The effect of different dietary potassium and chloride levels on performance and excreta dry matter in broiler chickens

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ABSTRACT: The aim of this 3 × 3 factorial experiment on broilers was to investigate the effect of different dietary levels of potassium and chloride on chicken performance, carcass composition and dry matter content in excreta. 360 one-day-old Ross 308 chickens were allocated to 9 groups, in 5 replications of 8 birds (4 ♂ and 4 ♀). Chickens from 1 to 42 days of age were kept in cages with wire floors to enable excreta collection, and were administered water and feed *ad libitum*. The basal starter (days 1–14) and grower (days 15–42) diet contained in 1 kg, as analysed, 2.11 g and 2.10 g chloride, 8.6 g and 7.8 g potassium and 2.04 g and 1.93 g sodium, respectively. Basal diets were supplemented with potassium and chloride containing, as analysed, 11.1 g or 10.6 g and 11.8 g or 11.9 g K and 2.95 g or 2.58 g and 3.16 g or 2.70 g/kg Cl, for the starter or grower periods of feeding, respectively. The sum of cations (K + Na) in diets used in the experiment ranged from 309 mEq to 390 mEq in the starter diet and from 283 mEq to 388 mEq/kg in the grower diet; the dietary electrolyte balance (DEB) values varied from 219 mEq to 331 mEq and from 207 mEq to 329 mEq/kg, respectively. During the starter feeding period the body weight gain (BWG) and feed conversion (FCR) were positively affected by increasing the chloride supplement and decrease of DEB values from 298 to 274 mEq/kg ($P \leq 0.001$). In the grower period and throughout the feeding period, the positive effect of chloride supplementation on BWG and FCR was not confirmed but a negative effect of potassium was found out. The interaction between dietary levels of chloride and potassium found for BWG and FCR suggests a reciprocal relationship for both electrolytes. Dry matter in excreta was decreased when the K level in the diet was increased to 11.9 g/kg and DEB value to 319 mEq/kg ($P \leq 0.001$) but breast meat yield ($P \leq 0.01$) and relative mass of heart in carcass ($P \leq 0.05$) were increased. Dietary chloride content elevated from 2.2 to 2.58 g/kg reduced pH in breast meat after 24 h ($P \leq 0.001$), whereas elevated potassium content (7.8 vs. 10.6 g/kg) reduced drip loss in 24 ($P \leq 0.01$) and 48 h stored meat ($P \leq 0.05$).

Keywords: broiler chickens; potassium; chloride; performance; excreta moisture; carcass indices

According to Mongin (1981), the value of dietary electrolyte balance (DEB) represents a difference in the sum of positive ($Na^+ + K^+$) and negative ion (Cl^-) equivalents in the diet. High levels of potassium in diets based on plant components may complicate the determination of optimal DEB for broiler diets, because the potassium level is sometimes much higher than the K requirement of chickens. The dietary sodium level consistent with requirements of chickens may cause that the sum of both cations (K + Na) is relatively high and generates the need for relatively high supplementation of chloride.

The effect of different potassium, sodium and chloride levels in the diet for chickens was investigated in a previous experiment (Koreleski et al., 2010, 2011). Starter diets with higher potassium

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levels (12.2 g and DEB 309–336 mEq) or with a lower potassium level (10.7 g/kg) but a higher content of sodium (2.0 g) and chloride (3.1 g/kg) and DEB 274 mEq/kg increased performance indices. The highest level of potassium (12.7 g/kg) decreased the dry matter content of excreta (Koreleski et al., 2011). When the high potassium and adequate chloride diets were used, moderate sodium supplementation (1.7 g/kg) improved the performance of chickens, carcass yield, nitrogen intake and retention and the ratio of N retained to N intake (Koreleski et al., 2010).

In this paper chicken performance, dry matter content in excreta, and carcass indices were investigated in broilers fed plant diets supplemented with different and relatively high levels of chloride and potassium, but with a standard (NRC, 1994) sodium content.

MATERIAL AND METHODS

The trial was conducted during the summer season with 360 Ross 308 sexed broiler chickens, allocated to 9 groups in 5 replications of 8 birds (4♂ and 4♀) kept together in one cage. Chickens from 1 to 42 days of age were kept on wire floors to enable excreta collection and were administered water and feed *ad libitum*. The Local Krakow Ethics Committee for Experiments with Animals approved all experimental procedures connected with the use of live animals.

The basal starter (days 1–14) and grower (days 15–42) diets (Table 1) were of the grain-soybean meal type (without ingredients of animal origin) and contained sodium at a level of 2.04 and 1.93 g per kg, respectively. The natural potassium and chloride level in the basal diet was 8.6 g and 7.8 g K, and 2.11 g and 2.1 g Cl, respectively. A 3 × 3 factorial arrangement with three dietary levels of potassium and three levels of chloride was used. The experimental diets were supplemented with either potassium hydrogen carbonate ($KHCO_3$) or ammonium chloride (NH_4Cl) in order to contain, as analysed: 11.1 g or 10.6 g and 11.8 g or 11.9 g/kg potassium, 2.95 g or 2.58 g and 3.16 or 2.7 g/kg of chloride for the first or second feeding period, respectively (Table 2). The potassium and sodium content in diets was analysed by atomic absorption spectrometry (ISO 6869, 2000). The chloride content was calculated from water-soluble chloride, analysed by the silver nitrate titration method (Volhard, 1874).

Table 1. Composition of basal diets (g/kg)

Component	Starter diet (1–14 days)	Grower diet (15–42 days)
Maize (ground)	558	595
Soybean meal	369	320
Rapeseed oil	25	36
Limestone	17	17.5
Dicalcium phosphate	14	13
NaCl	2.85	2.85
$NaHCO_3$	3.28	3.28
DL-Methionine (99%)	2.3	2.1
L-Lysine HCl (78%)	–	0.9
Sal Curb Dry**	4	4
Vitamin-mineral premix*	5	5
Analyzed content		
Crude protein	226	196
Potassium	8.6	7.8
Sodium	2.04	1.93
Chloride	2.11	2.10

*supplied in 1 kg of starter diet – IU: vitamin A 13 500; vitamin D_3 3 500; – mg: vitamin E 45; K_3 3; B_1 3.25; B_2 7.5; B_6 5; B_{12} 0.0325; biotin 0.15; Ca pantothenate 15; niacin 45; folic acid 1.5; choline chloride 600; Mn 100; Zn 75; Fe 67.5; Cu 17.5; J 1; Se 0.275, Co 0.4

supplied in 1 kg of grower diet – IU: vitamin A 12 000; vitamin D_3 3 250; – mg: vitamin E 40; K_3 2.25; B_1 2; B_2 7.25; B_6 4.25; B_{12} 0.03; biotin 0.1; Ca-pantothenate 12; niacin 40; folic acid 1.0; choline chloride 450; Mn 100; Zn 65; Fe 65; Cu 15; J 0.8; Se 0.25 and Co 0.4

**Kemin, Europe N.V.

Starter and grower diets were calculated to contain 12.5 and 13 MJ ME/kg, respectively, according to European Tables ... (1989)

During the experiment body weight and feed intake of chickens were measured and their mortality was registered. All chickens in each cage were weighed together. Body weight gain (BWG) and feed conversion ratio (FCR) were calculated for the starter period, grower period and for the entire feeding period. FCR data were corrected for mortality. Body masses of dead and culled birds were included for corrected body weight gain in feed: gain calculations. Crude protein content in diets was estimated by means of the Kjeldahl method (AOAC, 1990), using Kjeltec Auto 1030, Tecator.

Table 2. Sum of the DEB values (mEq/kg) in starter and finisher periods

Dietary K level (g/kg)	Dietary Na level (g/kg)	Sum of cations (mEq/kg)	Dietary level of Cl (g/kg) in both periods			Mean
			2.11 and 2.10	2.95 and 2.58	3.16 and 2.70	
Starter period						
8.6	2.04	309	249	225	219	231
11.1	2.04	373	313	289	283	295
11.8	2.04	390	331	307	301	313
Mean			298	274	268	
Finisher period						
7.8	1.93	283	224	211	207	214
10.6	1.93	355	296	282	279	286
11.9	1.93	388	329	315	312	319
Mean			283	269	266	

At 21 days samples of excreta were collected from dropping trays immediately after excretion. They were hermetically packed and analyzed for dry matter content in accordance with AOAC (1990)

At the end of the experiment and after 12 h of starvation, 4 representative cockerels and 4 pullets of the body weight close to the respective treatment mean were chosen from each group and decapitated. The mass of cooled carcasses and edible giblets was estimated, and carcass and breast meat yields and the relative weights of abdominal fat, liver and heart were calculated (Ziolecki and Doruchowski, 1989). The pH of breast meat was measured 15 min and 24 h *post mortem* using a portable CyberScan 10 pH-meter. Glass electrode calibrated with pH 4.01 and 7.00 was inserted at an angle of 45° halfway into the breast muscle (*m. pectoralis superficialis*). Drip loss was estimated after 24 or 48 h as a

Table 3. Effect of dietary K and Cl content on chicken performance from 1 to 14 days of age

Item	Dietary K level (g/kg)	Dietary level of Cl (g/kg)				SEM	Effect of		
		2.11	2.95	3.16	mean		K	Cl	interaction
Body weight gain (g)	8.6	343	369	363	358	2.44	NS	***	NS
	11.1	336	368	367	357				
	11.8	338	354	365	353				
	mean	339^a	364^b	365^b					
Feed intake (g)	8.6	545	532	536	538	3.27	NS	NS	NS
	11.1	537	523	547	536				
	11.8	511	529	538	526				
	mean	531	528	540					
Feed conversion ratio (g/g)	8.6	1.59	1.44	1.48	1.50	0.010	NS	***	*
	11.1	1.60	1.42	1.49	1.50				
	11.8	1.51	1.50	1.48	1.50				
	mean	1.57^b	1.43^a	1.48^a					

NS – not significant , *$P \leq 0.05$, ***$P \leq 0.001$

^{a,b}means in the same row with different letters differ significantly ($P < 0.05$)

Mortality – 0.7% across all experimental treatments

Diets contained 2.04 g sodium per kg

mass change of meat samples (80 g) stored at 4°C in hermetic containers, expressed as percentage of sample mass taken for analysis.

The data were subjected to a two-way factorial analysis of variance. The significance of differences between means was determined by Duncan's multiple range test and differences were considered significant at $P \leq 0.05$. Statistical analyses were performed using Statistica 5.0 PL software (Statsoft Inc.).

RESULTS

The starter diet used in the experiment contained 2.04 g and the finisher 1.93 g Na/kg. After potassium supplementation the sum of the cations (K + Na) in diets for the first and second period of feeding was 309–390 mEq and 283–388 mEq/kg, respectively (Table 2). Chloride content in diets was adequate to requirements (2.11 g or 2.1 g Cl/kg) according to NRC (1994) in basal diets and it was increased in experimental diets to 2.95 g or 2.58 g and 3.16 g or 2.70 g Cl/kg resulting in DEB values from 219 mEq to 331 mEq in the starter and from 207 mEq to 329 mEq/kg in the finisher.

During the starter period (Table 3) BWG and FCR of the chickens were improved ($P < 0.001$ or $P < 0.01$) by increasing the chloride supplement and when DEB values decreased from 298 mEq to 274 mEq per kg (Table 2). The positive effect of chloride supplementation on BWG ($P < 0.01$) and FCR ($P < 0.001$) was not confirmed in the grower period and throughout the experiment (Tables 4 and 5). However, in both feeding periods and throughout the experiment the negative effect of elevated dietary potassium on both performance indices was simultaneously found out ($P < 0.05$). The interaction between dietary levels of Cl and K was significant in BWG and FCR.

Dry matter content in excreta collected at 21 days decreased ($P < 0.001$) when dietary K was increased from 7.8 g and 10.6 g to 11.9 g/kg (Table 6) and the DEB value rose from 214 mEq and 286 mEq to 319 mEq/kg (Table 2). Slaughter analysis showed statistical effects only in breast meat and heart (Table 7). Elevated dietary potassium levels increased breast meat yield ($P < 0.01$) and proportion of heart in carcass ($P < 0.05$). An increase in dietary chloride content from 2.2 g to 2.58 g/kg lowered meat pH after 24 h ($P < 0.001$) in stored

Table 4. Effect of dietary K and Cl on chicken performance from 15 to 42 days of age

Item	Dietary K level (g/kg)	Dietary level of Cl (g/kg)				SEM	Effect of		
		2.10	2.58	2.70	mean		K	Cl	interaction
Body weight gain (g)	7.8	2 409	2 191	2110	2 237^{y}	13.2	**	***	***
	1.06	2 145	2 180	2 188	2 171^{x}				
	1.19	2 196	2 144	2 121	2 154^{x}				
	mean	2 250^{b}	2 172^{a}	2 140^{a}					
Feed intake (g)	7.8	3 985	4 056	3 889	3 976	16.1	NS	NS	NS
	1.06	4 043	4 005	4 011	4 020				
	1.19	3 984	3 923	4 040	3 982				
	mean	4 004	3 995	3 980					
Feed conversion ratio (g/g)	7.8	1.65	1.85	1.84	1.78^{x}	0.011	**	**	***
	1.06	1.89	1.84	1.83	1.85^{y}				
	1.19	1.81	1.83	1.91	1.85^{y}				
	mean	1.79^{a}	1.84^{b}	1.86^{b}					

NS – not significant, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$

$^{a, b}$in the same row with different letters differ significantly ($P < 0.05$)

$^{x, y}$means in the same column with different letters differ significantly ($P < 0.05$)

Mortality – 1.4% across all experimental treatments

Diets contained 1.93 g sodium per kg

Table 5. Effect of dietary K and Cl content on chicken performance from 1 to 42 days of age

Item	Dietary K level (g/kg)	Dietary level of Cl (g/kg)				SEM	Effect of		
		2.11/2.1	2.95/2.58	3.16/2.7	mean		K	Cl	interaction
Body weight gain (g)	8.6/7.8	2 752	2 560	2 473	2 596[y]	13.4	**	**	***
	11.1/10.6	2 482	2 548	2 555	2 529[x]				
	11.8/11.9	2 534	2 498	2 486	2 506[x]				
	mean	2 590[b]	2 536[a]	2 505[a]					
Feed intake (g)	8.6/7.8	4 530	4 583	4 425	4 513	16.0	NS	NS	NS
	11.1/10.6	4 580	4 527	4 557	4 555				
	11.8/11.9	4 493	4 451	4 574	4 506				
	mean	4 534	4 521	4 519					
Feed conversion ratio (g/g)	8.6/7.8	1.65	1.79	1.79	1.74[x]	0.009	**	*	***
	11.1/10.6	1.85	1.78	1.78	1.80[y]				
	11.8/11.9	1.77	1.78	1.84	1.80[y]				
	mean	1.76[a]	1.78[ab]	1.80[b]					

NS – not significant, $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$

[a,b]means in the same row with different letters differ significantly ($P < 0.05$)

[x,y]means in the same column with different letters differ significantly ($P < 0.05$)

Mortality – 2.1% average across all experimental treatments

breast meat (Table 8). Elevated dietary potassium content (10.6 vs. 7.8 g/kg) reduced breast meat drip loss after 24 h ($P < 0.01$) and 48 h ($P < 0.05$).

DISCUSSION

Electrolytes and performance

The level of sodium in the diets used was not adjusted and agreed with the NRC (1994) recommendation. Potassium levels in diets used in this experiment were higher than the requirement 3.0 g/kg given by NRC (1994) or practical values 6.6–7.45 g/kg reported by Borges et al. (2007). Satisfactory broiler performance was reported at DEB values from 245 mEq to 315 mEq in the first and 249 to 257 mEq in the second period of feeding (Murakami et al., 2001; Rondon et al., 2001) and 250 mEq for moderate and 350 mEq/kg for high environmental temperatures (Fixter et al., 1987). For the DEB range from 140 mEq to 240 mEq/kg Borges et al. (2007) reported normal acid-base balance in blood and suggested that DEB should range from 220 to 240 mEq/kg for broilers kept in the summer season (Borges et al., 2003b). Since the sum of cations in our experiment was reasonably high (283–388 mEq/kg), the application

Table 6. Effect of dietary K and Cl content on dry matter of excreta

Item	Dietary K level (g/kg)	Dietary level of Cl (g/kg)				SEM	Effect of		
		2.1	2.58	2.7	mean		K	Cl	interaction
Dry matter of excreta (%)	7.8	17.7	18.1	17.3	17.6[x]	8.82	***	NS	NS
	10.6	16.4	17.2	17.8	17.1[x]				
	11.9	15.2	15.2	15.5	15.3[y]				
	mean	16.4	16.8	16.9					

NS – not significant, $***P \leq 0.001$

[x,y]means in the same column with different letters differ significantly ($P < 0.05$)

Table 7. Effect of dietary K and Cl content on results of slaughter analysis

Item	Dietary K level (g/kg)	Dietary level of Cl (g/kg)				SEM	Effect of		
		2.1	2.58	2.7	mean		K	Cl	interaction
Carcass yield (%)	7.8	77.7	77.0	77.6	77.4	0.114	NS	NS	NS
	10.6	77.5	77.6	78.3	77.8				
	11.9	77.1	77.7	77.6	77.5				
	mean	77.4	77.4	77.8					
Breast meat yield (%)	7.8	25.2	24.9	25.1	25.1^{x}	0.201	**	NS	NS
	10.6	25.1	24.7	25.6	25.1^{x}				
	11.9	26.7	26.4	26.4	26.5^{y}				
	mean	25.7	25.3	25.7					
Abdominal fat pad (%)	7.8	2.05	1.40	1.63	1.70	0.069	NS	NS	NS
	10.6	1.78	1.56	2.04	1.79				
	11.9	1.30	1.79	1.79	1.59				
	mean	1.71	1.58	1.79					
Liver (% BW)	7.8	2.27	2.18	2.03	2.16	0.032	NS	NS	NS
	10.6	2.02	1.91	2.07	2.00				
	11.9	2.16	2.03	1.99	2.06				
	mean	2.15	2.04	2.03					
Heart (% BW)	7.8	0.297	0.310	0.315	0.308^{x}	0.004	*	NS	NS
	10.6	0.341	0350	0323	0.340^{y}				
	11.9	0.333	0.317	0.338	0.330^{y}				
	mean	0.324	0.326	0.326					

NS – not significant, *$P \le 0.05$, **$P \le 0.01$

^{x,y}means in the same column with different letters differ significantly ($P < 0.05$)

of chloride at a level similar to requirements (NRC, 1994) or higher (2.58–3.16 g per kg) resulted in DEB values 207–331 mEq/kg according to Mongin's (1981) formula.

During the starter period BWG and FCR were improved by increasing the chloride supplement and by decreasing DEB values from 298 mEq to 274 mEq/kg. In the grower period and throughout the experiment the positive effect of DEB values that decreased from 283 mEq to 269 mEq/kg as a result of chloride supplementation on BWG and FCR was not confirmed. Optimal DEB values of 274 mEq/kg in the starter and 269 mEq/kg in the finisher in this experiment are similar to DEB in the range of 246–315 mEq or 249 mEq to 257 mEq/kg reported by Rondon et al. (2001) and Murakami et al. (2001).

Dietary potassium had a negative effect on both BWG and FCR when DEB increased from 231 mEq to 295 mEq/kg or from 214 mEq to 286 mEq/kg in the two feeding periods. The interaction between Cl and K at a constant sodium content was significant in BWG and FCR. Since sodium was not adjusted, chloride supplementation counteracted the alkalinity effect arising from the potassium surplus. As reported by Borges et al. (2007), the ratio between Na, K and Cl is the determinant factor for performance.

Excreta moisture, carcass and meat characteristics

Water consumption in chickens depends directly on environmental temperature and on the cation electrolyte ratio in feed which affects litter moisture (Borges et al., 2007). In our experiment dry matter in excreta was decreased when the K level in

Table 8. Effect of dietary K and Cl content on pH and drip loss of breast meat

Item	Dietary K level (g/kg)	Dietary level of Cl (g/kg)				SEM	Effect of		
		2.1	2.58	2.7	mean		K	Cl	interaction
pH (15 min)	7.8	6.32	6.27	6.27	6.29	0.015	NS	NS	NS
	10.6	6.29	6.33	6.25	6.29				
	11.9	6.29	6.25	6.40	6.31				
	mean	6.30	6.28	6.31					
pH (24 h)	7.8	6.10	5.98	5.97	6.02	0.013	NS	***	NS
	10.6	6.16	5.94	6.02	6.04				
	11.9	6.08	6.03	5.98	6.03				
	mean	6.11^{b}	5.98^{a}	5.98^{a}					
Drip loss, 24 h (%)	7.8	0.924	0.734	0.998	0.886^{y}	0.040	**	NS	NS
	10.6	0.715	0.508	0.789	0.570^{x}				
	11.9	0.755	0.719	0.692	0.722^{xy}				
	mean	0.798	0.654	0.726					
Drip loss, 48 h (%)	7.8	1.56	1.53	1.77	1.62^{y}	0.062	*	NS	NS
	10.6	1.26	1.15	1.11	1.17^{x}				
	11.9	1.34	1.55	1.34	1.41^{xy}				
	mean	1.39	1.41	1.41					

NS – not significant, *$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$

^{a,b}means in the same row with different letters differ significantly ($P < 0.05$)

^{x,y}means in the same column with different letters differ significantly ($P < 0.05$)

the diet was increased to 11.9 g/kg and DEB value rose to 319 mEq/kg. Chloride supplementation and a decrease in DEB values from 283 mEq to 266 mEq did not affect dry matter content in excreta. Results are in general agreement with those reported by Borges et al. (2003a), where high dietary content of chloride and decreased DEB values did not stimulate water intake.

Slaughter analysis showed statistical effects only in breast meat and heart. Elevated dietary potassium levels and an increase in DEB from 214 mEq or 286 mEq to 319 mEq/kg increased breast meat yield. In contrast, Borges et al. (2003a) did not report any significant effect of DEB on carcass yield, breast meat yield or other carcass indices. The sodium source in the diet, however, affected breast meat yield in broilers kept in a hot environment (Ahmad et al., 2005).

Potassium supplementation of the diet and elevated DEB values from 214 mEq to 286 mEq or 319 mEq/kg increased the proportion of heart mass in body weight. It is not unlikely that bigger hearts contribute to higher water consumption in chickens fed a higher cation diet, possibly a result of higher blood osmotic pressure reported by Borges et al. (2003a).

Changes in the pH in stored meat are a result of the post mortem change from glycogen to lactic acid. When the dietary chloride content was elevated from 2.2 g to 2.58 g/kg and DEB values decreased from 283 mEq to 269 mEq/kg, the pH of breast meat was lowered after 24 h of storage. The possible explanation for this could in part be the acidogenecity of chloride anion and its activity to increase the blood hydrogen concentration (Ruiz-Lopez and Austic, 1993).

Elevated dietary potassium content (10.6 g/kg vs. 7.8 g/kg) reduced breast meat drip loss after 24 h and 48 h. This is probably due to the higher osmotic pressure of intracellular fluids (Mongin, 1981) in meat of chickens fed diets rich in potassium and sodium cations.

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