

## SELENIUM IN POULTRY NUTRITION: LESSONS FROM RESEARCH AND WILD NATURE

## SELEN U HRANIDBI PERADI: PREGLED REZULTATA ISTRAŽIVANJA U HRANIDBI PERADI I DIVLJIH PTICA

**T. T. Papazyan, S. A. Denev, P. F. Surai**

Scientific review - Pregledno znanstveni članak

UDC: 638.238; 636.5

Received - Primljeno: 28. june - srpanj 2006.

### SELENIUM AND CHICKEN EMBRYO DEVELOPMENT

Chick embryo tissues contain a high proportion of highly polyunsaturated fatty acids in the lipid fraction and therefore need antioxidant defence (Surai, 1999). It is well accepted that maternal diet composition is a major determinant of antioxidant system development during embryogenesis and in early postnatal development. The antioxidant system of the newly hatched chick includes the fat-soluble antioxidants, vitamin E and carotenoids, water-soluble antioxidants ascorbic acid and glutathione as well as antioxidant enzymes SOD, GSH-Px, catalase and selenium (Surai, 2002). Vitamin E and carotenoids are transferred from feed into egg yolk and further to embryonic tissues. Selenium content of the egg also depends on its concentration in the hen's diet, and also on the form of dietary Se used, since organic Se is more efficiently deposited in the egg yolk (Surai, 2006).

Therefore, during egg incubation fat-soluble antioxidants are transferred to the developing embryonic tissues mainly during the last week of incubation. Only vitamin A transfer to the embryonic liver starts earlier than that of vitamin E or carotenoids. As for Se transfer, it is still not clear from the present results at what stage of embryo development this trace element is transferred to the embryonic tissues. It seems likely that Se from the albumin is transferred to the embryo during first 2

weeks of the embryonic development, while Se from egg yolk is delivered to the embryo during the last week of incubation. The form of selenium in the egg yolk and embryonic tissues needs further investigation as well. It could well be that SeMet could represent a substantial proportion of the total Se in the embryo when Se is supplied to laying hens in the organic form. Water soluble antioxidant ascorbic acid started to be synthesised in the yolk sac membrane (YSM) at early stages of incubation and its concentration in this tissues progressively declined during embryonic development (Surai *et al.*, 1996). Reduced glutathione and antioxidant enzymes glutathione peroxidase, superoxide dismutase and catalase are also expressed in the embryonic tissues at various stages of their development (Surai, 1999a).

An accumulation of vitamin E in the liver and YSM during embryonic development was associated with the decreased susceptibility of these tissues to lipid peroxidation that reflects the protective effect of the natural antioxidant accumulation in the embryonic tissues at hatching time (Surai, 2002). Such protection allows these tissues to be quite resistant to oxidative stress of the hatching process. Nevertheless the susceptibility of lipids to peroxidation depends not only on the level of natural

---

T. T. Papazyan, All-Russian Institute of Poultry Farming, Sergiev Posad, Russia; S. A. Denev, Trakia University, Stara Zagora, Bulgaria; P. F. Surai, Avian Science Research Centre, Scottish Agricultural College, Scotland, UK.

antioxidants in tissues but also on the balance between the level of antioxidants/prooxidants and the concentration of PUFAs. It is necessary to underline that chicken egg yolk and embryo tissues are more unsaturated compared to other domestic avian species (Surai, 2002).

When chickens hatch, their immune system, digestive system, nervous system and endocrine system are still not mature and are actively developing during at least the first week posthatch. This development is associated with active lipid metabolism and long chain PUFAs play a regulatory role in this development. Therefore, proper antioxidant protection of the newly hatched chick is a crucial factor of their success in the future. For example, if the antioxidant system is not sufficient to prevent lipid peroxidation, the immune system development will be compromised. As a result undeveloped immune system will be a major cause of chicken mortality during first weeks of the postnatal development since efficiency of vaccination will be low. Furthermore immune cells produce free radicals and use them as an important weapon to destroy pathogens (Surai, 2006). Therefore in the case of low antioxidant defence and pathogen challenge, stimulated neutrophils will produce free radicals which will be able not only to kill pathogens, but also to damage normal tissues which could lead to the development of different disorders.

The regulation of the antioxidant system during embryo development and in early postnatal chick life is not clear at present, although, nutritional factors appear to be important. Indeed, one of the most impressive features of vitamin E metabolism in avian embryonic tissues is an abrupt decrease in the concentration of this vitamin over the first two weeks of postnatal development. As indicated previously the liver accumulates vitamin E during embryonic development to supply chickens with this vitamin in the first days of life after hatch (Surai *et al.*, 1996). This reserve of vitamin E is used by chickens during the first 2 weeks posthatch. During this period vitamin E concentration in the liver decreased by 10 times in chickens, goslings and ducklings (Surai, 2002) and more than 50 times in turkeys (Soto-Salanova *et al.*, 1993).

During chick embryo development there is an antioxidant/prooxidant balance in the tissues which

is responsible for normal embryonic development and posthatch chick viability. We suggest that an accumulation of natural antioxidants vitamins A, E and carotenoids as well as an increase in GSH-Px activity in the embryonic liver may have adaptive significance and were developed during evolution to protect unsaturated lipids against peroxidation during hatching stress conditions. On the other hand, an increased SOD activity and very high levels of ascorbic acid in the brain may be considered as another tissue-specific adaptive mechanism in embryo development.

The activity of GSH-Px significantly increased during postnatal development (Kalytka and Donchenko, 1995; Surai, 2000). Thus, in conditions when oxygen concentration in the tissues is higher, metabolic activity and superoxide radical production are increased and tocopherol and carotenoid concentrations are decreased, the required protection is provided through the major antioxidant enzymes SOD, GSH-Px and CAT. Therefore GSH-Px becomes the major antioxidant protection for the tissues at this period of the development and to maintain high GSH-Px activity in the chicken tissues during first days posthatch it is necessary to use organic form of selenium in the maternal diet which allows more selenium to be accumulated in the egg and transferred to the tissues of newly hatched chick.

#### EFFECT OF ORGANIC SELENIUM IN THE MATERNAL DIET ON ANTIOXIDANT DEFENCES OF THE DEVELOPING CHICKS

The most important opportunity to regulate antioxidant system of the newly hatched chick is by using organic selenium in the breeder's diet. In an experiment conducted at the Scottish Agricultural College, the effect of selenium and vitamin E supplementation of the maternal diet on their transfer to the egg yolk and their concentrations in the tissues of the newly hatched chick was studied and the effect of increased Se and vitamin E supply on the activity of Se-GSH-Px in the chick liver in early postnatal development was determined (Surai, 2000). In this experiment 90 Cobb broiler breeder hens were divided into nine equal groups and housed in pens at 25 weeks of age. Each hen

received one of the treatment diets. Selenium was supplemented in the form of selenium-enriched yeast (Sel-Plex, Alltech, Inc). After six weeks, the hens were artificially inseminated once a week. From week 8 eggs were collected and placed in an incubator. Liver, yolk-sac membrane, brain and blood plasma were collected from chicks for biochemical analysis.

Our results (Surai, 2000) indicated that the inclusion of organic Se into the commercial diet significantly increased the Se concentration in the egg yolk and the albumin. The correlation between dietary Se and egg yolk Se content was found to be very high. This relationship was quantified through a regression equation:

$$y = 179.4 + 1.01x \quad (r^2=0.96, P<0.01),$$

where y is Se concentration in the egg yolk, ppb; and x is the Se concentration in the feed, ppb).

Similarly, a significant correlation between Se in the egg white and feed was found and an equation describing Se concentration in the egg white (y) is as follows:

$$y = -24.8 + 0.68x \quad (r^2=0.98; P<0.01).$$

Using these equations it is easy to predict Se concentration in the egg when organic Se is used in the diet, because the Se content in the egg yolk and egg white reflect its concentration in the feed.

Results of our experiments indicate that the Se concentration in egg yolk was significantly higher than that in the albumen in all groups. However, it is interesting to note that the albumen response to Se supplementation was higher in comparison to egg yolk. For example, when chickens were fed a semi-synthetic diet, egg yolk Se content was almost 5-fold higher in comparison to the albumen. When organic Se was included in the diet at 0.4 ppm, this difference was reduced to 2-fold. Similar results were obtained in experiments with quail. For example, two groups of quail (3 families in each group consisting of 4 females and 1 male) were formed at the beginning of the reproductive period. They were fed a commercial maize-based diet containing 0.1 ppm feed-derived Se, supplemented with 0.2 ppm selenite Se (control group) or 0.5 ppm organic selenium (Sel-Plex™) for 6 months after which eggs were analyzed and incubated in standard conditions (Surai et al., 2006). Selenium

concentration in egg yolk and egg white significantly increased as a result of organic selenium supplementation. The highest increase (8.8-fold) was observed in egg albumin, while Se concentration in egg yolk increased only 2-fold.

During incubation Se accumulated in the egg was transferred to the developing embryo. As a result the liver Se concentration in day old chicks obtained from the eggs enriched with this element was significantly higher compared to those from the control eggs. Therefore, Se concentration in the egg yolk and in the liver of the newly hatched chicks depends on the Se level in the maternal diet.

Our data indicate that selenium in maternal diet affects Se concentration in tissues of postnatal quail. Indeed, when newly hatched quail from Se-enriched eggs and normal quail eggs were placed on low Se-diet (0.1 ppm) the selenium concentration in tissues dropped dramatically for the first 2 weeks posthatch. This finding suggests that Se accumulated in the liver of newly hatched quail is actively used during the first days posthatch. It is possible to suggest that Se absorption from the diet is not sufficient during the first few days of life and the chick must rely on reserves of the element accumulated during embryogenesis. However, the difference in selenium concentration between control and experimental groups was significant at 2 weeks posthatch. These results clearly indicate that the maternal diet affects not only newly hatched quails, but also chicks in postnatal development. When similar experiment was conducted with chicken breeders, it was shown that the maternal effect of Se was also significant at 28 days posthatch. Indeed, recently an experiment was conducted at SAC to address this question (Pappas et al., 2005). Maternal diet was supplemented with 0.4 ppm organic selenium in the form of Sel-Plex and comparison was made with a basic diet containing 0.1 ppm feed-derived selenium. As a result of dietary Se supplementation the Se concentration in the egg yolk, albumin, shell, shell membrane and perivitelline membrane was significantly increased. The newly hatched chicks were placed on basal diet (0.1 ppm) without Se supplementation for the next 4 weeks posthatch. After hatching, chickens fed diets low in Se (0.1 ppm) but originating from parents fed diets high in Se (0.5 ppm) had, up to 4 weeks post-hatch, significantly higher blood Se levels than those

originated from parents fed diets low in Se (0.1 ppm; Pappas *et al.*, 2005). Furthermore, our results indicate that maternal diet affected selenium concentration in the liver up to 3 weeks posthatch and in the breast muscle and blood up to 4 weeks posthatch. GSH-Px activity in the liver and muscles was also elevated. Taking into account recent data presented by Koutsos *et al.* (2003) showing similar effect of carotenoids in the maternal diet on the carotenoid concentration in 4-week-old chickens, it is possible to suggest that Se and probably carotenoids could affect gene expression during the embryonic development. As a result, Se/carotenoid assimilation in postnatal development could be affected. Alternatively, the antioxidant system could be affected and less Se/carotenoids being used for metabolic needs and higher concentrations of these compounds were observed in tissues. Indeed, this hypothesis needs further clarification, however, it is clear that maternal effect is seen beyond newly hatched chicks.

The benefit of organic selenium use in breeder diets lies in its efficient absorption, transport and accumulation in egg and embryonic tissues. This results in improved antioxidant status of the newly hatched chick. As the levels of major natural antioxidants (vitamin E and carotenoids) in chicken tissues progressively decline after hatch, the antioxidant enzymes become a critical arm of antioxidant defence. Therefore, enhanced GSH-Px activity in tissues as a result of organic Se supplementation of the maternal diet may have a positive impact on chick viability in the first few weeks posthatch. An improved antioxidant system of the chick may also enhance immune system function, which is extremely important at this point in physiological development. The sparing effect of organic Se on vitamin E also presents the possibility of further improvement of antioxidant defence of the chick. Indeed, the source and level of Se has a large influence on the amount of Se transferred to the developing embryo. It would also appear that the embryo absorbs greater amounts of Se during days 10 to 15 of incubation than during other periods. Improving the transfer of Se from the hen's diet by using a Se-yeast instead of inorganic sodium selenite is a useful strategy to improve the nutritional status of the embryo as well as that of the newly hatched chick (Surai, 2006).

## SELENIUM REQUIREMENT FOR BREEDERS

The Se requirement of poultry in physiological conditions is thought to be quite low, varying from 0.06 ppm (laying hen) up to 0.2 ppm (turkey, duck; NRC, 1994). However, in commercial conditions associated with various stresses the Se requirement increases substantially.

Although there was no significant difference between 0.2 and 0.4 mg/kg Se supplementation of the maternal diet in GSH-Px activity in the liver of day old chicks in our experiment, 0.4 mg/kg Se gave more protection against peroxidation due to higher levels of vitamin E and glutathione in the liver of day old and 5 day-old chicks (Surai, 2000). Indeed, 0.4 ppm Se supplementation in the breeder's diet significantly increased the Se concentration in all examined tissues. The age of the breeders had a significant effect on the accumulation of Se in the tissues. For example, at peak production when breeders were 27 wk old, those that were supplemented with NRC Se levels in their diet exhibited lower Se concentration in 3 out of 5 examined tissues compared to the levels that were noted when breeders were younger (Pappas *et al.*, 2005b). Therefore, there was an indication of depletion over time for the breeder hens that were fed NRC recommended Se levels. On the other hand, hens fed the high Se diets (0.5 ppm total Se) were supplied with enough Se to maintain their requirements as well as build Se reserves in the tissues.

Since the process of Se transfer from feed to egg yolk, and subsequently to embryonic tissues, has received limited attention, there is no clear answer as to which level of Se supplementation is optimal for broiler breeders. However, an analysis of published research and commercial data indicates that 0.3 ppm organic selenium in the form of Sel-Plex would be a recommended dose of Se dietary supplementation for breeders. For example, at 21 weeks of age Hubbard Ultra-Yield broiler breeders (11,600 pullets and 1530 roosters) were placed in each of two floor barns on two separate farms (Sefton and Edens, 2004). They were reared on Selenite until placement and after that fed on Selenite or Sel-Plex (0.3 ppm) for 33 weeks of production. Sel-Plex supplementation was associated with improvement of fertility (by 0.4-4.5%),

hatchability of fertile eggs (by 1-6%). As a result, the number of settable eggs was greater in Sel-Plex group showing an advantage of over 67,000 on one farm and over 8,500 on the second farm at 27 and 30 weeks of production respectively. An average 4.5 extra chicks per hen capitalized on Sel-Plex treatment was realized during the field trial. When data were combined for the whole production period (41 weeks on Farm 1 and 43 weeks on Farm 2) it was concluded that Sel-Plex in broiler breeder diets was very beneficial from both production and economic viewpoints (Edens and Sefton, 2003; Sefton and Edens, 2004a). Indeed, 5.63 extra chicks per hen housed were obtained as a result of Sel-Plex supplementation and it was calculated that the improved performance resulted in an increased potential revenue of +\$1.17 per hen housed.

From photostimulation (22 wk) Ross 508 pullets were fed a Se-free laying ration (-Se), a standard Selenite-supplemented ration (0.3 ppm, Selenite) or Sel-Plex-supplemented (0.3 ppm) ration (Renema and Sefton, 2004). The egg production was similar, with 175, 173 and 178 eggs produced by 58 wk of age. However, the rate of lay was affected after 48 wk of age, when hen-housed production was 68% in Sel-Plex group and 60 and 61% in -Se and Selenite groups respectively. In the Sel-Plex supplemented group settable egg production from 40 weeks (87.4) was higher than in -Se (80.6) or Selenite (83.7) birds. Prior to 34 wk, hatchability averaged 88% in Sel-Plex eggs compared to 80% in Selenite group and 77% in -Se group. Sel-Plex also reduced shell defects (Renema and Sefton, 2004a; Renema, 2003).

Two experiments with broiler breeders have recently been conducted in Brazil. In the first study, conducted at an integrated farm in the state Sao Paulo 42,000 Cobb breeders were divided in two groups and allocated in four farms (Rutz *et al.*, 2003). The control group was fed on a corn-soybean meal basal diet containing 0.5 ppm Se as sodium selenite, while in the experimental diet sodium selenite was replaced with 0.3 ppm Se from Sel-Plex and birds were on these diets throughout the laying period. In the second trial, conducted in the state of Parana 15270 Cobb breeders were used. The control diet was supplemented with 0.2 ppm Se in the form of sodium selenite and in the experimental diet sodium selenite was replaced with 0.3 ppm

selenium as Sel-Plex. The major results of the experiments are shown in Table 9 (Rutz *et al.*, 2003). As can be seen from the results, replacement of sodium selenite with Sel-Plex gave 1-2 extra chicks per hen housed. Similar results were reported by Renema (2004) showing increased egg production at 49-58 weeks and chick produced per hen housed as a result of replacement of 0.3 ppm sodium selenite with the same amount of Sel-Plex (Renema, 2004). Recently, it has been shown that embryonic mortality in eggs laid by 23 wk old broiler breeders was higher in the first and last week of incubation and significantly reduced as the age of the flock increased. In the 27 wk old breeders mortality in week 3 of egg incubation was 3.53%, and 10.6% in the soya oil and fish oils supplemented breeders (Pappas *et al.*, 2005c). Inclusion of Sel-Plex (0.4 ppm) in the diets decreased mortality to 3.06 and 6.22% respectively.

Unfortunately there is no data available on Se requirement of egg-type breeders in commercial conditions. Indeed, higher rate of egg production and lower feed consumption in laying type of breeders indicate that their Se requirement could be similar or even higher than that in broiler breeders. It seems likely that 0.3 ppm Se in the form of Sel-Plex could also be effective in the egg-type breeder diet. However, more research and commercial trials are needed to address this question.

#### PRACTICAL APPROACHES TO IMPROVE SELENIUM STATUS OF POULTRY

Poultry diets are supplemented with Se in order to provide a margin of safety against deficiency, meet physiological requirement in selenium and to maintain high productive and reproductive performance. In this respect, level and form of dietary Se are of great importance. During evolution all animals, including birds, adapted to metabolising the organic form of Se (Surai and Dvorska, 2001). Indeed feed ingredients contain Se only in organic form, mainly as SeMet. This means that the digestive system is ill-prepared for inorganic Se (selenite or selenate). This fact is underscored by the fundamental differences in absorption and metabolism of inorganic and organic Se sources. Organic Se (SeMet) is actively absorbed in the

intestine as an amino acid employing similar processes as methionine. To the contrary, inorganic Se is passively absorbed. The chemical similarity between SeMet and methionine allows the body to use them interchangeably in protein synthesis. This makes it possible to build Se reserves in the body (mainly in muscle). Our data with chicken and quail clearly indicate increased Se concentration in tissues of birds fed organic selenium in the form of Sel-Plex. Since SeMet is not synthesised in animals and only plants, bacteria and marine algae can synthesise this amino acid (Schrauzer, 2000), there is little if any Se reserve in the body when inorganic Se is used.

This difference in tissue reserves of Se can explain why organic Se is more effective than inorganic sources, especially in stress conditions. Consider two different scenarios for Se supplementation of poultry. The first and most common scenario is addition of inorganic Se to diets containing low levels of naturally occurring organic Se. When overproduction of free radicals occurs as a result of stress conditions, the body responds by attempting to mobilise antioxidant reserves; and more importantly, by synthesising additional selenoproteins. In this scenario, the main limitation is absence of Se reserves and a restricted ability to synthesise additional selenoproteins. Therefore in this scenario we would expect a decrease in productive and reproductive performance of poultry as well as compromised immunity defence.

Selenium reserves are much higher in the scenario where organic Se sources provide dietary Se. The major benefit would come from Se reserves accumulated in the form of SeMet in muscles. Protein catabolism during stress conditions releases SeMet to the free amino acid pool, thereby supplying Se needed for the synthesis of additional selenoproteins to prevent damaging effects of free radical overproduction. It must be emphasised that SeMet and SeCys are major forms of Se in the body. However, cells do not contain free pools of these selenoaminoacids. They are present only as parts of various selenoproteins, or in the case of SeMet in tissue proteins. When Se is supplemented in the form of SeMet, this amino acid will be non-specifically incorporated into various proteins in place of methionine, for example in muscle. This could be an advantage in comparison with SeCys, since Se-Cys-containing proteins are antioxidants

themselves and more expensive to degrade, but SeMet-containing proteins are not antioxidants and therefore would be less expensive for body antioxidant defence. Thus in this scenario, during protein catabolism by proteasomes much more Se will be released in the form of SeMet in comparison to SeCys.

Differences in Se status between birds that respond effectively to stress conditions and those that do not are often not dramatic. For this reason, we recognise the importance of marginal deficiencies in Se and other trace elements. These differences are very difficult to evaluate, particularly when our practical means of evaluating Se status tend to focus on only one of the functional selenoproteins. For example, if hatchability is 82%, is there any room for improvement due to improved Se status? The answer lies in the extent to which functional aspects of Se are limiting fertility or chick development. Many aspects of reproduction and embryonic and early chick mortality are sensitive to antioxidant/pro-oxidant balance (Surai, 1999; 2002).

While improving Se status cannot counter all the ill effects of stresses such as very high levels of mycotoxins or environmental temperature extremes, there is a range of everyday stress conditions on commercial farms where the organic Se supplementation model/scenario could be effective (Surai and Dvorska, 2001).

## LESSONS FROM WILD NATURE

It has been suggested that for the past 150 years our diet has changed substantially, while our genes have not been changed. In particular, animal-derived food composition has been dramatically changed as a result of using cheap feed ingredients. The meat from animals in the wild and chicken eggs produced under complete natural conditions contain higher amounts of omega-3 fatty acids compared to cultivated ones. Indeed, analyses of egg composition from various avian species in the wild conducted at the SAC indicate a great difference in fatty acid, vitamin E and carotenoid profile of eggs between commercial laying hens and wild birds. In fact, designer eggs enriched with omega-3 fatty acids are very similar in fatty acid profile to eggs produced in the wild or so called Greek eggs, produced by free

range birds having unlimited access to various greens, worms, insects etc. The same is true for selenium and carotenoids. Indeed, decreased Se levels in feeds and foods in many cases reflect consequences of our agricultural practises. Therefore, eggs or meat produced by free-range poultry/animals fed on natural feed sources grown on well-balanced soils 100-200 years ago would contain much higher Se concentration than we currently have in many European and Asian countries. Again, by supplementing animal diet with natural organic sources of Se we are returning to nature. Our recent data on the Se profile of eggs from various avian species in the wild confirmed this idea: the Se concentration in eggs collected in wild nature in many cases is much higher than that in commercial poultry production (Pappas *et al.*, 2006). Our results may imply that the Se requirement for birds breeding in captivity will vary among species. An appropriate guideline could be provided by considering the yolk Se concentration displayed by the free-living counterparts of the species. The Se level in the chicken eggs even after organic Se supplementation (Surai, 2000) only raised the yolk Se level to the lower end of the range achieved by avian species in the wild, suggesting there may be scope for much higher levels of supplementation for poultry. It seems likely that the Se level which is considered to be the norm for the commercial eggs is too low to be physiological and this should be studied in more detail in the future. Similar evidence of high Se concentrations in wild water birds were related to eggs of little egrets, black-crowned night herons and bridled terns from coastal areas of Hong Kong (Lam *et al.*, 2005). In tissues of the seabirds from the Barents Sea (Savinov *et al.*, 2003), from Alaska and arctic Russia (Stout *et al.*, 2002) as well as in bald eagles from Adak Island (Alaska; Stout and Trust, 2002) selenium levels were also several-fold higher in comparison to domestic chickens. Furthermore, high Se concentrations were reported in eggs from tree swallow, bank swallow and house wren (Dickerson *et al.*, 2002). Therefore Se-enrichment of eggs, meat and milk is nothing else but production of naturally-designed food ingredients. Indeed, production and commercialisation of such organic Se sources as selenized yeast (for example Sel-Plex™) has opened a new era in the Se supplementation of animals giving a real chance to producers to meet growing requirements of

consumers. Indeed, production of this kind of animal-derived foodstuffs is a natural way to health promotion.

## CONCLUSIONS

It is quite clear that the roles of Se in avian nutrition and reproduction need new consideration in the light of better understanding of molecular mechanisms of Se activity at the cellular and sub-cellular levels. In particular, discovery and characterisation of a range of new selenoproteins, better understanding of relationships between different antioxidants as important parts of integrated antioxidant system with possibilities for antioxidant recycling *in vivo* have given a new insight into this matter.

The most fascinating part of the Se-related research comes from understanding the principal difference between various Se sources in the diet. The digestive system of animals, including birds, adapted to metabolise organic Se from plant-based feedstuffs during evolution. Therefore, inclusion of selenite or selenate in the diet is not the 'natural' situation and differences in assimilation, distribution and accumulation of Se in tissues depend on source of Se. Furthermore, main Se compound of selenized yeast, SeMet itself, possesses antioxidant properties, which could be beneficial during digestion (Surai *et al.*, 2003; 2004). To the contrary, selenite is pro-oxidant and in combination with iron and zinc could stimulate lipid peroxidation and cause damage to enterocytes and as a result decrease absorption efficiency of various nutrients, including antioxidants. In addition, the natural form of Se, selenomethionine, contributes to Se tissue reserves thereby providing a better chance for animals to adequately respond to stress conditions by synthesising additional selenoproteins. However, most of the Se-related research in food of animals was until recently conducted using inorganic Se. Therefore much of the data related to effects of Se on various physiological processes and on the productive and reproductive performance of animals need to be re-evaluated using natural sources of Se. The data presented above and summarised in Table 19 indicate that replacement of sodium selenite with organic selenium in the form of Sel-Plex in the chicken diet improves antioxidant defences and has

a range of commercial advantages. Indeed, in breeders main advantages include:

- improved fertility
- improved hatchability
- increased early chick viability
- In growing broilers Sel-Plex is associated with:
  - better growth
  - improved FCR
  - decreased mortality
  - decreased drip loss
  - decreased lipid peroxidation during meat storage

Selenium detected in egg shell and Sel-Plex can increase Se concentration in all parts of the egg, including egg shell, shell membrane and perivitelline membrane. Replacement of sodium selenite with Sel-Plex in the laying hen diet has shown to

- improve FCR
- improve shell quality
- improve egg freshness during storage
- decrease lipid peroxidation during storage

Another important advantage of Sel-Plex in poultry production is related to possibilities of producing Se-enriched eggs, broilers and turkeys. Applications of Sel-Plex for turkey and waterfowl production are also of great importance. The data, accumulated for the last 5 years clearly indicate that the time has come to reconsider Se supplementation of poultry and redefine Se requirement. Indeed, full replacement of sodium selenite in poultry diets with organic sources of selenium, such as Sel-Plex, is just the matter of time. Furthermore, more research should be done with organic sources of Se in order to better understand and exploit its physiological role, solve Se deficiencies and improve general health of humans and animals. Indeed, analyses of eggs from wild birds have confirmed the idea that Se level in eggs of commercial breeders is comparatively low and probably need to be reconsidered.

## REFERENCES

1. Dickerson, K., Custer, T.W., Custer C.M. and Allen, K. (2002). Bioavailability and exposure assessment of petroleum hydrocarbons and trace elements in birds nesting near the north platter river, Casper, Wyoming. Contaminants Report Number: R6/716C/00. U.S. Fish and Wildlife Service, Region 6, pp.1-72
2. Edens, F.W. and Sefton, A.E. (2003). Sel-Plex in broiler breeder diets: improved performance. Poster presented at Alltech's 19<sup>th</sup> Annual Symposium on Nutritional Biotechnology in the Feed and Food Industries, Lexington, Ky, May 12-14, 2003, CD-ROM.
3. Kalytka, V.V. and Donchenko, G.V. (1995). The antioxidant system and lipid peroxidation in chickens during postnatal ontogenesis. *Ukrainian Biochemical Journal* 67: 80-85
4. Lam JC, Tanabe S, Lam MH, Lam PK. (2005). Risk to breeding success of waterbirds by contaminants in Hong Kong: evidence from trace elements in eggs. *Environmental Pollution* 135: 481-490
5. Pappas, A.C., Karadas, F., Surai, P.F. and Speake, B.K. (2005). The selenium intake of the female chicken exerts a continuing influence on the selenium status of her progeny. *Comparative Biochemistry and Physiology* 142B: 465-474
6. Pappas, A.C., Acamovic, T., Sparks, N.H.C., Surai, P.F., and McDevitt, R.M. (2005c). Embryonic mortality during incubation can be influenced by selenium and polyunsaturated fatty acids supplementation. *Proceedings of the UK Branch WPSA Spring Meeting, York*
7. Pappas, A.C., Karadas, F., Surai, P., Wood, N., Cassey, Ph. and Speake, B.K. (2006). Interspecies variation in yolk selenium concentrations among eggs of free-living birds. *Journal of Trace Elements in Medicine and Biology* (Submitted)
8. Renema, R.A. (2003). Effects of dietary selenium source on egg production, fertility, hatchability, and shell quality of broiler breeders. *Abstracts of the 92nd Annual Meeting of the Poultry Science Association*. July 6-9, 2003, Madison, Wisconsin, USA. *Poultry Science* 82 (Suppl. 1): 51
9. Renema, R.A. (2004). Reproductive responses to Sel-Plex organic selenium in male and female broiler breeders: impact on production traits and hatchability. In: *Nutritional Biotechnology in the Feed and Food Industries. Proceedings of 20th Alltech's Annual Symposium*, Edited by Lyons, T.P. and Jacques, K.A., Nottingham University Press, Nottingham, UK, pp. 81-91
10. Renema, R.A. and Sefton, A.E. (2004). Dietary selenium source can affect egg production, shell quality and fertility traits of broiler breeders. *Book of Abstracts XXII World's Poultry Congress*, 8-13 June, 2004, Istanbul, Turkey, p.521



11. Rutz, F., Pan E.A., Xavier, G.B. and Ancuti, M.A. (2003). Meeting selenium demands of modern poultry: responses to Sel-Plex organic selenium in broiler and breeder diets. In: *Nutritional Biotechnology in the Feed and Food Industries. Proceedings of 19th Alltech's Annual Symposium*, Edited by Lyons, T.P. and Jacques, K.A., Nottingham University Press, Nottingham, UK, pp. 147-161
12. Savinov, V.M., Gabrielsen, G.W. and Savinova, T.N. (2003). Cadmium, zinc, copper, arsenic, selenium and mercury in seabirds from the Barents Sea: levels, inter-specific and geographical differences. *The Science of the Total Environment* 306: 133-158
13. Sefton, A.E. and Edens, F.W. (2004). Sel-Plex improves semen quality in broiler breeder males in a cage environment. *Biotechnology in the Feed and Food Industry. Proceedings of the 20<sup>th</sup> Annual Symposium (Suppl. 1), May 22-26, 2004, Lexington, Kentucky, USA*, p. 33
14. Sefton, A.E. and Edens, F.W. (2004a). Sel-Plex improves broiler breeder performance. *Book of Abstracts XXII World's Poultry Congress*, 8-13 June, 2004, Istanbul, Turkey, p.257
15. Soto-Salanova, M.F. and Sell, J.L., Mallarino, E.G., Piquer, F.J., Barker, D.L., Palo, P.E. and Ewan, R.C. (1993). Research note: Vitamin E status of turkey poults as influenced by different dietary vitamin E sources, a bile salt, and an antioxidant. *Poultry Science* 72: 1184-1188
16. Stout, J.H. and Trust, K.A. (2002). Elemental and organochlorine residues in bald eagles from Adak Island, Alaska. *Journal of Wildlife Diseases* 38: 511-517
17. Stout, J.H., Trust, K.A., Cochrane, J.F., Suydam, R.S. and Quakenbush, L.T. (2002). Environmental contaminants in four eider species from Alaska and arctic Russia. *Environmental Pollution* 119: 215-226
18. Surai, P.F. (2006). *Selenium in Nutrition and Health*. Nottingham University Press, Nottingham.
19. Surai, P.F. (2002). *Natural Antioxidants in Avian Nutrition and Reproduction*. Nottingham University Press, Nottingham.
20. Surai, P.F. (1999). Vitamin E in avian reproduction. *Poultry and Avian Biology Reviews* 10: 1-60
21. Surai, P.F. (1999a). Tissue-specific changes in the activities of antioxidant enzymes during the development of the chicken embryo. *British Poultry Science* 40: 397-405
22. Surai, P.F. (2000). Effect of the selenium and vitamin E content of the maternal diet on the antioxidant system of the yolk and the developing chick. *British Poultry Science* 41: 235-243
23. Surai, P.F. and Dvorska, J.E. (2001). Is organic selenium better than inorganic sources. *Feed Mix* 9: 8-10
24. Surai, P.F., Noble, R.C. and Speake, B.K. (1996). Tissue-specific differences in antioxidant distribution and susceptibility to lipid peroxidation during development of the chick embryo. *Biochimica et Biophysica Acta* 1304: 1-10
25. Surai, P.F., Karadas, F., Pappas, A.C. and Sparks, N.H.C. (2006). Effect of organic selenium in quail diet on its accumulation in tissues and transfer to the progeny. *British Poultry Science* (In press)
26. Surai, K.P., Surai, P.F., Speake, B.K. and Sparks, N.H.C. (2003). Antioxidant-prooxidant balance in the intestine: Food for thought. 1. Prooxidants. *Nutritional Genomics & Functional Foods* 1: 51-70
27. Surai, K.P., Surai, P.F., Speake, B.K. and Sparks, N.H.C. (2004d). Antioxidant-prooxidant balance in the intestine: Food for thought. 2. Antioxidants. *Current Topics in Nutraceutical Research* 2: 27-46.