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Macromineral concentration and technological properties of poultry meat depending on slaughter age of broiler chickens of uniform body weight

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The aim of the study was to determine the effect of slaughter age of broiler chickens on macromineral levels of breast and leg muscles and their association with meat quality. Used were fast-growing Hybro chickens kept on litter and fed the uniform diet. Ten chickens weighing 2 kg each were selected for slaughter at 35, 38 and 42 day of life. Breast and leg muscles were evaluated for pH, colour (CIELAB), water-holding capacity, drip loss, cooking loss, shear force, as well as for Na, Ca, K, P and Mg content. The birds' age had an effect on the Na and K content of breast muscles and on the K, P and Mg content of leg muscles. No significant differences were found in most physicochemical characteristics of breast meat except pH which was the lowest in the oldest birds and cooking loss which was the highest in the youngest birds. No relationship between the level of individual minerals and meat quality traits was identified in breast muscles. In leg muscles Mg level correlated positively with pH_{15min} and drip loss, P level with pH_{15min}, and potassium level with water-holding capacity. Breast muscles turned out to be a richer source of K, Mg and P and leg muscles contained more Na.

KEY WORDS: broiler chicken / macrominerals / meat quality / slaughter age

From the perspective of human nutrition, poultry meat, in addition to large amount of easily assimilated animal protein and vitamins, is a valuable source of minerals [Lombardi-Boccia *et al*. 2005]. The level of those compounds, may vary not only according to the micro- and macroelement content of feeds but also according to the

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way animals are housed, their breed, sex and health, slaughter procedures, and type of muscle [Doyle 1980, Horbańczuk *et al*. 1998, Sales and Horbańczuk 1998, Zapata *et al*. 1998, Sadoval *et al*. 1999, Lombardi-Boccia *et al*. 2005, Pesut *et al*. 2005, Skrivan *et al*. 2005].

For many years, intensive poultry production has been oriented mainly towards obtaining large amounts of meat in a very short time. Therefore, the novel genetic types of broiler chickens introduced into the flocks are characterized by an increasingly rapid rate of growth, increasing weight of muscles, and progressively lower age at slaughter. However, the improvement of production parameters has its impact on metabolism, including the processes controlling mineral absorption and assimilation. When studying the elementary composition of liver, lungs, kidneys and cardiac muscle in chickens diagnosed with sudden death syndrome, Buckley and Gardiner [1990] demonstrated that the affected and healthy birds differed in the concentrations of Ca, P and Mg. Mineral components play an important role in the metabolism of skeletal muscles, and some elements (such as Na, Ca, K, P and Mg) play a vital role in enzymatic processes and are responsible not only for normal muscle function but also for the course and extent of postmortem changes in muscles [Podgórski *et al*. 2001, Keeton and Edy 2004]. The wide variation in the meat of modern broiler chickens in terms of its physicochemical traits and the increasingly common meat defects that negatively affect its quality can, therefore, point to differences in the course of metabolic processes, including the mineral metabolism.

The differences in poultry meat quality are due, among others, to slaughter age of birds. Today, this factor takes on special significance following the entry into force, on 30 June 2010, of regulations transposing into Polish law Council Directive 2007/43/EC laying down minimum rules for the protection of chickens kept for meat production. These regulations impose restrictions on increasing the stocking density of kg chickens per m^2 floor area. This helps to differentiate the age of slaughtered chickens because not infrequently, to reduce stocking rate in the finishing period, some younger birds, which managed to achieve the desired body weight in a shorter time, are allotted for slaughter from the flock. Both growth intensity and the duration of rearing are important factors affecting many meat quality traits. These factors can also affect the level of minerals of muscles, thereby modifying the technological quality of meat. A study by Mohanna and Nys [1998] indicates, for example, that the age of chickens has a significant effect on the level of trace elements (Zn, Fe, Mn, Cu) in whole body, the concentration of which decreases significantly as broilers grow old. Likewise, Doornenbal and Murray [1981], Kotula and Lusby [1982] and Lin *et al*. [1989] consider the age to be one of the major factors affecting the mineral content of animal tissues. Unfortunately, studies upon growth-related changes in macromineral concentrations and technological properties of meat are limited, especially in poultry.

The aim of the present study was to investigate the effect of slaughter age of fast-growing broiler chickens of uniform market weight on the level of Na, Ca, K, P and Mg in breast and leg muscles and to determine their association with meat quality traits.

Material and methods

The experiment comprised 750 fast-growing Hybro chickens reared on litter under optimum environmental conditions and fed *ad lib.* with the same complete prestarter, starter, grower and finisher diets, containing 21, 20, 18 and 18% CP and 2900, 3040, 3150 and 3200 kcal/kg ME, respectively. From the first day of the experiment, chickens' body weight was monitored at weekly intervals. On day 35, 38 and 42, 5 cockerels and 5 pullets weighing 2 kg were selected for slaughter. The pH of breast and leg muscles was determined 2 min. ($pH_{2min.}$) and 15 min. postmortem ($pH_{15min.}$) with a portable pH meter (CYBERSCAN10) equipped with a glass electrode. The pH measurement was repeated 24 h after slaughter (pH_{24h}) on carcasses chilled to 4°C. Samples were collected from dissected breast and leg muscles to determine the level of essential macrominerals and to evaluate some physicochemical traits of meat.

Na, Ca, K and Mg contents were determined by atomic absorption spectrophotometry, and P content by spectrophotometry at a wavelength of 700 nm.

Muscle colour readings were taken in the L*a*b* (CIE, 1976) colour space using MINOLTA CR 310 Chroma meter (Japan). CIE L*a*b* values were measured on the inner side of *pectoralis superficialis* muscle and thigh muscles, immediately after they were separated from the bone, with four measurements per muscle and calculation of the mean for individual colour parameters of L* (lightness), a* (redness) and b* (yellowness). Areas were selected free of any obvious blood-related defects, such as bruises, hemorrhages, or full blood vessels [Fletcher *et al*. 2000]. Water-holding capacity (WHC) was determined based on the volume of free water squeezed from a ground meat sample using the filter paper method [Grau and Hamm 1953]. Drip loss was determined from meat weight loss after 24-h cold storage at 4°C. Cooking loss was determined from percentage loss of meat weight as a result of cooking. Samples weighing about 80 g (e=0.001 g) were placed in individual plastic bags and cooked in a water bath at 100°C until a core temperature of 78°C was obtained in the thickest part of the sample. The samples were cooled and weighed for cooking loss determination, and the breast muscles were prepared for the shear force measurements. One 1.27 cm diameter core was removed from each sample parallel to the fibre orientation through the thickest portion of the cooked muscle. Shear force was determined as maximum force (N) perpendicular to the fibres using INSTRON 5542 equipped with a Warner-Bratzler blade.

The results were analysed statistically using two-way analysis of variance and significance of differences between the means were determined using Duncan's test (STATGRAPHICS Plus 6.0). In addition, Pearson's linear correlation coefficients were calculated for those traits to determine the relationship between the level of minerals in meat and its physicochemical characteristics.

Results and discussion

The mean mineral composition (g/kg) of breast and leg muscles from three age groups of chickens are presented in Tables 1 and 2. Similar to other studies, K was quantitatively the most important mineral in chicken meat, followed by P and Na [Lawrie 1990, Demirbas *et al*. 1999, Podgórski *et al*. 2001]. The mean body weight of 35, 38 and 42 day-old chickens was 1.78, 2.09 and 2.22 kg, respectively. The age at which they achieved a slaughter weight of 2 kg had a significant effect on the Na and K content of breast muscles (Tab. 1) and on the K, P and Mg content of leg muscles (Tab. 2). The highest content of Na in breast muscles (0.59 g/kg) was found in chickens slaughtered on day 38 of age. Meanwhile, the lowest Na (0.43 g/kg) and the highest K content (4.27 g/kg) was characteristic of breast muscles from the oldest and

Table 1. Macrominerals in breast muscles (g/kg tissue) of broiler chickens (means±SD)

Item	Age (days)					
	35		38		42	
	♂	♀	♂	♀	♂	♀
Na	0.46^{A}±0.03	0.43^{a}±0.02	0.53^{B}±0.05	0.49^{b}±0.07	0.44^{A}±0.03	0.41^{a}±0.05
Ca	0.04±0.01	0.03±0.00	0.04±0.00	0.04±0.01	0.04±0.00	0.04±0.00
K	4.00±0.16	4.15±0.10	3.95^{a}±0.08	4.01^{a}±0.18	4.24^{b}±0.13	4.30^{b}±0.25
P	2.36±0.06	2.45±0.09	2.33^{a}±0.05	2.41^{b}±0.08	2.28^{A}±0.04	2.42^{B}±0.15
Mg	0.30^{a}±0.01	0.32^{b}±0.02	0.31±0.01	0.32±0.01	0.30^{A}±0.01	0.34^{B}±0.02

$^{aA...}$Means in rows bearing with different letters differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

Table 2. Macrominerals in leg muscles (g/kg tissue) of broiler chickens (means ± SD)

Item	Age (days)					
	35		38		42	
	♂	♀	♂	♀	♂	♀
Na	0.67±0.07	0.67±0.05	0.74±0.04	0.70±0.05	0.75±0.05	0.71±0.03
Ca	0.05±0.00	0.05±0.01	0.05±0.00	0.05±0.00	0.05±0.01	0.05±0.00
K	2.77^{Ab}±0.11	2.97^{Aa}±0.18	3.42^{B}±0.09	3.34^{B}±0.18	3.34^{B}±0.12	3.22^{b}±0.09
P	1.84^{A}±0.07	1.88^{a}±0.07	1.94±0.04	1.98±0.08	2.06^{B}±0.03	2.03^{b}±0.05
Mg	0.23^{Aa}±0.01	0.23^{A}±0.00	0.24^{b}±0.00	0.24^{a}±0.01	0.25^{B}±0.01	0.25^{Bb}±0.00

$^{aA...}$Means in rows bearing with different letters differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

slowest growing birds. The same chickens showed a trend towards the lowest initial and final pH of breast muscles, which was significant in cockerels (Tab. 3). However, this study revealed no significant differences in the other physicochemical traits of breast meat except for cooking loss, which was the highest in the youngest and at the same time fastest growing birds.

Table 3. Quality traits of broiler chicken breast muscles (means ± SD)

Item	Age (days)					
	35		38		42	
	♂	♀	♂	♀	♂	♀
pH_{2min}	6.45^{a}±0.34	6.36±0.12	6.20±0.24	6.28±0.27	6.10^{b}±0.08	6.20±0.03
pH_{15min}	6.24^{a}±0.19	6.18±0.13	6.03±0.21	6.16±0.20	6.00^{b}±0.06	6.05±0.14
pH_{24h}	6.14±0.07	6.10±013	6.15^{a}±0.16	5.99^{b}±0.08	6.00^{b}±0.14	5.99±0.11
L*	56.23±1.40	57.86±2.86	55.38±2.49	55.99±2.66	57.65±4.30	53.91±4.67
a*	12.03±1.14	11.22^{a}±1.28	11.90±1.02	13.13^{b}±1.27	11.08±0.57	12.43±2.37
b*	8.23±1.11	9.22^{A}±1.72	7.91±1.83	7.40±0.78	7.07±1.40	5.98^{B}±1.81
W-HC (%)	15.10±3.02	13.05±5.90	14.98±3.23	17.05±3.48	15.55±4.60	14.65±5.09
Drip $loss_{24h}$ (%)	0.22±0.12	0.45±0.12	0.50±0.32	0.79±1.04	0.73±0.27	0.44±0.39
Cooking loss (%)	20.34^{a}±2.72	18.87^{a}±2.12	15.25^{b}±5.12	14.32^{b}±5.74	19.05±1.44	16.49±2.74
Shear force (N)	15.23±3.86	12.86±2.02	13.18±2.47	15.81±1.83	18.10±2.51	16.42±2.83

[aA...]Means in rows bearing with different letters differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

In the case of leg muscles, the lowest (P≤0.01) levels of K, P and Mg (2,87, 1.86 and 0.23 g/kg, respectively) were found in the fastest growing chickens which required just 35 days to reach market weight (Tab. 2). Also, the content of Na in the leg muscles of these chickens was lower (P>0.05) than in those aged 38 and 42 days. Meanwhile, the highest level of P (2.05 g/kg) and Mg (0.25 g/kg) was found in leg muscles of the oldest birds. According to Koreleski [2002], the low level of dietary minerals causes deficiency conditions, with decreased mineral content of blood serum, liver and other internal organs as well as meat. It is, therefore, possible that the lowest level of macrominerals in the leg muscles of the youngest and then fastest growing chickens resulted from the inadequate supply of these compounds in feed, or from their insufficient absorption and assimilation from the digestive tract of rapidly growing broilers. Nevertheless, it is surprising that the intensity of chicken growth had a greater impact on changes in the mineral levels and quality of leg muscles rather than breast muscles, because the latter are considered to be more susceptible to quality changes of this type.

The coefficients of correlation between the content of Na, Ca, K, P and Mg in meat and its physicochemical properties, proved mostly low and non-significant (figures not tabulated). For breast muscles, no correlation was found between the content of individual minerals and meat quality traits. This study appears to agree with that of Misra *et al*. [1980], in which the intracellular concentrations of K, Mg, and P measured directly in the fibres of *pectoralis major* muscle of 8-week-old, genetically dystrophic *vs.* normal chickens remained unchanged in the dystrophic muscles. However, the same authors found a significant increase in the concentration of intracellular Na in dystrophic condition. Meanwhile, Sandercok and Mitchell [2004] and Sandercok *et al*. [2009] showed that the higher concentration of Na in broiler breast muscle compared to that of unselected lines was potentially important as alterations in muscle cation homeostasis and might underlie the initiation of muscle degeneration and subsequent reductions in meat quality. Furthermore, in man, the elevated skeletal muscle Na content was associated with injury and disease states [Constantinides *et al*. 2000]. In this study, we obtained negative coefficients of correlation between the level of Na in breast muscles and their water-holding capacity, cooking loss and pH, but in no case were these relationships significant.

Unlike in breast muscles, certain relationships were observed in leg muscles. The leg muscles of birds slaughtered on day 38 of life, which were found to have the highest level of K (3.38 g/kg), were also characterized by the poorest water-holding capacity (12.74%), the highest cooking loss (25.04%) and the lowest pH of 6.56, 6.21 and 6.08 at 2 min, 15 min and 24 h postmortem, respectively – Table 4. A positive correlation was found between K level and water-holding capacity ($r = 0.40$; P=0.027). There were also positive correlations between the level of phosphorus and pH_{15min} ($r = 0.36$; P=0.048), and between the level of magnesium and pH_{15min} ($r = 0.42$; P=0.022) and drip loss ($r = 0.42$; P=0.020). In addition, a negative relationship was revealed between phosphorus level and yellowness ($r = –0.39$; P=0.034).

Table 4. Quality traits of broiler chicken leg muscles (means ± SD)

Item	Age (days)					
	35		38		42	
	♂	♀	♂	♀	♂	♀
pH_{2min}	6.73±0.34	6.55±0.22	6.46±0.21	6.65±0.44	6.75±0.22	6.65±0.22
pH_{15min}	6.43^{a}±0.13	6.45^{a}±0.12	6.16^{Ab}±0.31	6.26^{A}±0.23	6.59^{B}±0.24	6.58^{Bb}±0.14
pH_{24h}	6.33±0.10	6.30±0.10	6.09^{a}±0.30	6.04^{a}±0.22	6.46^{b}±0.30	6.40^{b}±0.24
L*	46.44±1.66	45.90±2.28	45.45±2.58	47.33^{A}±1.66	45.49±3.33	42.22^{B}±2.26
a*	17.52±1.40	17.68±0.81	17.10±0.60	17.13±0.62	16.84±1.45	16.95±0.84
b*	7.35±0.76	7.69±0.95	6.43±0.58	7.48^{a}±0.44	7.06±1.30	6.38^{b}±1.11
W-HC (%)	8.02±1.69	7.45^{a}±2.58	11.31±4.23	14.17^{Ab}±2.95	9.14±3.96	6.65^{B}±1.85
Drip $loss_{24h}$ (%)	0.20^{a}±0.12	0.16±0.16	0.21^{a}±0.13	0.31±0.05	0.45^{b}±0.38	0.21^{a}±0.11
Cooking loss (%)	20.36^{a}±2.62	18.98±3.04	26.63^{Ab}±5.03	23.44^{b}±4.14	15.92^{B}±3.84	17.52^{a}±2.61

[aA...]Means in rows bearing with different letters differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

According to Grabowski and Kijowski [2005], the minerals in meat play a significant role in enzymatic processes, also affecting the pH of muscle tissue and protein hydration. Na, K, Ca and Mg contribute to maintaining osmotic pressure and the electrolyte balance in cells and tissues, thus playing a major role in regulating the level of meat hydration. Also P, which is found in meat in the form of phosphates, contributes significantly to the water-holding capacity of meat. There are many indications of the intimate role which Mg plays in muscular contraction and in catalysing several enzymatic processes concerned with the transfer, storage and utilization of energy in the skeletal muscles. According to Houston and Harper [2008], Mg regulates the intracellular level of Ca, Na, K and pH. A close relationship between Mg and K concentration in muscles is also well known [Podgórski *et al*. 2001]. Our results seem to confirm that the level of some macroelements, such as K and Mg in chicken muscles may influence the physicochemical properties of meat, although in this study the concentration of these elements was mainly related to water holding capacity in red muscles. The higher K and Mg levels were paralleled by the higher loss of meat juice. At the same time, the higher magnesium and phosphorus levels were associated with lower pH of meat measured 15 min postmortem.

Age has been reported to be an important factor affecting the mineral content of animal tissue [Doornenbal and Murray 1981, Kotula and Lusby 1982, Lin *et al*. 1989]. Similarly, this study shows a significant effect of age on the Na, K, P and Mg content of chicken muscles. Our present results are slightly different from those reported by Nieß *et al*. [2005], who found no significant differences in the concentration of Na and K in fresh and fat-free body matter of chickens slaughtered at different ages. However, like in present study, they found a lower concentration of P in the body of younger birds and found no differences in the level of Ca in chickens of different ages. When analysing the effect of age on the macroelement content of rabbit muscles, Hermida *et al*. [2006] found that age factor created significant differences in the level of K, Na and Mg while having no effect on the level of P and Ca. Meanwhile, Hoffman *et al*. [2007] demonstrated no differences in the mineral content of *M. longissimus dorsi* in springbok of different ages.

Despite a fairly large number of relevant studies, the effect of birds' age at slaughter on meat quality has not been well established for modern broilers at current commercial slaughter ages. Smith *et al*. [2002] observed no birds' age effect on broiler breast muscle colour between 42 and 52 day of age, and, like in the present study, these chickens did not differ in body weight. Poole *et al*. [1999] reported that meat tenderness tends to decrease with the birds' age. A similar but non-significant trend was also observed in this study. Meanwhile, according to Schneider *et al*. [2012], breast muscles of chickens slaughtered at the age of 28, 35, 42, 49 and 56 days differed significantly for all evaluated quality traits, with no direct trends for drip loss and Allo-Kramer shear values as bird age increased. By contrast, in this study water-holding capacity and drip loss of breast muscle from chickens of different ages did not differ significantly, and the lowest cooking loss (14.09%) was noted in the group of 38-day-old birds ($P \leq 0.05$). Another trend was reported by Schneider *et al*. [2012], who showed that cooking loss increased with age between 28 and 49 days at slaughter. In this study, we found a marked and significant tendency towards increasing pH of breast muscle in older chickens. However, this was not accompanied by a corresponding tendency in the other physicochemical characteristics of meat, although several studies have reported strong correlations between muscle pH, colour and water-holding capacity [Van Lack *et al*. 2000, Quiao *et al*. 2002, Barbut *et al*. 2005] and variations in meat quality, normally attributed to the rate and extent of pH decrease postmortem [Warriss *et al*. 1999]. This tendency existed for leg muscles, because the group with the lowest values and the highest pH decline postmortem was also characterized by the poorest water-holding capacity (12.74%) and the highest cooking loss (25.04%), but there was no direct trend according to the age of the birds.

When comparing the most valuable two types of broiler muscles for the consumer for their mineral content, it was found that breast muscles were a richer source of K, Mg and P, and leg muscles contained more Na. The level of Ca in both muscle types did not differ significantly between ages, although this element showed a trend towards higher concentration in leg muscles. According to Addis [1986], the higher content of calcium in dark meat may be associated with a greater demand of leg muscle contraction as compared to that in light breast muscle. Our observations for the different levels of minerals in breast and leg muscles support those of Zapata *et al*. [1998] and Goluch *et al*. [1997]. Also Zarkadas *et al*. [1987] noted considerable differences in potassium content according to the type of avian muscles. It is known that breast and leg muscles in gallinaceous poultry differ markedly in the histochemical profile and in the nature of metabolic processes. For this reason, the level of individual minerals in these muscles may differ. Zapata *et al*. [1998] reported values of 4.71, 224.28, 28.59, 327.99 and 46.83 mg/100 g tissue for Ca, P, Mg, K and Na, respectively, in broiler chicken light meat, and of 5.69, 191.78, 20.17, 280.25 and 66.11 mg/100 g tissue, respectively, in dark meat. These mean values are, except for Ca level, slightly lower than those found in this study, and in the case of leg muscles, they most closely correspond to the values that we obtained for the youngest chickens. Lower levels of these elements in chicken meat, compared to ours, were also found by Hamm and Searcy [1981]. Similarly to the studies of Grześkowiak *et al.* [2011] and Poławska *et al.* [2011], P and K content of poultry meat is lower. As already mentioned, the level of K and Na in breast muscle and the level of K, P and Mg in leg muscles changed with chickens' age, which makes a comparison with the findings of other authors difficult. It is, therefore, possible that the variation of data found in the literature results from the age-dependent nature of their accumulation in poultry meat. Moreover, according to Hermida *et al*. [2006] the average macrominerals concentration in muscles depend not only on the type of cuts, but on other factors which are often not reported. Therefore, comparison between studies must be considered with caution.

The present study showed that even a small difference in the duration of the period in which chickens are grown to a certain slaughter weight could contribute to large variation in meat quality. The breast muscle of the slowest growing, 42-day-old chickens had lower pH than that of birds achieving the same weight in a shorter time. Higher acidity reduces the growth of microflora and increases the storage quality of meat, making it a more attractive product for the fresh meat market. In this case lower pH, which normally determines the other physicochemical characteristics of meat, did not significantly change water-holding capacity, which is why the breast muscle of older chickens is also a valuable raw material for the processing industry. In contrast, the breast muscle of the youngest, fastest-growing chickens, despite the small drip loss, was characterized by high cooking loss, which considerably reduced their processing yield. The highest nutritive value was characteristic of the meat from the oldest chickens. Due to the high K and low Na content, the breast muscle of these birds is particularly recommended for hypertension diets. Also the leg meat from slower-growing chickens compared to the meat of chickens with a faster rate of growth, has a greater nutritive value for the consumer due to its higher K, Mg and P levels. Muscle type proved a major determinant of the mineral content of meat. Breast muscles turned out to be a richer source of K, Mg and P, and leg muscles contained more Na.

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