Selenium-enriched eggs as a functional food: a review

Miroslava Fašiangová, Gabriela Bořilová

Department of Meat Hygiene and Technology
Faculty of Veterinary Hygiene and Ecology
CEITEC – Central European Institute of Technology
University of Veterinary and Pharmaceutical Sciences Brno
Brno, Czech Republic

Abstract

In the last few years, consumers have started to realize that an unbalanced diet can cause the disruption of their metabolism and serious health problems. In their effort to live more healthily, they are demanding food enriched with scarce nutrients. The results of various studies show that selenium–enriched eggs with a defined selenium content may be used as a functional food with the ability to increase human selenium intake and, thereby, the amount of selenium in the body. A selenium-enriched egg weighing 60 g contains 22 – 27 µg of selenium which represents as much as 40 – 50% of the Recommended Dietary Allowance. Additionally, the antioxidant function of selenium contributes to the oxidation stability of egg fats and proteins and thereby prolongs the shelf life of eggs. Several studies have confirmed that selenium slows down lipid and protein oxidative fragmentation, slows down the increase of pH values, increases the strength of the vitelline membrane, prolongs the stability of egg-yolk pigments, and has a positive effect on Haugh units, egg weight and the percentage of egg albumen. Selenium can be introduced into eggs by supplementing the laying hens' diet in organic and inorganic chemical form with different biological availability. It has been proven that the amount and chemical form of the selenium supplement influences the final impact of selenium on egg properties.

Antioxidant, egg, selenium, storage, supplementation

Introduction

Many chemical changes take place inside table eggs during their storage. The egg yolk contains a lot of polyunsaturated fatty acids that are susceptible to oxidation (Pappas et al. 2005). Additionally, the egg yolk membrane loses its elasticity (Kirunda and McKee 2000), the pigmentation of egg yolk color disappears (Mohiti-Asli et al. 2010) and albumen proteins are oxidized, thereby losing their functional properties (Wang et al. 2010). Lipid and protein fragmentation leads to the creation of oxidation products deteriorating the nutritional and sensorial properties of the eggs (Pappas et al. 2005; Mohiti-Asli et al. 2008 and Kralik et al. 2014). The presence of antioxidants such as selenium, which can be introduced into eggs by supplementing the laying hens' diet, is necessary for this reason.

Selenium is a trace element important as an antioxidant participating in protective metabolic processes against lipid and protein oxidation. It is an essential part of various selenoproteins, such as gluthathione peroxidase (GSH-Px) (Pappas et al. 2005), which protects cells and tissues from oxidative damage (Heindl et al. 2010 and Skrivan et al. 2010). Selenium is necessary in the metabolism of prostaglandins (Pappas et al. 2005), reproduction and the activity of the brain and thyroid (Rayman 2008). In animal nutrition, it has a positive effect on feed conversion, utility and health status (Attia et al. 2010 and Surai and Fisinin 2014). Interest in the utilization of selenium addition in animal feed has increased in recent years for these reasons.

Animal diet may be supplemented in both organic and inorganic form. Sodium selenite is the most common dietary supplement (Skrivan et al. 2010; Heindl et al. 2010 and Jing et al. 2015), although it has limited biological utilization (Heindl

Address for correspondence:

Ing. Miroslava Fašiangová
Department of Meat Hygiene and Technology
Faculty of Veterinary Hygiene and Ecology
University of Veterinary and Pharmaceutical Sciences Brno
Palackého tř. 1946/1, 612 42 Brno, Czech Republic

E-mail: fasiangovam@vfu.cz
Tel: +420 541 562 752

et al. 2010 and Surai and Fisinin 2014). Several studies have shown that organic selenium has greater biological availability than inorganic selenium (Surai and Fisinin 2014). Selenium in organic form is actively absorbed and can be directly incorporated into protein, whereas inorganic selenium is absorbed by the body passively (Mohiti-Asli et al. 2008). In addition, selenomethionine is absorbed in a similar way as methionine which allows their mutual substitution in protein synthesis and the creation of selenium reserves in the body (Arpasova et al. 2012).

Selenium content in eggs after supplementation

Results from several studies show that the dietary supplementation of selenium increases its content in eggs (Skrivan et al. 2006; Pan et al. 2007; Mohiti-Asli et al. 2008 and Jing et al. 2015).

According to Surai (2000), the selenium content in an egg can be increased from 7.1 µg to 30.7 µg (49% of the Recommended Dietary Allowance or RDA of selenium) after supplementation with 0.4 $mg \cdot kg^{-1}$ of organic selenium. The selenium concentration is dependent on the chemical form of supplementation. In the studies by Surai (2000), Skrivan et al. (2006), Pan et al. (2007) and Skrivan (2009), organic selenium supplements resulted in a higher selenium concentration in eggs than inorganic selenium supplements. According to the study by Skrivan et al. (2006), organic selenium supplementation in the form of selenized yeast and selenized algae (genus *Chlorella*) is able to increase the selenium content by a factor of more than three and a half after 14 days of the start of feeding with a supplemented diet. The authors claim that Se-Chlorella is equally effective as Se-yeast for selenium transfer from feed to eggs. However, the results of the present study show that the sodium selenite effect is clearly less strong. With selenium addition of 0.3 mg, sodium selenite doubles the selenium content in eggs (Skrivan et al. 2006). Skrivan (2009) claims that the selenium content in Czech eggs without supplementation can be expected to amount to 5.5 – 8.0 µg in one egg weighing 60 g. This selenium level represents 10 – 15% of the RDA. The amount of selenium in sixty-gram eggs with inorganic selenium supplementation will be 10 – 14 µg which represents 20% of RDA, and the selenium content in sixty-gram eggs with organic selenium addition 22 µg, representing as much as 40% of RDA. Table 1 shows the selenium concentration after supplementation with organic and inorganic selenium.

Table 1. Selenium content in eggs after selenium supplementation (values of selenium concentration [$\mu g \cdot g^{-1}$] have been calculated for a 65 g egg)

Organic supplementation	Inorganic supplementation	Dietary supplement [$mg \cdot kg^{-1}$]	Duration of experiment [days]	References
Se per egg [µg]				
9.75	9.10	0.1	33	Paton et al. (2002)
15.08	15.15	0.2	21	Pan et al. (2007)
14.30	10.40	0.2	33	Paton et al. (2002)
16.25	10.40	0.3	33	Paton et al. (2002)
19.83	18.92	0.5	21	Pan et al. (2007)
23.60	24.25	1.0	21	

The effect of selenium on certain properties of eggs

During the storage of eggs, oxygen gets inside through the egg shell pores, carbon dioxide diffuses out of the egg and proteins catabolize producing ammonia. These reactions are connected with an increase in the pH of both parts of the egg. The pH of the yolk of a newly laid egg is about 6.0 (Brake et al. 1997), while the pH of the albumen is within 7.6 and 8.5 (Heath 1977). The pH of the yolk gradually rises to between 6.4 and 6.9 and the pH of the albumen to 9.7 (Heath 1977). Several studies have shown that the antioxidant function of selenium slows down the increase of the pH of the yolk caused by the oxidation of yolk lipids during storage. Additionally, selenium changes the eggshell structure, thereby slowing down the pH increase in the albumen caused by carbon dioxide diffusion from the egg albumen through egg shell pores (Pappas et al. 2005 and Fernandes at al. 2008). In fact, selenium may affect eggshell quality either by direct interaction with calcium crystals during eggshell formation or by its function in the role of a component of key enzymes such as thioredoxin reductases. These enzymes are involved in the processes of membrane and eggshell synthesis (Fernandes at al. 2008 and Pavlović et al. 2010).

The authors of several studies have reported that organic selenium retards egg aging more effectively than inorganic selenium which may be shown by lower egg pH values after organic supplementation. However, according to Table 2, the differences between organic and inorganic supplementation are not significant, for which reason the greater influence of organic selenium on egg content pH could not be confirmed by the values stated in the table.

Table 2. The pH value of egg yolk and albumen in fresh and stored eggsafter selenium supplementation

Fresh yolk	Stored yolk	Fresh albumen	Stored albumen	Dietary supplement [mg·kg^{-1}]	Duration of experiment [weeks]	References
			Organic selenium			
6.163	6.392	8.390	9.277	0.20	8	Aljamal et al. (2014)
6.260	-	9.020	-	0.40	7	Mohiti-Asli et al. (2008)
6.100	-	8.440	-	0.40	7	Mohiti-Asli et al. (2010)
6.190	6.299	8.396	9.259	0.40	8	Aljamal et al. (2014)
			Inorganic selenium			
6.254	6.357	8.428	9.277	0.20	8	Aljamal et al. (2014)
6.060	-	8.390	-	0.40	7	Mohiti-Asli et al. (2010)
6.270	-	9.010	-	0.40	7	Mohiti-Asli et al. (2008)
6.152	6.315	8.455	9.284	0.40	8	

Trial with the eggs of Japanese quails

The quality of eggs is characterized by Haugh units (HU) which are calculated using values of egg weight and the thick albumen height (Skrivan et al. 2006). The properties and quality of the albumen change during storage. The reason for this is the loss of *o*-glycosidically linked carbohydrate units of ovomucin (Kirunda and McKee 2000) and the breaking of the complex of lysozyme and ovomucin. Dissociation of the lysozyme-ovomucin complex leads to the reduction of albumen viscosity and the thinning of thick albumen (Lomakina and Mikova 2006). Therefore, HU values decrease during storage (Pappas et al. 2005; Mohiti-Asli et al. 2008 and Arpasova et al. 2012). Eggs with an HU values higher than 80 are considered as eggs of good quality. Eggs with an HU values between 70 and 65 are acceptable. Eggs with an HU between 40 and 60 are of limited quality and eggs with an HU lower than 40 are not suitable for human consumption (Mikova and Davidek 2000). According to the studies by Pappas et al. (2005), Skrivan (2009) and Arpasova et al. (2012), HU values can be affected by selenium intake. It has been proven that selenium increases egg weight and the proportion of egg albumen which are used for calculation of the HU (Skrivan et al. 2006; Skrivan 2009 and Arpasova et al. 2012). Pappas et al. (2005) explain the positive effect of selenium on HU values by the activity of glutathione peroxidase (GSH-Px) which slows the rate of lipid and protein oxidation during egg storage, leading to improved egg quality during storage. Table 3 shows HU values after supplementation with organic and inorganic selenium.

Table 3. The Haugh units after selenium supplementation

Organic selenium	Inorganic selenium	Dietary supplement [$mg \cdot kg^{-1}$]	Duration of experiment	References
98.17	99.53	0.2	8 weeks	Aljamal et al. (2014)
84.71	85.40	0.3	27 weeks	Skrivan et al. (2006)
62.02	63.58	0.4	7 weeks	Mohiti-Asli et al. (2008)
98.56	97.60	0.4	8 weeks	Aljamal et al. (2014)
87.21	86.60	0.4	9 months	Arpasova et al. (2012)
87.01	86.69	0.4	9 months	Arpasova et al. (2009a)

Antioxidants such as selenium are important components of the protective metabolic processes against lipid peroxidation in view of the fact that the egg yolk contains a lot of polyunsaturated fatty acids that are susceptible to oxidation (Pappas et al. 2005 and Mohiti-Asli et al. 2008). It is assumed that the yolk of selenium-enriched eggs has a higher concentration of polyunsaturated fatty acids than yolk without supplementation due to the protective effect of selenium against oxidation (Pappas et al. 2005; Mohiti-Asli et al. 2008). The content of the secondary oxidation product – malondialdehyde (MDA) – is used as an indicator of lipid oxidation and increases during storage (Pappas et al. 2005; Mohiti-Asli et al. 2008; Ren et al. 2013 and Kralik et al. 2014). Ren et al. (2013) noticed that the malondialdehyde content increased while the docosapentaenoic acid (DPA) content decreased, which can be explained by the aging of the egg. Several studies have reported that the amount of MDA in selenium-enriched eggs is lower than in non-enriched eggs (Skrivan et al. 2010 and Wang et al. 2010). This is a result of the increased GSH-Px content and activity after supplementation with selenium. It is assumed that the increased content and activity of GSH-Px also decreases the carbonyl content in the egg white which is used as a marker of protein oxidation (Wang et al. 2010).

The reactions connected with the aging of eggs are also present in the egg vitelline membrane. This leads to changes in vitelline membrane stability and to a loss of its strength. These changes are based on the degradation of structural glycoprotein and disulfide bonds of the ovomucin in the outer layer of the vitelline membrane. Additionally, the displacement of water from the albumen into the yolk leads to a stretching of the membrane and loss of its elasticity (Kirunda and McKee 2000). According to the results of Scheideler et al. (2010) and Aljamal et al. (2014), selenium incorporated into proteins causes changes in the vitelline membrane protein composition and contributes to its strength.

It seems that selenium-enriched eggs have a more stable yolk color than non-enriched eggs (Arpasova et al. 2009b and Mohiti-Asli et al. 2010). Selenium likely protects the oxycarotenoids present in egg yolk against oxidation which leads to the protection of yolk pigmentation. Mohiti-Asli et al. (2010) found that egg yolk color was significantly increased by selenium-yeast dietary supplements. Arpasova et al. (2009b) reported that eggs with a lower amount of selenium addition were lighter than yolks with a larger amount of selenium.

Conclusions

Numerous studies have proved that selenium dietary supplementation can increase the selenium content in eggs. A single selenium-enriched egg, which represents about 50% of the Recommended Dietary Allowance, may be used as a functional food with the ability to increase the amount of selenium in the human body. Selenium, as an important part of the antioxidant enzyme GSH-Px, protects the cells and tissues from oxidative damage and thereby protects the consumer's health. Additionally, selenium incorporated into enriched eggs may slow down the oxidation reactions going on inside the eggs and thereby prolong their shelf life. Various studies have shown that the antioxidant properties of selenium can have a positive effect on the quality and oxidation stability of eggs. Nowadays, when consumers pay close attention to their nutrition and when great efforts are made to produce food products that retain their freshness for a long time, it is possible that all these findings will also provide a chance for selenium-enriched eggs to find greater opportunities on the food market in the Czech Republic.

Acknowledgements

This research has been financially supported by the Ministry of Education, Youth and Sports of the Czech Republic under project CEITEC 2020 (LQ1601).

References

Aljamal AA, Purdum SE, Hanford KJ 2014: The effect of normal and excessive supplementation of selenomethionine and sodium selenite in laying hens. J Appl Poult Res **3**: 33-38

Arpasova H, Mellen M, Kacaniova M, Hascik P, Petrovic V, Cobanova K, Leng L 2009a: Effects of dietary supplementation of sodium selenite and selenized yeast on selected qualitative parameters of laying hens eggs. Slovak J Anim Sci **42**: 27-33

Arpasova H, Petrovic V, Mellen M, Kacaniova M, Cobanova K, Leng L 2009b: The effects of supplementing sodium selenite and selenized yeast to the diet for laying hens on the quality and mineral content of eggs. J Anim Feed Sci **18**: 90-100

Arpasova H, Hascik P, Kacaniova M, Galik B, Golian J, Mellen M 2012: The effect of various forms and doses of selenium supplementation of the hens diet on selected qualitative parameters and freshness of table eggs. Scientific Papers: Anim Sci Biotech **45**: 11-16

Attia YA, Abdalah AA, Zeweil HS, Bovera F, Tag El-Din AA, Araft MA 2010: Effect of inorganic or organic selenium supplementation on productive performance, egg quality and some physiological traits of dual-purpose breeding hens. Czech J Anim Sci **55**: 505-519

Brake J, Walsh TJ, Jr. Benton CE, Petitte JN, Meijerhof R, Penalva G 1997: Egg handling and storage. Poultry Sci **76**: 144-151

Fernandes JIM, Murakami AE, Sakamoto MI, Souza LMG, Malaguido A, Martins EN 2008: Effects of organic mineral dietary supplementation on production performance and egg quality of white layers. Braz J Poult Sci **133**:197-202

Heath JL 1977: Chemical and related changes in egg albumen during storage. Poultry Sci **56**: 822-828

Heindl J, Ledvinka Z, Tumova E, Zita L 2010: The importance, utilization and sources of selenium for poultry: a review. Sci Agri Bohemica **41**: 55-64

Jing CL, Dong, XF, Wang ZM, Liu S, Tong, JM 2015: Comparative study of DL-selenomethionine vs sodium selenite and seleno-yeast on antioxidant activity and selenium status in laying hens. Poultry Sci **94**: 965-975

Kirunda DFK, Mckee SR 2000: Relating quality characteristics of aged eggs and fresh eggs to vitelline membranes strength as determined by a texture analyzer. Poultry Sci **79**: 1189-1193

Kralik Z, Kralik G, Grcevic M, Galovic D 2014: Effect of storage period on the quality of table eggs. Acta Agr Kapos **18**: 200-206

Lomakina K, Mikova KA 2006: Study of the factors affecting the foaming properties of egg white – a review. Czech J Food Sci **24**: 110-111

Mikova K, Davidek J 2000: Criteria of quality and freshness of hen eggs. Czech J Food Sci **18**: 250-255

Mohiti-Asli M, Shariatmadari F, Lotfollahian H, Mazuji MT 2008: Effects of supplementing layer hen diets with selenium and vitamin E on egg quality, lipid oxidation and fatty acid composition during storage. Can J Anim Sci **88**: 475-483

Mohiti-Asli M, Shariatmadari F, Lotfollahian H 2010: The influence of dietary vitamin E and selenium on egg production parameters, serum and yolk cholesterol and antibody response of laying hen exposed to high environmental temperature. Arch Geflügelk **74**: 43-50

Pan CL, Huang KH, Zhao YX, Qin SY, Chen F, Hu Q 2007: Effect of selenium source and level in hen´s diet on tissue selenium deposition and egg selenium concentrations. J Agr Food Chem **55**: 1027-1032

Pappas AC, Acamovic T, Sparks NHC, Surai PF, Mcdevitt RM 2005: Effects of supplementing broiler breeder diets with organic selenium and polyunsaturated fatty acids on egg quality during storage. Poultry Sci **84**: 865-874

Paton ND, Cantor AH, Pescatore AJ, Ford MJ, Smith CA 2002: The effect of dietary selenium source and level on the uptake of selenium by developing chick embryos. Poultry Sci **81**: 1548-1554

Pavlovic Z, Miletic I, Jokic Z, Pavlovski Z, Skrbic Z, Sobajić S 2010: The effect of level and source of dietary selenium supplementation on eggshell quality. Biol Trace Elem **133**:197-202

Rayman MP 2008: Food-chain selenium and human health: emphasis on intake. Br J Nutr **100**: 254-268

Ren Y, Perez TI, Zuidhof MJ, Renema RA, Wu J 2013: Oxidative stability of omega−3 polyunsaturated fatty acids enriched eggs. J Agric Food Chem **61**: 11595-11602

Scheideler SE, Weber P, Monsalve D 2010: Supplemental vitamin E and selenium effects on egg production, egg quality, and egg deposition of α-tocopherol and selenium. J Appl Poult Res **19**: 354-360

Skrivan M, Simane J, Dlouha G, Doucha J 2006: Effect of dietary sodium selenite, Se-enriched yeast and Se-enriched chlorella on egg Se concentration, physical parameters on eggs and laying hens production. Czech J Anim Sci **51**: 163-167

Skrivan M 2009: The increase of selenium in eggs; methodology. Institute of Animal Science, Prague (In Czech)

Skrivan M, Bubancova I, Marounek M, Dlouha G 2010: Selenium and α-tocopherol content in eggs produced by hens that were fed diets supplemented with selenomethionine, sodium selenite and vitamin E. Czech J Anim Sci **55**: 388-397

Surai PF 2000: Organic selenium and the egg: Lessons from nature. Feed Compounder **20**: 16-18

Surai PF, Fisinin VI 2014: Selenium in poultry breeder nutrition: An update. Anim Feed Sci Technol **191**: 1-15

Wang ZG, Pan XJ, Zhang WQ, Peng ZQ, Zhao RQ, Zhou GH 2010: Methionine and selenium yeast supplementation of the maternal diets affects antioxidant activity of breeding eggs. Poultry Sci **89**: 931-937