336	862	546	1,893
	2.6	144	344	831	640	1,959
	3.5	150	328	840	564	1,883
	4.4	141	314	851	558	1,864
Salt	NaHCO$_3$	137	317	838	591	1,884
	Na$_2$SO$_4$	155	344	854	563	1,916
Interaction effects (Salt×dNa)						
NaHCO$_3$	1.7	147	338	864	592	1,941
NaHCO$_3$	2.6	138	324	849	630	1,941
NaHCO$_3$	3.5	143	295	807	584	1,829
NaHCO$_3$	4.4	122	311	833	558	1,824
Na$_2$SO$_4$	1.7	151	334	859	500	1,844
Na$_2$SO$_4$	2.6	150	364	813	650	1,977
Na$_2$SO$_4$	3.5	157	361	874	545	1,936
Na$_2$SO$_4$	4.4	161	318	868	558	1,905
SEM		2.0	9.0	18.0	27.3	34.1
p-value (df = 24)						
	Level	0.376	0.049	0.794	0.741	0.247
	Source	≤0.001	0.188	0.451	0.304	0.306
	Salt×dNa	0.008	0.635	0.220	0.369	0.036
	Level (L)	0.713	0.428	0.316	0.069	0.176
	Level (Q)	0.177	0.657	0.663	0.055	0.156
Main effects (dNa/Salt)		---------------------------------- Feed intake (g/bird) ----------------------------------				
dNa (g/kg)	1.7	235	643	1,649	1,036	3,564
	2.6	227	663	1,654	1,089	3,634
	3.5	234	652	1,652	1,067	3,605
	4.4	228	681	1,612	1,101	3,622
Salt	NaHCO$_3$	222	653	1,640	1,089	3,604
	Na$_2$SO$_4$	240	667	1,644	1,058	3,608
Interaction effects (Salt×dNa)						
NaHCO$_3$	1.7	236	635	1644	1,071	3,586
NaHCO$_3$	2.6	222	658	1652	1,099	3,631
NaHCO$_3$	3.5	216	650	1725	1,057	3,649
NaHCO$_3$	4.4	215	668	1539	1,129	3,551
Na$_2$SO$_4$	1.7	234	651	1654	1,002	3,542
Na$_2$SO$_4$	2.6	232	669	1657	1,080	3,637
Na$_2$SO$_4$	3.5	251	653	1578	1,078	3,560
Na$_2$SO$_4$	4.4	242	694	1685	1,073	3,694
SEM		4.6	22.4	69.5	33.9	64.9
p-value (df = 24)						
	Level	0.371	0.163	0.606	0.122	0.485
	Source	≤0.001	0.391	0.944	0.209	0.935
	Salt×dNa	0.001	0.880	0.569	0.727	0.267
	Level (L)	0.692	0.776	0.651	0.692	0.572
	Level (Q)	0.076	0.314	0.894	0.235	0.482

Table 2. ii) Effect of dietary sodium and sodium salts on body weight gain, feed intake and gain:feed of broilers during various phases of experiment

		d 1 to 10	d 11 to 20	d 21 to 33	d 34 to 42	d 1 to 42
Main effects (dNa/salt)						
		--- Gain:Feed (g:g) -------------------------------------				
dNa (g/kg)	1.7	1.58	1.94	1.92	2.06	1.95
	2.6	1.59	1.92	2.00	1.71	1.80
	3.5	1.57	2.01	1.97	1.90	1.89
	4.4	1.64	2.22	1.90	1.98	1.95
Salt	$NaHCO_3$	1.64	2.10	1.97	1.85	1.88
	Na_2SO_4	1.55	1.95	1.93	1.98	1.91
Interaction effects (Salt×dNa)						
$NaHCO_3$	1.7	1.61	1.88	1.91	1.81	1.82
$NaHCO_3$	2.6	1.62	2.05	1.96	1.76	1.83
$NaHCO_3$	3.5	1.54	2.22	2.14	1.81	1.91
$NaHCO_3$	4.4	1.78	2.25	1.86	2.02	1.98
Na_2SO_4	1.7	1.55	1.96	1.93	2.32	2.08
Na_2SO_4	2.6	1.55	1.84	2.04	1.66	1.76
Na_2SO_4	3.5	1.61	1.81	1.81	1.99	1.88
Na_2SO_4	4.4	1.51	2.20	1.94	1.93	1.91
SEM		0.065	0.078	0.082	0.134	0.107
p-value (df = 24)						
	Level	0.371	0.035	0.763	0.925	0.792
	Source	0.088	0.154	0.521	0.466	0.755
	Salt×dNa	0.231	0.505	0.672	0.315	0.172
	Level (L)	0.497	0.349	0.183	0.211	0.189
	Level (Q)	0.600	0.837	0.816	0.383	0.401

L = Linear; Q = Quadratic. Number of observations per mean value = 40 birds×4 replicates = 160 birds.

the model by using polynomial contrasts. The level of significance was 0.05 unless or otherwise stated.

RESULTS

At the start of the experiment, the analysis of water was performed for sodium absorption (25.6) and residual sodium carbonate (9.02). The concentration of various minerals (cations plus anions) and values of pH (7.17 to 7.49), DO (3.70 to 5.60 mg/L), temperature (24.0 to 29.7°C), EC (1.06 to 1.39 millisiemens/cm), TDS (1,060 to 1,284 ppm) and salinity (1.2 to 1.3 g/kg) of the drinking water were also analyzed and found within the satisfactory range (detailed data not shown).

In the present experiment, the growth performance (BWG, FI, and FG) was affected by dNa levels, salts or their interaction (level×source) only during the first half (prestarter and starter) of the experiment and was not affected in the second half (grower and finisher) of the experiment. During d 1 to 10, diets containing Na_2SO_4 salt (interaction effects) showed highest BWG (p≤0.008) and FI (p≤0.001) at 4.4 and 3.5 g/kg, respectively. The BWG (p≤0.049) and FG (p≤0.035) were improved on 2.6 g/kg

dNa level during d 11 to 20 (Table 2). The supplementation of Na_2SO_4 to attain 2.6 g/kg dNa ameliorated BWG during the overall study period i.e. d 1 to 42 (p≤0.036; interaction effects). In the rest of the experimental phases, the dNa levels, salts or their interaction (level×source) was found not to influence any of the growth parameters. Mortality of birds among all the dietary treatments were found non-significant therefore were excluded from the tables.

A significant rise in DWI with increasing dNa levels was noticed during d 21 to 33 (p≤0.007), d 34 to 42 (p≤0.012) and d 1 to 42 (p≤0.036). The highest consumption of water was observed at the highest level of dNa i.e. 4.4 g/kg. The supplementation of both salts (main effect) or level×source (interaction effect) did not influence DWI during the overall experimental period. A higher value of DWI:FI was found in $NaHCO_3$ supplemented diets during d 1 to 10 (p≤0.036; 3.03) and in Na_2SO_4 supplemented diets during d 34 to 42 (p≤0.026; 2.51; Table 3). Both levels and sources of dNa did not affect DWI:FI during the rest of the phases. On the other hand, litter moisture contents and mortality were not affected by dNa, salt or interaction of both (p>0.05; data not shown).

The increasing amount of dNa from either source (level

Table 3. Effect of dietary sodium and sodium salts on water intake and water intake-to-feed intake ratio of broilers during various phases of experiment

Item		d 1 to 10	d 11 to 20	d 21 to 33	d 34 to 42	d 1 to 42
Main effects (dNa/salt)		-- Water intake (mL) ----------------------------------				
dNa (g/kg)	1.7	685	1,777	3,411	2,422	8,294
	2.6	683	1,817	3,740	2,657	8,898
	3.5	666	1,751	3,730	2,561	8,709
	4.4	650	1,722	3,835	2,733	8,940
Salts	NaHCO$_3$	674	1,766	3,589	2,544	8,574
	Na$_2$SO$_4$	668	1,767	3,769	2,642	8,846
Interaction effects (Salt×dNa)						
NaHCO$_3$	1.7	720	1,833	3,340	2,349	8,241
NaHCO$_3$	2.6	695	1,740	3,651	2,596	8,683
NaHCO$_3$	3.5	670	1,796	3,631	2,472	8,570
NaHCO$_3$	4.4	611	1,696	3,734	2,760	8,801
Na$_2$SO$_4$	1.7	650	1,721	3,482	2,494	8,347
Na$_2$SO$_4$	2.6	671	1,894	3,829	2,718	9,112
Na$_2$SO$_4$	3.5	662	1,706	3,830	2,649	8,848
Na$_2$SO$_4$	4.4	689	1,747	3,936	2,706	9,078
SEM		36.9	77.4	86.0	97.1	109.1
p-value (df = 24)						
	Level	0.305	0.354	0.007	0.012	0.036
	Source	0.821	0.988	0.073	0.168	0.135
	Salt×dNa	0.062	0.620	0.817	0.386	0.820
	Level (L)	0.788	0.524	0.254	0.651	0.301
	Level (Q)	0.896	0.564	0.301	0.063	0.137
Main effects (dNa/salt)		-------------------------------- Water intake-to-feed intake ratio (mL/g) -----------------------				
dNa (g/kg)	1.7	2.91	2.76	2.09	2.36	2.33
	2.6	3.01	2.74	2.28	2.44	2.45
	3.5	2.87	2.71	2.28	2.40	2.42
	4.4	2.84	2.53	2.40	2.48	2.47
Salts	NaHCO$_3$	3.03	2.72	2.20	2.34	2.38
	Na$_2$SO$_4$	2.79	2.66	2.32	2.51	2.46
Interaction effects (Salt×dNa)						
NaHCO$_3$	1.7	3.05	2.89	2.03	2.19	2.30
NaHCO$_3$	2.6	3.13	2.64	2.22	2.36	2.39
NaHCO$_3$	3.5	3.10	2.78	2.13	2.34	2.35
NaHCO$_3$	4.4	2.84	2.55	2.43	2.44	2.48
Na$_2$SO$_4$	1.7	2.78	2.64	2.15	2.52	2.36
Na$_2$SO$_4$	2.6	2.90	2.84	2.34	2.52	2.51
Na$_2$SO$_4$	3.5	2.63	2.63	2.43	2.46	2.49
Na$_2$SO$_4$	4.4	2.84	2.51	2.36	2.53	2.46
SEM		0.106	0.128	0.123	0.102	0.087
p-value (df = 24)						
	Level	0.482	0.083	0.070	0.293	0.167
	Source	0.036	0.517	0.296	0.028	0.243
	Salt×dNa	0.574	0.701	0.699	0.249	0.685
	Level (L)	0.567	0.393	0.755	0.986	0.573
	Level (Q)	0.472	0.762	0.546	0.438	0.397

L = Linear; Q = Quadratic. Number of observations per mean value = 40 birds×4 replicates = 160 birds.

×source effects) were shown to rise blood pH (p≤0.033; Table 4). The impact of NaHCO$_3$ supplemented diets on blood pH at higher dNa levels is more pronounced as compared to Na$_2$SO$_4$ supplemented diets. In the present study, dressing weight (p≤0.001) and abdominal fat (p≤0.001; quadratic effect) were reduced, whereas breast

Table 4. Effect of dietary sodium and sodium salts on blood and carcass responses of broilers at the end of the experiment

Item		Blood pH	Dressing weight[1]	Breast weight[2]	Thigh weight[2]	Abdominal fat[1]	Lame birds[3]
Main effects (dNa/salt)							
dNa (g/kg)	1.7	7.30	56.12	31.85	45.26	3.01	6.2
	2.6	7.33	54.18	32.98	46.28	3.12	3.1
	3.5	7.35	52.94	33.79	47.34	2.44	3.8
	4.4	7.37	52.07	34.31	48.30	2.61	4.1
Salts	NaHCO$_3$	7.35	53.95	33.16	46.28	2.74	5.1
	Na$_2$SO$_4$	7.33	53.70	33.30	47.31	2.86	3.6
Interaction effects (Salt×dNa)							
NaHCO$_3$	1.7	7.31	55.68	32.11	45.29	2.96	5.0
NaHCO$_3$	2.6	7.34	54.85	32.56	45.05	2.93	4.5
NaHCO$_3$	3.5	7.36	53.38	33.57	46.79	1.93	7.2
NaHCO$_3$	4.4	7.38	51.90	34.40	48.01	3.12	3.5
Na$_2$SO$_4$	1.7	7.30	56.56	31.60	45.24	3.06	7.5
Na$_2$SO$_4$	2.6	7.32	53.50	33.40	47.51	3.31	1.8
Na$_2$SO$_4$	3.5	7.34	52.51	34.01	47.90	2.94	0.2
Na$_2$SO$_4$	4.4	7.36	52.24	34.22	48.58	2.11	4.8
SEM		0.003	0.599	0.492	0.886	0.35	1.76
p-value (df = 56)							
	Level	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	0.312
	Source	0.011	0.561	0.678	0.109	0.014	0.240
	Salt×dNa	0.033	0.770	0.853	0.927	0.915	0.048
	Level (L)	0.001	0.212	0.385	0.960	0.567	0.173
	Level (Q)	-	0.854	0.983	0.955	0.018	0.092

[1] % of live weight (without visceral organs). [2] % of dressed weight. [3] Percentages.
L = Linear; Q = Quadratic. Number of observations per mean value = 2 birds×4 replicates = 8 birds.

(p≤0.001) and thigh (p<0.001) weights were aggravated with increasing dNa (linear effects; Table 4). The level× source interaction influenced the number of lame birds (p≤0. 048).

The weights of the gizzard (p≤0.002), bursa (p≤0.001; quadratic effect), gall bladder (p≤0.003), lungs (p≤0.033; linear effect) and intestine (p≤0.031; quadratic effect) responded to dNa levels while the weights of the kidney (p≤0.001) and gall bladder (p≤0.001) were influenced by replacing salts (Table 5). The level×source interaction was found to influence weights of the kidney (p≤0.006), bursa (p≤0.001) and intestine (p≤0.001). The weights of the proventriculus, heart, liver, spleen and pancreas, and shank length were measured and found similar between all dietary treatments (data not shown; p>0.05).

A quadratic increase in serum Na$^+$ (p≤0.002), K$^+$, Cl$^-$ and Mg^{2+} (p≤0.001), whereas a linear rise in serum HCO$^-$ and Ca^{2+} were observed with increasing dNa from 1.7 to 4.4 g/kg (Table 6).

DISCUSSION

The concentration of electrolytes and other attributes (EC, TDS, salinity) of water are anticipated to maneuver the electrolyte concentration of bird's digesta. The results obtained from the present study indicated that the electrolyte concentration in the water was too low to have any impact on the growth performance. The range of water pH i.e. 6.0 to 8.5 has been considered as optimal for broiler performance (Socha et al., 2002; Borges et al., 2003a, 2003b), whereas water TDS levels between 1,000 to 3,000 ppm were considered satisfactory for broilers (Chiba, 2009).

The present experiment was conducted to find out the exact requirements of dNa and its salt for each described phase of broiler's life but in most of the stances we remained uncertain to bring forth the amount of dNa for each phase. The improvement of BWG and FI during d 1 to 10 indicated that higher levels of sulphates in Na$_2$SO$_4$-supplemented diets might induce appetite in birds since better absorption of sulphates is Na dependent active process or because Na involves in cysteine sparing effect as per Langridge-Smith et al. (1983), Ahearn and Murer (1984) and Florin et al. (1991). But, this weight gain was not translated into better FG *per se*, which showed that birds ate and weighed more but did not convert feed into weight efficiently as it has to be. Afterwards, the amelioration in BWG and FG signified that during these crucial days of life broilers were more efficiently able to transform feed into weight *per se*. Among the growth

Table 5. Effect of dietary sodium and sodium salts on body organ weights[1] of broilers at the end of the experiment

Item		Gizzard	Kidney	Bursa	Gall bladder	Lungs	Intestinal weight[2]
Main effects (dNa/salt)		-- % of dressed weight --					
dNa (g/kg)	1.7	2.41	0.31	0.23	0.08	0.56	58.2
	2.6	2.57	0.36	0.15	0.08	0.58	54.3
	3.5	2.98	0.37	0.21	0.09	0.60	54.9
	4.4	2.99	0.37	0.25	0.12	0.48	56.1
Salts	$NaHCO_3$	2.85	0.42	0.21	0.07	0.58	56.3
	Na_2SO_4	2.62	0.28	0.22	0.11	0.54	55.4
Interaction effects (Salt×dNa)							
$NaHCO_3$	1.7	2.72	0.42	0.16	0.07	0.64	58.8
$NaHCO_3$	2.6	2.65	0.47	0.18	0.07	0.61	56.2
$NaHCO_3$	3.5	2.98	0.41	0.22	0.04	0.54	58.7
$NaHCO_3$	4.4	3.05	0.39	0.26	0.11	0.51	51.6
Na_2SO_4	1.7	2.11	0.21	0.29	0.10	0.49	57.7
Na_2SO_4	2.6	2.48	0.24	0.13	0.09	0.56	52.4
Na_2SO_4	3.5	2.98	0.33	0.20	0.13	0.64	51.1
Na_2SO_4	4.4	2.93	0.35	0.24	0.12	0.46	60.7
SEM		0.21	0.04	0.02	0.01	0.04	1.62
p-value (df = 56)							
	Level	0.002	0.089	0.294	0.003	0.089	0.321
	Source	0.408	≤0.001	0.614	≤0.001	0.218	0.346
	Salt×dNa	0.379	0.006	≤0.001	0.575	0.099	≤0.001
	Level (L)	0.682	0.403	0.109	0.184	0.033	0.101
	Level (Q)	0.169	0.873	≤0.001	0.972	0.420	0.031

[1] Weights of proventriculus, heart, liver, and pancreas, and shank length were excluded from the data because of having non-significant effects.
[2] Measured in grams.
L = Linear; Q = Quadratic. Number of observations per mean value = 2 birds×4 replicates = 8 birds.

Table 6. Effect of dietary sodium and sodium salts on serum mineral chemistry of broilers at the end of the experiment

Item		Na	K	Cl	Ca	Mg	HCO_3
Main effects (dNa/salt)		-- mmol/L --					
dNa (g/kg)	1.7	131	3.04	102	2.52	1.06	30.8
	2.6	132	3.05	102	2.56	1.15	31.1
	3.5	135	3.07	104	2.68	1.18	30.0
	4.4	137	3.04	101	2.71	1.14	30.6
Salts	$NaHCO_3$	134	3.06	102	2.50	1.14	31.4
	Na_2SO_4	132	3.05	102	2.73	1.12	30.8
Interaction effects (Salt×dNa)							
$NaHCO_3$	1.7	132	3.04	103	2.45	1.11	31.1
$NaHCO_3$	2.6	134	3.06	102	2.40	1.07	31.4
$NaHCO_3$	3.5	137	3.09	104	2.56	1.28	29.7
$NaHCO_3$	4.4	138	3.02	100	2.60	1.11	30.7
Na_2SO_4	1.7	130	3.04	101	2.58	1.01	30.5
Na_2SO_4	2.6	131	3.04	102	2.71	1.22	30.7
Na_2SO_4	3.5	133	3.05	103	2.79	1.09	30.2
Na_2SO_4	4.4	135	3.06	102	2.82	1.18	30.4
SEM		0.3	0.005	0.4	0.079	0.025	0.205
p-value							
	Level	<0.001	0.001	0.001	0.005	0.001	0.011
	Source	0.231	0.031	0.431	<0.001	0.292	0.324
	Salt×dNa	0.121	0.097	0.543	0.089	0.077	0.223
	Level (L)	<0.001	0.001	0.001	0.007	<0.001	0.007
	Level (Q)	0.002	<0.001	<0.001	0.064	<0.001	0.019

L = Linear; Q = Quadratic. Number of observations per mean value = 2 birds×4 replicates = 8 birds.

parameters it seems that BWG is more sensitive to the level and source of dNa. It is clear from the present results that selection of right dietary salt and dNa level could play a crucial role particularly in feed intake (prestarter) and feed conversion (starter) and birds are more sensitive to the level and source of Na during these days rather when they become heavier, however birds showed the direct impact of dNa on body weight throughout their life and the requirements of dNa were decreased over the age.

With regards to the increasing DWI with increasing dNa levels during the whole experimental period, the findings of Julian et al. (1992), Murakami et al. (2000) and Rondon et al. (2001) also confirmed the enhanced water consumption with increasing level of dNa. It is anticipated that higher level of dNa could modify body fluids and osmotic balance that increases thirst and leads to increased water consumption (Smith and Teeter, 1989; Borges et al., 2004a, 2004b). This water is not excreted through faeces in the present study as evident from the similar litter condition (p>0.05) at all levels of dNa and is thought to retain in the muscle tissues, which is also reflected from higher dressing weight observed in the present study.

It is suggested that the higher water consumption limits the gut capacity for feed intake and excretes nutrients in faeces thus reduces weight as evident from lower BWG in $NaHCO_3$ and Na_2SO_4 supplemental diets during first and last ten days of age, respectively, in the present study. These results are in contrast with Hooge et al. (1999) who reported that added level of dNa from Na_2SO_4 didn't affect DWI:FI and litter moisture while he noticed moderate effects on these parameters when $NaHCO_3$ was used to add dNa. The contrary results might be due the impact of a number of coccidiostats used by Hooge et al. (1999) that changed the water intake behavior in birds.

Patience et al. (1986) stated that metabolizable ions like HCO_3^- cause acid neutralization and increase blood pH. In our study, the increased pH in $NaHCO_3$ supplemental diets resulted in the numerical decrease in BWG at d 42 (p>0.05). The value of pH greater than 7.35 is known to reduce growth performance in broilers (Ahmad et al., 2005) as evident from the numerical decline in weight gain with increasing levels of dNa. Mushtaq et al. (2007) also observed rise in pH by increasing dNa (2.0 to 3.0 g/kg) during d 29 to 42. The decline in weight gain in the present study might be the impact of acid base imbalance. Increased levels of dNa should be compensated with dCl so as to conserve nominal effects of alkalosis that is the main ideology behind electrolyte balance theory. As per Lehninger (1970), for proper functioning of intermediary metabolism and cellular activity, body physiological system requires an optimum pH, which in turn controls enzymatic activity and ultimately leads towards better growth performance. According to the statement of Mongin (1981)

when DEB is more or less than 250 mEq/kg of diet, it either causes alkalosis or acidosis that lead to retarded growth performance. This is also evident from the present study that highest level of dNa (4.4 g/kg; DEB = 320 mEq/kg) showed poor growth performance (1,864 g) as compared to 2.6 g/kg dNa or DEB = 240 mEq/kg (1,959 g; p>0.05).

The higher breast and thigh meat yield in the present study might be attributed to increased water accumulation in muscle tissues as higher water intake (p≤0.04) was observed in high dNa diets. The findings of Borgatti et al. (2004) are in line with our results who also observed higher weights of breast and thigh meat with increasing level of DEB. Contrarily, Mushtaq et al. (2007) observed reduced breast and leg meat by increasing dNa from 2.0 to 3.0 g/kg. These attributes (breast and thigh meat weights) were negatively affected by heat stress condition provided in the experiment by Mushtaq et al. (2007) therefore it is obvious that more nutrients were utilized to maintain acid base balance and not converted into meat. It can, therefore, be suggested from the present study that by increasing dNa under normal physiological condition might improve the basal metabolism, which leads to proper energy utilization for meat production and thus very less energy is wasted for abdominal fat deposition.

The increase in weight and size of most of the body organs (i.e. hypertrophy) is the indication of stress condition (Koong et al., 1985), which might be induced by high levels of dNa. The higher weight of lymphoid organ (bursa) showed intruded immune function of the body in the present study and might result in numerically retarded growth performance. In case of other organs, Johnson and Karunajeewa (1985), Borges et al. (1999) and Borgatti et al. (2004) also did not observe any combination effects of electrolytes on the weights of proventriculus, heart, liver, and pancreas, and shank length.

A direct response of dNa was noticed in the concentration of serum Na^+ and the explanation of increased level of serum K^+ and Cl^- might be to compensate higher level of serum Na^+ and to sustain acid base balance. Mushtaq et al. (2005) suggested that cations and anions maintain each other in the body fluids in order to keep the acid-base homeostasis. This homeostasis could be maintained by providing proper DEB so that mild alkalosis caused by increased dNa could be compensated by dietary supplementation of anions. Further, it was observed that serum Na^+ and K^+ are directly related to each other in the blood and leads towards osmoregulation of body fluids (Mushtaq et al., 2007). An elevated level of serum HCO_3^- is the direct response of dietary $NaHCO_3$ that caused an increase in pH, which resulted in retarded growth parameters as reflected in the present experiment. Ahmad et al. (2005) suggested $NaHCO_3$ as the best choice among salts. The contradiction among results might be the

difference in heat stress condition, which causes metabolic acidosis and increased the requirement of HCO_3^-.

CONCLUSION

It can be inferred from the present findings that higher dietary sodium (2.6 to 3.5 g/kg) from sodium sulphate is the better choice in broiler diets for better growth efficiency especially in the first half (prestarter and starter) of life. The weight gain and feed intake could be optimized by reducing dietary sodium and water intake from d 21 to 42 (grower and finisher). The breast and thigh meat yield could be improved by increasing dietary sodium. Moreover, it is suggested to verify the requirements of dietary sodium by changing other electrolytes (potassium and chloride) with same or other salt sources at constant dietary electrolyte balance.

ACKNOWLEDGEMENTS

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