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NUTRITIONAL VALUE AND THE CONTENT OF MINERALS IN EGGS PRODUCED IN LARGE-SCALE, COURTYARD AND ORGANIC SYSTEMS

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Abstract

The aim of this study was to determine the content of basic nutrients as well as selected macro- and micro-elements in the albumen and yolk of eggs produced at large-scale, commercial poultry production farms (10) as well as in organic (8) and courtyard farms (12). Ten eggs were randomly collected 3 times on each farm. For chemical analyses, the eggs were hard-boiled for 15 min and then stored at a temp. of 4°C until analyzed. The albumen and yolk of hard-boiled eggs were assessed for the content of dry matter, total protein, crude fat and crude ash, and for their energy value (net Atwater equivalents) as well as the concentrations of K, Na, Ca, Mg, P, Fe, Zn, Cu, Se and Mn. No differences were observed in the content of dry matter, total protein and crude ash. However, differences were demonstrated for the crude fat content, the highest ($P < 0.05$) level of which was found in eggs from the organic system (higher by 60% in albumen and by 17% in yolk than in the other eggs), which was accompanied by an increased energy value of these eggs. In all the analyzed eggs, similar concentrations were noted for Mg (egg white) and P (egg albumen and yolk). The albumen of eggs from the organic system was characterized by the highest ($P < 0.05$) content of K, Na, Ca, Zn, Se and Mn. In turn, the albumen of eggs from large-scale commercial poultry production farms contained the highest ($P < 0.05$) levels of Fe, Cu and Se. Yolks of the eggs from the organic system accumulated the highest ($P < 0.05$) levels of K, Na, Ca, Mg and Fe. In turn, the highest ($P < 0.05$) concentrations of Zn, Se and Mn were determined in yolks of the eggs produced in the homestead system, and that of Cu – in yolks of the eggs from large-scale commercial production. A highly positive correlation between concentrations of minerals in the albumen and yolk of the analyzed eggs was reported for the following pairs: K-Na, Se (0.998, 0.93); Na-Na (0.949); Ca-Mg, Mn (0.994, 0.951); Mg-Ca,

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Mn (0.986, 0.982); P-Ca, Mn (0.997, 0.961); Fe-K, Mg, P, Zn (0.999, 0.937, 0.988, 0.999); Zn-Ca, Mn (0.999, 0.945); Se-Cu (0.971) and Mn-Ca (0.902), whereas a negative correlation for: Ca-Fe, Cu (-0.974, -0.994); Mg-Cu (-0.921); P-Fe (-0.933); Zn-Fe (-0.912); Cu-Na (-0.951); Se-K, P, Zn (-0.960, -0.910, -0.962) and Mn-Se (-0.979).

Keywords: poultry keeping system, egg laying, eggs, nutritional value, mineral elements.

INTRODUCTION

As food, eggs are distinguished by a high nutritional value, not only owing to the levels and ratios of nutrients they contain, but also because of their bioavailability and chemical characteristics that respond well to the nutritional demands of man. Having multifunctional properties, eggs are perceived as a nutraceutical food product (Kovac-Nolan et al. 2005, Kijowski et al. 2013).

The mineral composition of hens' egg may be modified, *iter alia*, by the quality of administered feed, the rearing system of hens and the birds' genetic traits (Kücükyilmaz et al. 2013). The content of eggs is especially rich in phosphorus, chlorine, potassium, sodium, sulfur, calcium, magnesium and iron. Lower and sometimes even trace levels are reported for zinc, fluorine, bromine, iodine, copper, manganese, arsenic, boron, barium, chromium, aluminum, silicon, lithium, molybdenum, lead, rubidium, selenium, strontium, cobalt, titanium, uranium, vanadium and silver (Giannenas et al. 2009, Bouvarel et al. 2011). Consumption of an egg covers around 10% of the daily demand for many of these elements (Jarosz, rychlik 2012).

The growing consumer awareness of food quality and safety is reflected by an increasing interest in foods produced without genetically-modified ingredients and originating from animals and birds allowed to use free ranges. This demand is satisfied by certified organic production and by the traditional rearing of hens at a homestead, which today is a niche production sector (Trziszka et al. 2006).

This study was aimed at determining the content of basic nutrients and selected macro- and microelements in the albumen and yolk of eggs produced in large-scale commercial poultry farms as well as in organic and courtyard farms.

MATERIAL AND METHODS

The investigations were carried out on eggs of hens (Rhode Island Red) in their second egg-laying year. The eggs were produced in 10 large-scale poultry farms, 12 courtyard homesteads and 8 certified organic farms, in June - September 2013. On each farm, 10 eggs laid on the same day were randomly collected 3 times. The hens' feeding on each farms was carried out according to the recommendations, including free access to feed and water. Optimized amounts of minerals, such as Na, Ca, P-available, Mg, Fe, Zn, Cu, Se, Mn, and J and Cb (Smulikowska, Rutkowski 2005) were added to the basic diet. In large-scale commercial poultry farms, birds were kept in cages installed in a room with controlled temperature and humidity. In these farms, hens were fed commercial feed mixes (based on maize, soybean meal and wheat). In courtyard homesteads and organic farms, hens received feed mixes made mainly from home-grown cereals (wheat, corn, triticale, rapeseed meal, peas) supplemented with mineral concentrates according to the nutritional needs of birds. These hens had free access to green, grassy paddocks of an area of 9 m^2/head.

For chemical analyses, the eggs were hard-boiled for 15 min and then stored at a temperature of 4°C until analyses. The content of dry matter, total protein, ether extract and crude ash in the experimental material was determined according to standard procedures (AACC 2000). The energy value was estimated using net Atwater equivalents, considering protein and fat (Rutkowska 1981). Minerals were determined with the method of flameless atomic absorption spectrometry. The determinations were carried out on a Spectr AA 880 Varian apparatus with atomization in a graphite furnace and with the Zeeman background correction (309.3 nm, 10 mA, gap – 0.5 nm, argon – flow rate 3 l min^{-1}), and pyrolytically in coated graphite cuvettes (Ghaedi et al. 2009).

The results were subjected to statistical analysis aided by Statistica 10.0 software, in which mean values in groups ($\bar{x}$) and standard error of the mean (SEM) were obtained. Correlation coefficients (r) were computed between the content of the analyzed minerals in egg yolk and albumen. The non-parametric Spearman's correlation rank test was used to determine the effect of the rearing environment of hens on the nutritional value of their eggs (EI). Differences between mean values were determined with the multiple range test (analysis of variance Anova, α = 95%; $P < 0.05$), and their significance was verified with the Duncan's test (a *post-hoc* test).

RESULTS AND DISCUSSION

No significant variability was observed in the analyzed eggs regarding the content of dry matter, total protein and crude ash in both egg albumen (Table 1) and egg yolk (Table 2). However, the eggs from organic and courtyard farms tended to accumulate more of the nutrients. Similar results were observed by Sokołowicz et al. (2012). In contrast, differences were reported in the content of crude fat, the highest ($P < 0.05$) level of which was determined in eggs from organic farming (by 60% in albumen and 17% in yolk, compared to the remaining eggs). Although linked with an increasing

Table 1

The content of nutrients and mineral elements in the egg albumen ($\bar{x}$)

Nutrients	Experimental group			Statistical parameters		
	large-scale system	courtyard system	organic system	SEM	*P*-value	EI
Basic nutrients (g kg^{-1} d.m.)						
dry matter	12.97	13.57	13.78	0.011	0.078	0.001
crude protein	11.09	11.61	12.63	0.084	0.125	0.001
ether extract	0.153^b	0.181^b	0.254^a	0.004	0.027	0.002
crude ash	0.682	0.754	0.713	0.007	0.458	0.001
energy (kcal)*	45.74^b	48.67^b	52.81^a	0.037	0.046	0.001
Mineral elements						
K (mg kg$^{-1)}$	127.2^b	133.4^b	169.5^a	0.943	0.024	0.002
Na (mg kg^{-1})	178.7^b	161.3^b	183.4^a	0.255	0.034	0.001
Ca (mg kg^{-1})	5.111^b	6.483^a	6.751^a	0.062	0.025	0.001
Mg (mg kg^{-1})	10.24	10.41	11.73	0.076	0.378	0.001
P (mg kg^{-1})	11.41	11.64	11.93	0.056	0.167	0.001
Fe (μg kg^{-1})	4.722^a	3.423^b	3.011^c	0.012	0.013	0.001
Zn (μg kg^{-1})	1.761^b	1.922^b	2.893^a	0.011	0.046	0.002
Cu (μg kg^{-1})	0.483^a	0.371^b	0.312^b	0.003	0.034	0.001
Se (μg kg^{-1})	0.082^a	0.031^b	0.074^a	0.001	0.039	0.001
Mn (μg kg^{-1})	0.221^b	0.333^a	0.352^a	0.547	0.029	0.001

* Atwater equivalents – considering protein and fat,
± SD (Standard Deviation),
EI – Environmental Impact – the effect of rearing environment of hens on the nutritional value of their eggs,
a.b.c... – statistical differences (P < 0.05).

(P < 0.05) calorific value of a food product, the increase in this nutrient's content from ca. 11% (in yolk) to 23% in (albumen) is desirable from the nutritional point of view. Lipids of eggs, and especially of egg yolk, are characterized by a beneficial ratio of unsaturated to saturated fatty acids (2:1). They are also a rich source of arachidonic acid (ARA) as well as phospholipids, lecithin, choline, xanthophylls and immunoglobulins. Owing to their high biological activity, these compounds are taken advantage of in the prophylaxis of many diseases, including disorders of the cardiovascular system, neoplasms or Alzheimer's disease (McNamara 2000, Brown, Hamilton 2001, Nain et al. 2012).

Irrespective of a production system, the albumen of eggs was found to contain similar levels of Mg and P, which did not deviate from the standard value (Marzec et al. 1992). The eggs originating from hens reared in the organic system were characterized by the highest (P < 0.05) content of K (by

Table 2

The content of nutrients and mineral elements in the egg yolk ($\bar{x}$)

Nutrients	Experimental group			Statistical parameters		
	large-scale system	courtyard system	organic system	SEM	*P*-value	EI
Basic nutrients (g kg^{-1} d.m.)						
dry matter	45.48	48.57	49.73	0.351	0.578	0.001
crude protein	15.39	16.31	17.03	0.034	0.139	0.001
ether extract	27.45^{b}	28.18^{b}	33.25^{a}	0.025	0.037	0.002
crude ash	1.181	1.332	1.702	0.006	0.448	0.001
energy (kcal)*	308.8^{b}	318.9^{b}	367.4^{a}	0.937	0.047	0.001
Mineral elements						
K (mg kg$^{-1)}$	117.7^{a}	102.5^{b}	118.4^{a}	0.013	0.043	0.002
Na (mg kg^{-1})	58.14^{ab}	53.78^{b}	63.61^{a}	0.055	0.027	0.001
Ca (mg kg^{-1})	15.11^{c}	16.48^{b}	18.23^{a}	0.032	0.125	0.001
Mg (mg kg^{-1})	15.28^{b}	16.44^{a}	16.53^{a}	0.036	0.038	0.001
P (mg kg^{-1})	515.4	566.5	559.1	0.076	0.357	0.001
Fe (µg kg^{-1})	59.70^{b}	61.14^{b}	70.01^{a}	0.045	0.013	0.002
Zn (µg kg^{-1})	24.76^{b}	29.92^{a}	26.89^{b}	0.013	0.046	0.002
Cu (µg kg^{-1})	0.083	0.072	0.071	0.003	0.064	0.001
Se (µg kg^{-1})	0.282^{a}	0.301^{a}	0.174^{b}	0.001	0.029	0.001
Mn (µg kg^{-1})	0.723^{c}	0.984^{a}	0.821^{b}	0.007	0.029	0.001

Explanations under Table 1

23% on average), Na (by ca. 11%) and Ca (by ca. 32%) in egg albumen compared to the eggs produced in conventional and courtyard farming (Table 1). The macronutrient content of an egg largely depends on the hens' feeding. The increased accumulation of macroelements in the content of eggs produced in the organic system was also reported by Szablewski et al. (2013), who additionally observed a significant increase in the Ca content.

The present study also showed differences in the accumulation of microelements in eggs. Similar to macroelements, the content of Zn, Se and Mn was the highest ($P < 0.05$) in the albumen of eggs from the organic production system (i.e. 2.893, 0.074 and 0.352 µg kg^{-1}, respectively). However, the highest ($P < 0.05$) concentrations of Fe and Cu were noted in the albumen of eggs from the conventional farming system (by an average 43% higher than in the extensive production systems). A high content of Fe and Cu in eggs usually corresponds to their levels in the diet. In the feeding of hens on farms with intensive production systems, the commercial mixes fed to the birds fully covered their nutritional needs, including micronutrients. However, the high level of Fe and Cu found in the albumen is difficult to explain, since it was unobserved in the yolk. Among the microelements present in eggs, high nutritional significance is ascribed to selenium, iron and zinc, the human demand for which can be satisfied in 13, 10 and 6%, respectively, by eating an egg (Jarosz, rychlik 2012, Kunachowicz et al. 2012).

The content of P and Cu was similar in the yolk of eggs from the three different production systems (Table 2). The lowest (*P* < 0.05) content of K (102.5 mg kg^{-1}) and Na (53.78 mg kg^{-1}) was determined in the yolk of eggs from homestead rearing. In turn, the organic production system stimulated a high (*P* < 0.05) accumulation of Ca (18.23 mg kg^{-1}), Mg (16.48 mg kg^{-1}) and Fe (70.01 mg kg^{-1}) in egg yolk. The high content of iron, which improves the nutritional value, occurs in eggs from both organic and inorganic farms (Skrivan et al. 2005). Over 95% of iron in egg yolk occurs in the phosvitin-bound form, whose bioavailability is estimated to be about 30%. Phosvitin is used to produce phosphopeptides, which can bind calcium in a human body, thus increasing its availability (in this study, the Ca-Fe correlation coefficient reached -0.974). For this reason, phosvitin is claimed to be a functional component (Jiang, Mine 2000).

The highest (*P* < 0.05) accumulation of Zn, Se and Mn was observed in yolks of eggs produced in the courtyard system (higher by an average 13, 43 and 20%, respectively, than in the other eggs). Similar results were reported by Vincevica-Gaile et al. (2013), who analyzed the content of microelements in hen eggs depending on a feeding and rearing system of hens.

In the present study, the biggest differences were observed in the Se content. In egg yolk, Se is bound with phosphoavidin, whereas in egg albumen, it mainly binds to ovalbumin (Golubkina, Papazyan 2006). Selenium accumulation in eggs depends on its content in feed (Dobrzański et al. 2003). Egg yolk is better at selenium accumulation than egg albumen. An increase in the selenium concentration in a feed mix for laying hens is accompanied by an increasing concentration of antioxidative vitamin E in egg yolk as well as an enhanced activity of selenoenzyme, i.e. glutathione peroxidase. This improves the oxidative stability of eggs during storage (Bargellini et al. 2008).

The environmental factors influence egg production, which is inextricably linked to the type of feeding, shaping the content of nutrients in egg albumens and yolks. In all the analyzed cases, statistically significant Spearman correlation (EI) was demonstrated at P values ranging from 0.001 to 0.002 (Tables 1, 2). Sahin et al. (2002) observed a similar effect of the environment on the nutritional value and mineral composition of eggs originating from hens kept in various production systems and supplemented with vitamin E.

Other factors which significantly affect the level of minerals in eggs include biological dependencies between elements. Such relationships between the levels of elements analyzed in egg albumen and egg yolk were verified by correlation coefficients (Table 3). High positive correlations (*r* > 0.09) were

Table 3

The correlation coefficients (*r*) between the accumulation of mineral elements in the egg albumen and yolk

Albumen	Yolk									
	K	Na	Ca	Mg	P	Fe	Zn	Cu	Se	Mn
K	0.521	0.793	0.898	0.578	0.502	**0.999**	0.453	-0.789	**-0.960**	0.004
Na	**0.998**	**0.949**	0.144	-0.349	-0.431	0.569	-0.480	**-0.951**	-0.769	-0.823
Ca	-0.542	0.203	0.785	**0.986**	**0.997**	0.427	**0.999**	0.210	-0.167	**0.902**
Mg	0.198	0.537	**0.994**	0.822	0.767	**0.937**	0.730	-0.534	-0.808	0.345
P	0.391	0.695	0.953	0.691	0.623	**0.988**	0.579	-0.691	**-0.910**	0.150
Fe	0.129	-0.239	**-0.974**	-0.962	**-0.933**	-0.773	**-0.912**	0.229	0.574	-0.631
Zn	0.526	0.796	0.896	0.573	0.479	**0.999**	0.448	-0.793	**-0.962**	0.001
Cu	0.006	-0.353	**-0.994**	**-0.921**	-0.882	-0.845	-0.855	0.348	**0.971**	-0.530
Se	**0.938**	0.751	-0.254	-0.687	-0.749	0.202	-0.785	-0.755	-0.458	**-0.979**
Mn	-0.216	0.148	**0.951**	**0.982**	**0.961**	0.714	**0.945**	-0.142	-0.500	0.697

observed for the following pairs: K-Na, Se; Na-Na; Ca-Mg, Mn; Mg-Ca, Mn; P-Ca, Mn; Fe-K, Mg, P, Zn; Zn-Ca, Mn; Se-Cu and Mn-Ca, whereas negative correlations were reported between Ca-Fe, Cu; Mg-Cu; P-Fe; Zn-Fe; Cu-Na; Se-K, P, Zn and Mn-Se (yolk-albumen, respectively). For the other pairs of minerals, the computed correlations were moderate (*r* ±0.4-0.7), low (*r* ±0.2-0.4) or none (*r* to ±0.2). All the observed correlations may have resulted from coincident physicochemical properties of the analyzed elements, their bioavailability, co-occurrence with other nutrients, and co-participation in physiological and metabolic processes.

CONCLUSIONS

The nutritional value and the content of minerals in the two parts of an egg varied significantly, depending on the rearing system of laying hens. Eggs from the production systems allowing the birds to use free ranges, i.e. organic and homestead ones, were the richest in nutrients. The free range system allows hens to supplement their usual dietary ration, which may contribute to a significant increase in the content of crude fat, macroelements: K and Na (albumen and yolk), Ca and Mg (yolk), and microelements: Zn, Se and Mn (albumen and yolk) and Fe (yolk).

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