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Effect of Dietary Se Supplementation on the Se Status and Physico-chemical Properties of Eggs – a Review

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Abstract

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In the last few years, interest in the supplementation of selenium (Se) to animal feed has increased. The results of various studies have shown that eggs with defined selenium content may be used as a new potential source of this scarce element in human nutrition. The selenium content in eggs after dietary supplementation in organic form is about 22–27 μg/egg. This amount represents up to 40–50% of the Recommended Dietary Allowance, which is 55 μg of Se for the adult human. Additionally, due to its antioxidant properties, selenium contributes to the oxidation stability of fat and protein in the eggs of laying hens fed a selenium-supplemented diet. Therefore, selenium addition can affect certain properties of eggs and improve their shelf life. The results of investigations into the physico-chemical properties of different forms of Se have proven that dietary supplementation in the organic form shows higher biological availability than inorganic selenium.

Keywords: selenium; feed additive; antioxidant; egg; quality properties

Selenium is an essential trace element important for animal and human health (Pan *et al*. 2007; Tufarelli & Laudadio 2011). It influences the immune system, reproduction, and ageing (Ševčíková *et al.* 2006; Surai 2009). Together with vitamin E, selenium protects animal and human cells and tissues from oxidative damage (Pavlata *et al.* 2002; Heindl *et al.* 2010). Selenium plays an important role as a catalyst in the production of active thyroid hormone (Rayman 2000; Ševčíková *et al.* 2006). The recommended dietary allowance of selenium is 55 μg daily for both adult men and women (Scientific Committee on Food 2003). Insufficient intake of selenium can cause a range of health problems, e.g., increased susceptibility to inflammation or metabolic stress (Beck *et al.* 2003; Kinal *et al*. 2012). The European Union has set a daily upper limit intake for selenium intake of 300 μg in adults. An amount of 5 μg per 1 kg of human weight is still considered as a safe dose (Skřivan 2009).

Various studies have shown that meat and eggs with defined selenium content represent a new potential source of this element in human nutrition (Surai 2006; Pan *et al.* 2007; Fisinin *et al.* 2009), and interest in the supplementation of animal feed with selenium has increased in recent years. The reasons for this trend are the effects of selenium on feed efficiency, utility, and health status. Due to its antioxidant properties, selenium supplemented to feed acts to stabilise fats and proteins in the meat and eggs of laying hens. Thus, selenium has the ability to influence the quality and freshness of animal products (Ševčíková *et al.* 2006; Skřivan *et al.* 2008; Wang *et al.* 2010).

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The amount and chemical form of supplementation influence how selenium affects the products from animals fed supplemented diets. For instance, in egg production, selenium exerts effects either on the yolk or albumen depending on the amount and form of selenium which is supplemented. Inorganic selenium (selenite) is mostly found in egg yolk, while organic selenium (selenomethionine) is deposited in egg albumen (Stibilj *et al.* 2004; Skřivan 2009).

In the majority of European countries, it is recommended that basal diets contain merely 0.03–0.14 mg Se/kg of dry matter. In the Czech Republic, the recommended supplementation is 0.3 mg/kg (Skřivan 2009). If the organic form of selenium is used for diet fortification, then the amount must not exceed 0.2 mg/kg of the diet (Commission Implementing Regulation (EU) No 121/2014).

Selenium supplementation of animal diets

In nature, there are two chemical forms of selenium – organic and inorganic. These forms influence the biological availability of selenium in animal and human organisms. Organic selenium plays a significant role in physiology as an integral part of amino acids like selenocysteine and selenomethionine (Underwood & Suttle 1999; Dobrzanski & Jamroz 2003; Kinal *et al.* 2012; Tufarelli *et al.* 2016a). Inorganic selenium can be bound in selenate, selenide, and selenite, which is a common form of selenium used in animal diets (Skřivan *et al.* 2006). During evolution, the digestive system of animals has adapted to the organic form, which is absorbed through the epithelial cells by active transport (Underwood & Suttle 1999; Dobrzanski & Jamroz 2003; Kinal *et al.* 2012), resulting in a higher biological availability of organic selenium from feed (Kinal *et al.* 2012). In addition, the studies of Kuricová *et al.* (2003) and of Payne and Southern (2005) confirmed that supplementation with selenium-enriched yeast exerted more significant effects than supplementation with sodium selenite.

Selenomethionine can be synthesised only by plants and yeasts (Kyriakopoulos & Behne *et al.* 2002; Arpášová *et al.* 2012). Plants absorb selenium in the inorganic form from soil and transform it into selenoamino acids, especially selenomethionine (Skřivan 2009) and selenocysteine (Skřivan 2009). Various studies have confirmed that Se-enriched edible plants such as broccoli sprouts (Finley *et al.* 2001), green onions (Kapolna & Fodor 2006), garlic (Tsuneyoshi *et al.* 2006) or tritordeum (Tufarelli *et al.* 2016b) can be successfully produced for human and animal nutrition. Additionally, these selenised plants have anticarcinogenic properties (Finley *et al.* 2001; Yoshida *et al.* 2007). Special freshwater selenium-enriched algae (genus *Chlorella*) represent another possible form of selenium addition to the diet (Skřivan 2009; Surai & Fisinin 2014). It has been suggested that the selenium in *Chlorella* is incorporated into protein structure in a similar way to that of Se in yeast. *Chlorella* contains twice as many proteins as legumes. Moreover, it does not produce toxic metabolites and its biomass contains a large number of biologically active substances (Ševčíková *et al.* 2006).

In addition, the chemical similarity of selenomethionine and methionine permits their mutual substitution in protein synthesis. This enables the creation of selenium reserves in the body, mainly in muscle (Surai 2000a; Arpášová *et al.* 2012), while the inorganic form is absorbed by passive diffusion (Arthur & Beckett 1994; Kinal *et al.* 2012) and used immediately as the organism does not have the ability to make selenium reserves (Surai & Fisinin 2014). In the case of organic selenium, 85–95% of the total intake is absorbed, while 40–70% of inorganic selenium is absorbed, depending on whether it is selenite or selenate. The remaining organic selenium that is not used in protein synthesis is deposited in tissues, while the inorganic selenium is immediately excreted in the urine (Mosnáčková *et al.* 2003). Figure 1 shows the pathways of selenium metabolism in organisms. The differing effects of selenium on the tissues of animals depending on the form of selenium that is supplemented underlines the

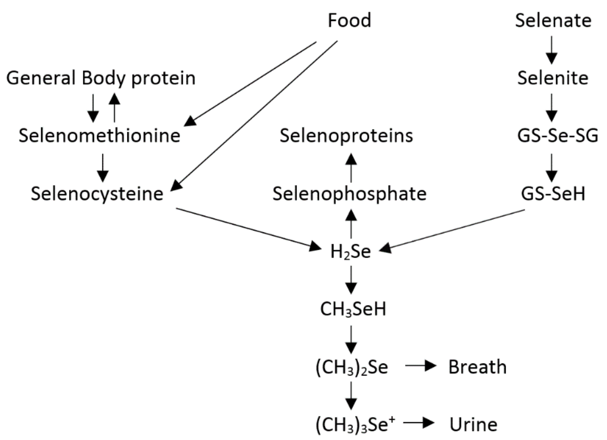

Figure 1. Pathways of selenium metabolism – modified from Ganther (1986) and Rayman *et al.* (2008)

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importance of the biological availability of different selenium-supplemented diets.

Nowadays, the positive effects of selenium-enriched yeast are the subject of intense study because of the effective selenium utilisation of these organisms and their ability to form mobile body deposits of the microelement (Wakebe 1998). The amount of selenomethionine in selenium yeast is variable (Surai & Fisinin 2014). Skřivan (2009) and Heindl *et al.* (2010) claimed that selenomethionine represents 54–74% of the total selenium contained in selenium yeast. Wrobel *et al.* (2003) reported that the selenomethionine in yeast comprised 65% of total selenium. However, according to the data of Schrauzer (1998), in yeast more than 90% of the total Se content consists of L-selenomethionine, with only traces of inorganic Se. Rayman (2004) reported that selenium yeast consists of 60–84% selenomethionine and 0.1–15% selenite. Selenium-enriched yeasts are prepared by fermentation in medium with minimal concentrations of sulfur and high concentrations of selenium. Generally, sulphur has very similar chemical properties to selenium, which leads to its substitution by selenium in the cells of yeast (Kim & Mahan 2003).

Sodium selenite as the commonly used inorganic form of selenium contains 45.66% selenium (Skřivan 2009). However, absorption of sodium selenite is limited (Payne & Southern 2005; Suchý *et al.* 2014), and can be toxic in higher amounts (Suchý *et al.* 2014). Selenite is a pro-oxidant (Spallholz 1997; Lyons *et al.* 2007; Surai & Fisinin 2014), i.e., a chemical compound involved in reactions yielding toxic forms of oxygen (Spallholz 1997; Lyons *et al.* 2007). Even though sodium selenite is the most commonly used selenium diet supplementation, it has very limited biological utilisation (Kim & Mahan 2003). Some countries have even established a total prohibition of the utilisation of this source of selenium.

Selenium content in eggs after supplementation

According to several studies, dietary supplementation with selenium increases its abundance in eggs (Surai 2000b; Stibilj *et al.* 2004; Benkova *et al.* 2005; Skřivan *et al.* 2006; Pan *et al.* 2007; Mohiti-Asli *et al.* 2008; Chinrasri *et al.* 2009; Jing *et al.* 2015).

Generally, trace elements are deposited mainly in egg yolk. However, selenium is bound in many selenoproteins, which means that selenium is present in albumen as well (Skřivan 2009).

Selenomethionine, which is non-specifically incorporated into egg proteins in place of methionine (Schrauzer 2003; Rayman 2004; Surai & Fisinin 2014), comprises 53–71% of total selenium in the egg albumen and 12–19% in the egg yolk (Lipiec *et al.* 2010).

Obtaining the maximum selenium concentration in eggs requires about 4–5 weeks of feeding with the supplemented diet. Sodium selenite in feed is able to increase egg selenium content one and a half- to two-fold in comparison with eggs without selenium supplementation (Skřivan 2009). In the studies of Hassan (1990), Surai (2000a), Kuricová *et al.* (2003), Skřivan *et al.* (2006), Pan *et al.* (2007), Chinrasri *et al.* (2009), and Skřivan (2009), supplementation with organic selenium resulted in a higher concentration of selenium in eggs in comparison with inorganic selenium supplementation. Hassan (1990) compared Se-enriched barley with sodium selenite; Surai (2000a), Kuricová *et al.* (2003), and Pan *et al.* (2007) compared Se-yeast with sodium selenite; Skřivan *et al.* (2006) and Skřivan (2009) compared Se-yeast and Se-*Chlorella* with sodium selenite; Chinrasri *et al.* (2009) compared Se-enriched bean sprout and Se-enriched yeast with sodium selenite. However, the effect of the organic selenium supplement is dependent on the background selenium level, and it is possible that high background selenium would mask the effect of low levels (0.1 mg/kg or less) of organic selenium supplementation (Surai & Fisinin 2014).

Organic selenium in the form of Se-yeast is able to increase the selenium content in eggs to levels twice that of sodium selenite (Skřivan 2009). Surai (2000a) reported that egg selenium content can be easily increased from 7.1 μg to 30.7 μg after selenium supplementation with Se-yeast harbouring 0.4 mg/kg of selenium. Delezie *et al.* (2014) reported that selenomethionine could be incorporated into the egg as effectively as methionine.

Tables 1–3 show the increase in selenium content in egg yolk and albumen after selenium supplementation in various chemical forms (Se-yeast, selenomethionine, Se-malt, sodium selenite) and at various levels (from 0.1 to 1.0 mg/kg).

It was reported that the organic form of selenium (in ng/g of dry matter) is mainly deposited in egg

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Table 1. Selenium content in egg albumen and yolk after organic selenium supplementation

Albumen (ng/g wet weight basis)	Yolk (ng/g wet weight basis)	Supplement (mg/kg DM of diet)	Type - of supplement	Experiment duration	Reference
80.00	320.00	0.1	Se-yeast	33 days	Paton *et al.* (2002)
231.50	584.80	0.2	Se-yeast	30 days	Gajcevic *et al.* (2009)
130.00	420.00	0.2	Se-yeast	33 days	Paton *et al.* (2002)
193.70	605.30	0.2	Se-yeast	8 weeks	Surai (2000a, b)
231.00	876.00	0.3	Se-yeast	15 days	Jing *et al.* (2015)
197.00	825.00	0.3	Se-yeast	30 days	Jing *et al.* (2015)
150.00	480.00	0.3	Se-yeast	33 days	Paton *et al.* (2002)
345.00	779.50	0.4	Se-yeast	30 days	Gajcevic *et al.* (2009)
236.83	412.88	0.4	Se-yeast	7 weeks	Mohiti-Asli *et al.* (2008)
403.70	854.00	0.4	Se-yeast	8 weeks	Surai (2000a, b)
Albumen (mg/kg DM)	yolk (mg/kg DM)	supplement (mg/kg DM of diet)	type of supplement	experiment duration	reference
2.33	1.57	0.2	SM	8 weeks	Aljamal *et al.* (2014)
2.05	1.48	0.3	Se-yeast	14 days	Skřivan *et al.* (2006)
1.47	1.25	0.3	Se-yeast	3 weeks	Skřivan (2009)
1.79	2.60	0.3	Se-yeast	6 weeks	Chinrasri *et al.* (2009)
2.93	1.63	0.4	SM	8 week	Aljamal *et al.* (2014)
1.58	2.17	0.51	Se-malt	16 days	Jiakui & Xiaolong (2004)
1.59	2.26	0.51	Se-malt	24 days	Jiakui & Xiaolong (2004)

DM – dry matter; SM – selenomethionine

albumen, and the inorganic form of selenium is mostly deposited in egg yolk (Skřivan 2009; Stibilj *et al.* 2004). These findings obviously contrast with the findings of other authors (Surai 2000a, b; Paton *et al.* 2002; Mohiti-Asli *et al.* 2008; Gajcevic *et al.* 2009; Scheideler *et al.* 2010; Jing *et al.* 2015)

Table 2. Selenium content in egg albumen and yolk after inorganic selenium supplementation

Albumen (ng/g wet weight basis)	Yolk (ng/g wet weight basis)	Supplement (mg/kg DM of diet)	Type of supplement	Experiment duration	Reference
70.00	330.00	0.1	SS	33 days	Paton *et al.* (2002)
70.00	370.00	0.2	SS	33 days	Paton *et al.* (2002)
158.00	864.00	0.3	SS	15 days	Jing *et al.* (2015)
149.00	780.00	0.3	SS	30 days	Jing *et al.* (2015)
70.00	380.00	0.3	SS	33 days	Paton *et al.* (2002)
158.38	431.87	0.4	SS	7 weeks	Mohiti-Asli *et al.* (2008)
Albumen (mg/kg DM)	yolk (mg/kg DM)	supplement (mg/kg DM of diet)	type of supplement	experiment duration	reference
1.36	0.93	0.3	SS	14 days	Skřivan *et al.* (2006)
0.86	0.96	0.3	SS	3 weeks	Skřivan (2009)
0.67	2.57	0.3	SS	6 weeks	Chinrasri *et al.* (2009)
1.67	2.15	0.51	SS	16 days	Jiakui & Xiaolong (2004)
1.67	2.15	0.51	SS	24 days	Jiakui & Xiaolong (2004)
1.90	1.41	0.2	SS	8 weeks	Aljamal *et al.* (2014)
1.95	1.49	0.4	SS	8 weeks	Aljamal *et al.* (2014)

DM – dry matter; SS – sodium selenite

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Table 3. Selenium content in the whole egg after organic and inorganic selenium supplementation

Content (μg Se/egg)		Supplement (mg/kg DM of diet)	Type of supplement	Experiment duration	Reference
after organic supplementation	after inorganic supplementation				
9.75[1]	9.10[1]	0.1	Se-yeast/SS	33 days	Paton *et al.* (2002)
15.08[1]	15.15[1]	0.2	Se-yeast/SS	21 days	Pan *et al.* (2007)
14.30[1]	10.40[1]	0.2	Se-yeast/SS	33 days	Paton *et al.* (2002)
18.04	–	0.2	Se-yeast	8 weeks	Surai (2000a)
16.25[1]	10.40	0.3	Se-yeast/SS	33 days	Paton *et al.* (2002)
42.61	29.47	0.3	Se-yeast/SS	6 weeks	Chinrasri *et al.* (2009)
30.67	–	0.4	Se-yeast	8 weeks	Surai (2000a)
19.83[1]	18.92[1]	0.5	Se-yeast/SS	21 days	Pan *et al.* (2007)
22.55	22.15	0.51	Se-malt/SS	24 days	Jiakui & Xiaolong (2004)
43.35	–	0.8	Se-yeast	8 weeks	Surai (2000a)
23.60[1]	24.25[1]	1.0	Se-yeast/SS	21 days	Pan *et al.* (2007)

[1]values of selenium concentration (μg/g) have been calculated for a 65 g egg; DM – dry matter; SS – sodium selenite

who reported that the majority of organic Se compounds (in ng/g of wet matter) were deposited in the yolk rather than the albumen. However, if these data are corrected for dry matter with estimates of approximately 500 g/kg for the yolk and 200 g/kg for the albumen (Solomon 1991), the concentration of selenium in the albumen is greater than or equal to that in the yolk (Pappas *et al.* 2005).

According to the results of the study of Skřivan *et al.* (2006), addition of 0.3 mg selenium in the form of sodium selenite per kg of the diet for 21 weeks resulted in a doubling of the selenium content in eggs. In the case of Se-yeast and Se-*Chlorella*, the selenium content was increased more than three and a half-fold compared to the untreated control after 14 days of feeding with the supplemented diet. The increase of selenium in the egg yolk was lower than in the egg white. The authors demonstrated that Se-*Chlorella* was equally effective as Se-yeast for the transfer of selenium from feed into eggs, but the influence of sodium selenite was clearly less strong.

Surai (2000a) reported the coefficient of determination (R^2) between dietary organic selenium and selenium in egg yolk to be 0.96, whereas for egg albumen the coefficient was 0.98 at the significance level of $P < 0.01$. Skřivan (2009) claimed that the total Se content in Czech eggs without supplementation can be expected to reach 5.5–8.0 μg in an egg weighing 60 g, which represents 10–15% of the Recommended Dietary Allowance (RDA 55 μg). After addition of inorganic forms of selenium such as sodium selenite, the selenium concentration in egg increases to up to 10–14 μg, which represents 20% of RDA, and resulting in the accumulation of 4 μg selenium in albumen and 7 μg in yolk. The selenium content in eggs with organic selenium (Se-yeast) addition will reach 22 μg, which represents 40% of RDA. Mosnáčková *et al.* (2003) published very similar values of total Se content: 11–13 μg/egg after addition of sodium selenite and 22–27 μg of selenium after addition of Se-yeast. Chinrasri *et al.* (2009) reported much higher values of selenium content. The egg selenium content of laying hens fed a diet supplemented with sodium selenite reached 29.47 μg, and with selenium yeast the value was 42.61 μg; these results were probably influenced by the high selenium content naturally present in the basal diet (0.40 mg/kg).

The effect of Se on the physico-chemical properties of eggs

During storage, egg content changes and some substances inside of the egg undergo degradation. Oxygen gets into the eggs through the pores in the egg shell, which causes oxidation of albumen and yolk. The properties and quality of albumen proteins are changed due to the loss of *O*-glycosidically linked carbohydrate units of the glycoproteins, ovomucin (Kirunda & McKee 2000) and due to the breakdown of the lysozyme-ovomucin complex. Dissociation of lysozyme and ovomucin leads in turn to a reduction in albumen viscosity and a thinning of thick albumen (Hammershøj & Qvist 2001; Lomakina & Míková

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2006), which is a result of protein degradation in albumen. During storage, the sulfhydryl content increases, which is associated with an increase of albumen pH (Heath 1977). The diffusion of carbon dioxide out of the egg leads to changes in albumen pH as the egg ages (Williams 1992; Brake *et al.* 1997; Silversides & Scott 2001). The albumen pH value of a newly laid egg is within the range of 7.6–8.5 and during storage the value can rise to 9.7 (Heath 1977). Yolk pH is about 6.0 (Brake *et al.* 1997), but during egg storage this value can gradually rises to between 6.4 and 6.9 (Stadelman & Cotterill 1995). The increase in yolk pH during storage is due to protein catabolism resulting in the production of ammonia (Stadelman & Cotterill 1995).

The quality and freshness of eggs are characterised using Haugh units (HU), which are calculated using values of egg weight and the height of thick albumen (Skřivan *et al.* 2006). Values of HU decrease with decreasing egg freshness (Silversides & Scott 2001; Pappas *et al.* 2005; Mohiti-Asli *et al.* 2008; Arpášová *et al.* 2012), which is influenced by storage time, and temperature (Baylan *et al.* 2011; Arpášová *et al.* 2012). The mechanism of HU decrease is connected with the above-mentioned carbon dioxide loss. HU values are also influenced by bird age. The eggs of younger birds have a higher content of ovomucin, which means that these eggs have higher HU values (Williams 1992; Brake *et al.* 1997; Pappas *et al.* 2005). In some countries of Western Europe, methods of measuring HU are included in national norms. Eggs with HU values of higher than 90 are considered as eggs with high quality, eggs with HU values between 80 and 90 have very good quality, eggs with HU values between 70 and 65 are acceptable, while eggs with HU values between 40 and 60 have limited quality and eggs with HU values lower than 40 are not suitable for consumption (Míková & Davídek 2000).

Selenium is likely to reduce oxidation reactions inside the egg and to slow down the increases in pH values in different parts of the egg. Scheideler *et al.* (2010) reported that the eggs from hens fed inorganic selenium had a higher yolk pH (6.12; $P < 0.008$) and albumen pH (8.98; $P < 0.002$) than those that were fed organic selenium (6.08 and 8.89).

According to the studies of Pappas *et al.* (2005), Skřivan (2009), Pan *et al.* (2011), and Arpášová *et al.* (2012) HU values can be affected by selenium intake, which acts to increase egg albumen content, leading, in turn, to an increase of egg weight. In the study of Arpášová *et al.* (2012), it was found that the eggs from hens fed a Se-yeast-supplemented diet had higher HU values when compared to the control group and the group of hens fed selenite. The study demonstrated that the groups fed organic selenium (Se-yeast) generally showed the best results for both fresh and stored eggs. Skřivan *et al.* (2006) showed that Se-*Chlorella* also has a significant positive impact on HU values. In their study, in which three different kinds of Se supplementation (sodium selenite, Se-yeast, Se-*Chlorella*) at 0.3mg/kg were compared, the group with Se-yeast had a HU value of 84.7, Se-*Chlorella* had a HU value of 87.37 and sodium

Table 4. Haugh unit values after selenium supplementation in either organic or inorganic form

Organic selenium	Inorganic selenium	Supplement (mg/kg, DM of diet)	Type of supplement	Experiment duration	Reference
88.66	–	0.2	Se-yeast	30 days	Gajcevic *et al.* (2009)
98.17	99.53	0.2	SM/SS	8 weeks	Aljamal *et al.* (2014)
84.71	85.40	0.3	Se-yeast/SS	14 days	Skřivan *et al.* (2006)
74.58	78.17	0.3	Se-yeast/SS	6 weeks	Chinrasri *et al.* (2009)
62.02	63.58	0.4	Se-yeast/SS	7 weeks	Mohiti-Asli *et al.* (2008)
90.23	–	0.4	Se-yeast	30 days	Gajcevic *et al.* (2009)
98.56	97.60	0.4	SM	8 weeks	Aljamal *et al.* (2014)
87.21	86.60	0.4	Se-yeast/SS	9 months	Arpášová *et al.* (2012)
87.01	86.69	0.4	Se-yeast/SS	9 months	Arpášová *et al.* (2009a)
87.11	–	0.9	Se-yeast/SS	9 months	Arpášová *et al.* (2009a)
86.93	–	0.9	Se-yeast/SS	9 months	Arpášová *et al.* (2012)

SM – selenomethionine; SS – sodium selenite

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selenite a HU value of 85.40. Pappas *et al.* (2005) explain this mechanism by the activity of glutathione peroxidase (GSH-Px), which could slow the rate of lipid and protein oxidation during egg storage, leading to better egg quality. Data on the effect of Se supplementation on HU are shown in Table 4.

Organic selenium (Se-yeast or Se-*Chlorella*) also significantly increases the weight and proportion of egg albumen (Skřivan *et al.* 2006; Skřivan 2009; Arpášová *et al.* 2012), while the proportion of yolk in the egg decreases. Therefore, it has been assumed that Se-yeast and Se-*Chlorella* might decrease the proportion of egg yolk; this was confirmed by the study of Skřivan (2009).

In the study of Skřivan *et al.* (2006), a higher egg weight was recorded in the groups fed Se-yeast and Se-*Chlorella* in comparison to the control group and the group fed sodium selenite. Payne *et al.* (2005), Skřivan *et al.* (2006), Skřivan (2009), Arpášová *et al.* (2009b, 2010, 2012), Attia *et al.* (2010), and Gjorgovska *et al.* (2012) also reported that selenium supplementation, especially that of organic selenium, may have a positive effect on egg weight.

Generally, heavier eggs have thinner and weaker eggshells. Thus, selenised eggs, which are heavier than non-enriched eggs, have lower eggshell quality (Skřivan *et al.* 2006; Skřivan 2009). Skřivan (2009) reported that the addition of 0.4–0.5 mg/kg of organic selenium (Se-yeast and Se-*Chlorella*) could decrease eggshell proportion and strength. Lower values for eggshell strength after Se supplementation were also noted by Arpášová *et al.* (2009, 2010) and Payne *et al.* (2005). However, Paton and Cantor (2000) and Fisinin *et al.* (2009) reported that organic Se increased the shell breaking strength.

CONCLUSION

A healthy diet is an essential part of a healthy lifestyle, and such diets are increasing in popularity among consumers. Clinical studies have shown that Se-enriched eggs may represent a functional food that can be used to increase human selenium intake and thus the selenium content in the human body. Additionally, selenium supplementation contributes to the oxidation stability of eggs. Selenium reduces hydrolytic and oxidation reactions inside the egg, thus slowing down carbon dioxide diffusion and the elevation in pH values. The positive effect of selenium is connected with the activity of glutathione peroxidase (GSH-Px), which can act to slow the rate of lipid and protein oxidation during egg storage. Therefore, Se supplementation can prolong the shelf life of eggs. Additionally, selenium improves shell egg quality parameters, such as Haugh units and egg weight. In contrast, several studies from around the world have confirmed a negative effect of selenium on eggshell quality.

It has been proven that organic forms of selenium supplementation such as selenomethionine, Se-enriched yeast or Se-enriched *Chlorella* have higher biological availability than inorganic forms such as sodium selenite or selenate. A Czech study showed that Se-yeast is able to increase the selenium content in eggs to values twice greater than those achieved using sodium selenite. Regarding the selenium content naturally present in the basal diet of European countries and with respect to European regulations regarding selenium feed additives, the suitable amount of selenium supplementation is 0.3 mg/kg of complete feed.

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