J. Elem. s. 265–275 DOI: 10.5601/jelem.2014.19.1.414

REVIEW PAPERS

THE EFFECT OF DIETARY SODIUM CHLORIDE CONCENTRATIONS ON BLOOD ELECTROLYTE CONCENTRATIONS, THE INCIDENCE OF FOOT PAD DERMATITIS AND BONE MINERALIZATION IN BROILER CHICKENS AND TURKEYS

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Abstract

Among numerous changes that have occurred in poultry feeding over the last decades, an important one consists in an increase in the dietary content of strong electrolytes (Na, K and Cl) for slaughter chickens and turkeys. This coincided with a higher incidence of such unfavourable developments as the wet litter syndrome, foot-pad dermatitis (FPD) and deformations of the birds' legs. This paper reviews the results of the latest experiments that have analyzed the effect of different amounts of supplemental NaCl as a source of Na in diets for broiler chickens and turkeys on the concentrations of electrolytes in their blood, the incidence of FPD and leg bone deformations. It has been determined that an increase in Na in chickens' diets within the range of 0-0.25% did not affect FDP symptoms. Turkey diets containing 0.20% of Na intensified the symptoms of FDP compared to a diet without added sodium chloride. In chickens, significant disorders in the mineral balance, including worse physicochemical parameters of the tibia, appeared only when the birds were given feeds with a very low content of sodium (0.02 and 0.07%), made without or with very low sodium supplementation. Increasing the amount

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of added sodium to over 0.14% of a diet for broiler chickens and to 0.13% for turkeys did not improve the analyzed bone mineralization parameters. The reports reviewed in this paper indicate that the risk of inferior bone mineralization process, mainly due to Na deficiency, as well as a higher litter moisture content and more frequent cases of FPD (as the dietary Na content increases) are more profound among slaughter turkeys than broiler chickens.

Keywords: electrolyte balance, sodium, faeces moisture, FPD, tibia mineralization.

WPŁYW ZAWARTOŚCI CHLORKU SODU W PASZY NA STĘŻENIE ELEKTROLITÓW WE KRWI, CZĘSTOŚĆ WYSTĘPOWANIA ZAPALENIA SKÓRY STÓP I MINERALIZACJĘ KOŚCI U KURCZĄT BROJLERÓW I INDYKÓW

Abstrakt

Wśród wielu zamian, jakie zaszły w żywieniu drobiu w ostatnich dekadach, ważne miejsce zajmuje wzrost zawartości silnych elektrolitów (Na, K i Cl) w dietach kurcząt i indyków rzeźnych. W tym samym bowiem czasie nasiliło się występowanie takich niekorzystnych zjawisk, jak syndrom mokrej ściółki, foot-pad dermatitis (FPD) oraz deformacje kończyn ptaków. W pracy podsumowano wyniki najnowszych doświadczeń, w których oceniano wpływ zawartości elektrolitów w dietach na występowanie zakłóceń w odchowie kurcząt i indycząt, pogarszających dobrostan (głównie wskutek występowania FPD i deformacji kończyn) tych ptaków. Stwierdzono, że zwiększenie zawartości Na w diecie kurcząt w zakresie 0-0,25% nie miało wpływu na występowanie FPD. W żywieniu indyków diety o zawartości do 0,20% Na nasilały objawy FPD, w stosunku do diety bez dodatku chlorku sodu. U kurcząt istotne zakłócenia gospodarki mineralnej, w tym pogorszenie parametrów fizykochemicznych kości piszczelowej, występowały jedynie w przypadku mieszanek o bardzo niskiej zawartości sodu (0,02 i 0,07%), sporządzonych bez dodatku lub z bardzo niewielkim dodatkiem tego pierwiastka. Zwiększenie dodatku sodu u najmłodszych kurcząt ponad 0,14% i u indycząt ponad 0,13% diety nie poprawiało analizowanych parametrów mineralizacji kości. Wyniki doświadczeń wskazują, że ryzyko pogorszenia procesu mineralizacji kości, głównie w przypadku niedoboru Na, oraz możliwość zwiększenia wilgotności ściółki i występowania FPD (wraz ze zwiększeniem zawartości Na w diecie) są znacznie większe u indyków rzeźnych niż u kurcząt broilerów.

Słowa kluczowe: bilans elektrolitów, dodatek paszowy sodu, wilgotność odchodów, mineralizacja kości piszczelowej.

INTRODUCTION

Freedom from discomfort by providing an appropriate environment and freedom from pain, injury or disease by prevention or rapid diagnosis and treatment are important elements of animal welfare (Beaumont et al. 2010). In this context, it is worrying to notice that mass-scale poultry production and more intensive feeding of reared birds create worse indoor environmental conditions, leading to such health problems as foot-pad dermatitis (FPD) as well as deformations of and damage to legs (Oviedo-Rondon et al. 2006, Venäläinen et al. 2006). Leg diseases are frequently initiated by excessive moisture of the litter, which is caused by a variety of factors, not fully recognized yet but associated with intensive feeding of poultry (Francesch, Brufau 2004, Mayne et al. 2007). An excessive level of dietary sodium, ad-

ministered to birds to accelerate their growth, is indicated among the aforementioned factors. An increased dietary intake of sodium stimulates higher water consumption and consequently raises the moisture content of faeces (Borges et al. 2003, Oviedo-Rondon et al. 2006, Mushtaq et al. 2007).

Deformations of legs and leg damage deteriorate the welfare of birds and slow down their growth rate (Oviedo-Rondon et al. 2006, Nääs et al. 2009). Inadequate bone mineralization in poultry is most often attributed to certain disorders in the mineral balance, especially calcium and phosphorus (Kestin et al. 2001, Rao et al. 2003, Venäläinen et al. 2006, Tatara et al. 2011). Less is known about the effect of strong electrolytes such as sodium, potassium and chlorine, in diets for young chickens and turkeys on the course of mineralization processes and stability of the skeleton which stores 1/3 of the sodium resources found in the whole body.

It has been demonstrated experimentally that disorders in mineralization processes, which manifested themselves as a reduced bone ash content, resulted from an increased amount of sodium in chickens' diet, while a higher dietary content of chlorine counteracted this effect (Murakami et al. 1997*a*,*b*). It has also been observed that sodium interacting with calcium can play an important role in the pathogenesis of skeletal muscles in broiler chickens (Sandercock, Mitchell 2004), which may enhance problems induced by bone deformations. Similar though scanty findings have stimulated the most recent experiments, recapitulated herein, which focused on the effect of sodium and – to some extent – potassium and chlorine on such litter moisture, incidence of FDP as well as mineral composition and deformations of the skeleton of slaughter chickens and turkeys. The purpose of this article has been to summarize the results of such experiments.

CONTENT AND BALANCE OF ELECTROLYTES IN DIETS FOR BROILER CHICKENS AND TURKEYS

According to the most commonly applied nutritional requirements of broiler chickens (NRC 1994), the optimum doses of sodium, potassium and chlorine in starter diets are 0.20, 0.30 and 0.20%, respectively. For grower and finisher diets, it is recommended to ensure the following rates of these elements: 0.15 and 0.12% of sodium, 0.15% and 0.12% of chlorine and 0.30% of potassium, respectively.

Higher doses of Na in diets were tested in numerous experiments conducted in the early 21st century, in the hope that they would contribute to an increased feed consumption and growth rate of chickens. From 1 to 21 day of age, for example, an optimum dose of sodium in a diet was suggested as 0.25% (Murakami et al. 1997*a*) and even higher: 0.28-0.30% (Oviedo-Rondon et al. 2001). In the second nutritional period of broiler chickens (21-35 days

of age), 0.15-0.29% of Na in a diet was recommended as an optimal level (Murakami et al. 1997b). Because of the widespread use of NaCl as a source of dietary sodium, diets have also become richer in chlorine.

With respect to turkeys, the percentage of sodium in a diet should be 0.17% in the first and 0.15% and second month of rearing turkey poults; afterwards, until the fattening is terminated, 0.12% of Na in a diet is considered as sufficient (NCR, 1994). The percentage of chlorine in a diet should be on a similar level (a little lower in the early phase), while the recommended percentage of K in a starter diet is 0.70% and should gradually decrease down to 0.40% in finisher feeds (NCR 1994).

In recent years, the content of K in a diet has risen considerably. There are several reasons, e.g. higher potassium fertilization of crops, the EU ban on using animal meals in animal nutrition, as a result of which plant feed mixtures are now richer in plant protein sources, especially soybean meal. Due to a high content of potassium in soybean meal, feed mixtures without any other high-protein ingredients are characterized by a relatively high content of K. This is illustrated by the data set in Table 1 concerning diets for broiler chickens and turkeys made without supplemental feed salt or a different source of sodium.

Table 1

Content of Na, K and Cl in feed mixtures without NaCl addition (Jankowski et al. 2011*a*)

Specification	Sodium	Potassium	Chlorine
Content in a feed mix, g kg^{-1}	0.03	0.94	0.14
Nutritional requirement coverage for chickens, % of the NRC standard	16.5	313	72
Nutritional requirement coverage for turkeys, % of the NRC standard	19.4	134	96

Na, K and Cl have a substantial and mutually correlated impact on the water and electrolyte balance as well as the acid and alkaline balance of a living organism, hence they are known as strong electrolytes. When preparing animal feed mixtures, it is important to consider the content of all these elements as well as their sum, including the valence of a given element. This is known as the dietary electrolyte balance (DEB), which encompasses the sum of milliequivalents of Na^+ and K^+ minus the content of milliequivalents of Cl^- (Mongin 1980).

It is assumed that under neutral environmental conditions, the DEB value for chickens is approximately 250 mEq kg (Mongin 1981), being a mean value of quite a wide range of 220-270 mEq kg^{-1} (Mushtaq et al. 2007). For young turkeys, the DEB value derived from the recommended content of Na, K and Cl (NRC 1994) is 211 mEq kg^{-1}, thus being much lower than the optimal value in nutrition of broiler chickens.

EFFECT OF THE CONTENT OF NA ON LEVEL OF ELECTROLYTES IN BLOOD OF BROILER CHICKENS AND TURKEYS

Analysis of the level of electrolytes in blood serum, indicating possible consequences of the deficiency of excess of sodium in diets for broiler chickens and turkeys has been the subject of the experiment presented in Table 2, in which six diets were tested: with different amounts of supplemental NaCl and without this compound. As the synthetic presentation of the results of the tests on chickens shows, statistically significant differences were found between the group fed a diet without added NaCl versus the other nutritional regimes. Supply of diet no 1 caused a decrease in Na concentrations, while raising the concentrations of K, Ca and Mg, which suggests that Na deficit disturbed the mineral balance in chickens. Even a low level of supplemental

Table 2

Effect of different amounts of supplemental NaCl on the concentrations of electrolytes in the blood serum of broiler chickens (TYKAŁOWSKI et al. 2011) and turkeys (LICHTOROWICZ et al. 2012)

Specification	NaCl addition to diet (%)					
	0	0.13	0.25	0.38	0.51	0.64
Content of electrolytes in diet, %*						
Na	0.02	0.07	0.12	0.17	0.22	0.26
K	0.89	0.90	0.89	0.88	0.89	0.88
Cl	0.11	0.20	0.27	0.34	0.41	0.48
Content of electrolytes in chickens' blood						
Na, mmol l^{-1}	136^{b}	151^{a}	150^{a}	150^{a}	149^{a}	148^{a}
Cl, mmol l^{-1}	103^{b}	115^{a}	116^{a}	114^{a}	113^{a}	112^{a}
K, mmol l^{-1}	8.46^{a}	5.72^{b}	5.32^{b}	5.21^{b}	5.45^{b}	5.54^{b}
Ca, mgl dl^{-1}	12.1^{a}	11.1^{b}	10.5^{b}	11.2^{b}	10.6^{b}	10.5^{b}
P, mgl dl^{-1}	7.04^{a}	7.29^{a}	6.41^{b}	6.78^{b}	6.52^{b}	6.12^{b}
Mg, mgl dl^{-1}	3.09^{a}	2.56^{b}	2.31^{c}	2.41^{b}	2.30^{c}	2.24^{c}
Content of electrolytes in turkeys' blood						
Na, mmol l^{-1}	141	150	148	150	146	148
Cl, mmol l^{-1}	105^{b}	110^{a}	110^{a}	109^{a}	110^{a}	110^{a}
K, mmol l^{-1}	3.56	3.85	3.55	3.28	2.71	3.27
Ca, mgl dl^{-1}	13.7^{a}	13.3^{ab}	12.8^{b}	13.3^{ab}	13.3^{ab}	12.9^{b}
P, mgl dl^{-1}	6.30^{c}	9.21^{a}	7.63^{b}	8.56^{a}	8.89^{a}	7.77^{b}
Mg, mgl dl^{-1}	2.83^{a}	2.34^{b}	2.37^{b}	3.37^{b}	2.41^{b}	2.46^{b}

* Data refer to chickens' diets. In turkeys' diets, with a higher content of soybean meal, the content of K was 0.2% higher while the content of Na and Cl was similar.

NaCl, such as 0.13%, which increased the content of Na in a diet from 0.02 to 0.07% and the content of Cl from 0.11 to 0.20%, ensured the concentrations of most of the analyzed elements at a level similar to that determined in diets with 2-5-fold higher NaCl supplementation. Significantly less Mg was observed in groups 3-6 compared to groups 1 and 2. This indicates that higher NaCl supplementation can decrease the concentrations of Mg in blood, but only with respect to groups receiving diets poor in sodium and chlorine, causing certain changes in the blood concentrations of electrolytes.

In an experiment conducted on young turkeys, diets with different amounts of Na and Cl did not cause changes in the concentrations of sodium and potassium in six-week-old turkeys' blood serum. The lowest level of sodium and chlorine in the diet decreased the concentrations of chlorine while increasing the concentrations of Ca and P in blood serum. With respect to a diet deficient in sodium, the highest NaCl supplementation decreased the concentrations of Ca.

In another experiment (Jankowski et al. 2012a), in which the amounts of Na in diets were 0.07, 0.12, 0.17 and 0.22%, the concentrations of microelements were analyzed in the blood serum of turkeys that completed a full rearing cycle at 18 weeks of age. It was found that the blood serum concentrations of all elements (Y) except Mg tended to increase as the percentage of Na in a diet (X) increased. With respect to sodium, the increase followed the equation: $Y = 149.5 + 14X$ ($R^2 = 0.891$, $p = 0.056$). The same tendency was observed regarding the concentration of K ($Y = 2.14 + 2.36\ X$, $R^2 = 0.904$, $p = 0.049$) and the concentration of phosphorus in serum ($Y = 7.95 + 4.64\ X$, $R^2 = 0.945$, $p = 0.028$), while the dependences determined for Cl, Ca and Mg produced low coefficients of statistical significance.

Some other investigations demonstrated that excess of sodium caused increased blood volume and decreased counts of lymphocytes (Ekanayake et al. 2004). Another experiment (Tykałowski et al. 2011) showed that a sodium-deficient diet (without supplemental NaCl) reduced the concentrations of the analyzed subpopulations of T-lymphocytes, but the differences versus the other groups were not statistically significant. This was also a result of a relatively high variation of the analyzed parameters, which did not show a straight linear dependence on the content of Na in a feed mixture.

The results of the authors' own experiments show that variations in the concentrations of microelements in blood serum, dependent on the amount of added NaCl, are relatively small, which limits the diagnostic value of this analytical determination.

EFFECT OF THE CONTENT OF ELECTROLYTES IN A DIET ON WATER INTAKE AND MOISTURE OF THE LITTER

It is known that dietary sodium is an important factor in birds' response to stress, especially heat stress, for instance through increased consumption of water (Olanrewaju et al. 2007). As evidenced experimentally (Borges et al. 2003), giving chickens a starter diet with the DEB increasing in the range of 0, 120, 240 and 360 mEq kg^{-1} caused an increase in water and feed intake from 2.31 do 2.76 l kg^{-1} during a six-week trial. Typically, as long as the thermal comfort is maintained, water intake is twice as high as the amount of ingested feed, but this ratio increases when the content of electrolytes in a diet, especially sodium, goes up. Then, the moisture content of bird excreta rises, as well.

An experiment conducted by Enting et al. (2009) suggests that the litter moisture is highly significantly correlated with the moisture content of birds' faeces. In an earlier study of Murakami et al. (2001), it was shown that differences in the content of dietary Na within 0.1 to 0.35% caused a proportional increase in the moisture content of litter. In another trial (Vieira et al. 2003), during the first week of age of chickens, as the content of Na in a feed mixture increased successively from 0.12 to 0.48%, so did the water intake while the dry matter content in excreta decreased from 28% do 18%. In another experiment (Mustaq et al. 2007) with similar percentages of Na in diet, i.e. 0.20, 0.25 and 0.3% Na, respectively, the litter moisture (in %) was 33.2^{b}, 37.5^{a} and 29.3^{c} (significance of differences $p<0.05$).

In one of our experiments (Jankowski et al. 2011*a*), it was noted that the addition of NaCl, increasing the content of both elements in the diet, affected some parameters of the small intestine, for instance decreased the pH of the intestinal contents (Table 3). On the other hand, the amount of Na in the diet had no effect on the percentage of dry matter in the caecal contents.

A similar analysis of varied levels of NaCl added to feeds was completed experimentally (Jankowski et al. 2012*a*) for slaughter turkeys. Analogously to the aforementioned experiment on chickens (Table 3), differences in the amounts of Na added to turkeys' diets caused significant changes in the functions of the small intestine, but led to much smaller alterations in the parameters of the caecum. Thus, the content of dry matter in excreta of these birds was even, despite different quantities of dietary Na, ranging from 0.05 to 0.20%. At the completion of both turkey rearing periods, i.e. at 8 and 18 weeks of age, significant intensification of FPD symptoms was observed (Table 4). In the 8^{th} week, the advancement of FPD rose from 1.7 to 2.0 points, and in the 18^{th} week of turkey rearing it went up from 3.2 to 3.5 points. This score can indicate that turkeys are more sensitive to leg disorders classified as FPD. In the final phase of rearing, a small increase in the content of dietary Na, from 0.10 to 0.15%, intensified the symptoms of FPD.

Table 3

Parameters of digestive tract function in chickens fed diets with different amounts of supplemental NaCl (JANKOWSKI et al. 2011*a*)

Specification	Supplemental Na in feed (%)		
	0	0.10	0.25
Small intestine			
the total mass, g kg^{-1} BW	47.0^{a}	43.7^{ab}	42.5^{b}
DM of contents, %	19.3^{a}	17.2^{b}	17.4^{b}
viscosity, mPas	2.11^{a}	1.65^{b}	2.20^{a}
pH of contents	5.77^{a}	5.22^{b}	5.27^{b}
Caecum			
mass of contents, g kg^{-1} BW	4.94^{a}	4.71^{b}	6.29^{a}
DM of contents, %	18.1	16.7	18.0
pH of contents	6.16	6.22	6.08

Table 4

Effect of the Na content in feeds on moisture of faeces and incidence of FPD in turkeys aged 8 and 18 weeks (JANKOWSKI et al. 2012*a*)

Na added to feed (%)	8 weeks		18 weeks	
	dry matter (%)	FPD	dry matter (%)	FPD
0.05	19.0	1.7^{b}	20.5	3.2^{b}
0.10	19.4	1.8^{ab}	20.0	3.3^{b}
0.15	19.2	1.7^{b}	20.2	3.5^{a}
0.20	19.0	2.0^{a}	19.9	3.5^{a}

EFFECT OF SODIUM ON BONE MINERALIZATION IN BROILER CHICKENS AND TURKEYS

Experiments testing the effect of varied amounts of dietary sodium on bone mineralization in poultry are relatively few. Selected results of one of such experiments are presented in Table 5.

Uniform measurements of the tibia's relative mass suggest that different Na and Cl supplementation levels did not reduce the share of the tibia's mass in the total body mass of chickens. This finding also held true for chicken fed on a mix without supplemental Na. However, the growth rate of chickens in that group was inhibited, so that the final body weight was less than 0.5 kg. Likewise, in the second group, where the percentage of Na added to the feed mixture was small (0.05%), the final body weight was less than 1.5 kg. In the other groups, it was significantly higher (1.64-1.71 kg). Feeding chickens on a diet without added Na decreased the content of ash,

Table 5
Parameters of the mineralization and strength of the tibia in chicken fed diets with different supplemental Na (JANKOWSKI et al. 2011*a*)

Specification	Content of Na in diet* (%)					
	0.02	0.07	0.12	0.17	0.22	0.26
Relative bone mass, % body weight	0.49	0.54	0.53	0.51	0.52	0.50
Bone content of:						
ash, % dry matter	50.7^{b}	53.8^{a}	54.8^{a}	52.1^{ab}	52.5^{ab}	50.7^{b}
Ca, % dry matter	18.0^{b}	18.8^{ab}	19.5^{a}	18.2^{b}	18.5^{ab}	17.9^{b}
P, % dry matter	8.69^{B}	9.36^{A}	9.41^{A}	8.82^{B}	9.06^{AB}	8.78^{B}
Minimum breaking strength, kN	0.23^{C}	0.63^{A}	0.62^{AB}	0.56^{AB}	0.59^{AB}	0.54^{B}

* Content in grower diet, given from 15-35 days of age of chickens;
$^{a, b}$ and $^{A, B}$ – significance of differences at 0.005 and 0.001

Ca and P in the tibia's dry matter and radically increased its vulnerability to fracture. Even a small amount of Na added to a diet (0.05%) sufficed to offset the above negative consequences of sodium deficiency in chickens' diet. In the group which received the feed mixture with the highest Na content (0.26%), a decrease in the content of ash, Ca and P in the tibia was noted, similarly as in the group fed a sodium-deficient diet, but the tibia did not become more breakable.

In an experiment on young turkeys (to six weeks of age), it was found that a sodium-deficient diet (0.035) decreased the body weight of birds, including the weight of the tibia, but did not reduce the content of bone ash, ca and P (JANKOWSKI et al. 2012*b*). This research problem was analyzed on turkeys reared in a full cycle, to 18th week of age, using diets with four levels of Na, from 0.07 to 0.22% (JANKOWSKI et al. 2012*a*). Different concentrations of Na in a diet did not affect the relative bone mass of the tibia or the content of ash, Ca and P in the bone. Significant differences were noted while analyzing the parameters of tibia breaking strength. An increased content of Na in diets, from 0.07 and 0.12 raised to 0.17 and 0.22%, caused a significant increase in the perimeter and density of the tibia, reflected in higher elastic and breaking strength of the bone.

The results of the experiments discussed above imply that deterioration of the parameters of bone mineralization can be induced by both a deficient and an excessive Na content of a diet. Regarding chickens, worse bone mineralization parameters were achieved when the dietary content of Na was either decreased from 0.07-0.22% to 0.02% or increased to 0.26%. With respect to slaughter turkeys, better bone mineralization parameters were observed when dietary sodium levels were increased from 0.07-0.12 to 0.17-0.22%.

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