NATURAL ANTIOXIDANTS IN TURKEY PRODUCTION

P.F. Surai

Scottish Agricultural College, Edinburgh, UK and University Glasgow, UK

Summary

Antioxidants play an important role in turkey reproduction. Main antioxidants to be considered in relation to turkey production are vitamin E, carotenoids, selenium and ascorbic acid. It has been shown that there are principal features of antioxidant defences in turkey in comparison to other avian species. In particular, in comparison to chicken turkey eggs and tissues are characterized by:

- Substantially lower vitamin E and carotenoid concentrations in egg yolk. When dietary vitamin E supplementation for chicken and turkey was similar, alpha-tocopherol concentration in turkey egg yolk was more than 4 times lower in comparison to chicken eggs. Carotenoid concentration in turkey egg yolk was also lower than in the chicken egg.
- Lower vitamin E and carotenoid concentration in the liver and other tissues and lower Se concentration in breast muscle, but similar GSH-Px activity. Similar ascorbic acid concentration in the liver of newly hatched chicks but lower vitamin C level in the brain.
- Lower proportion of docosahexaenoic acid (DHA) in the yolk lipids. When chicken and turkey were fed on similar grain-based diets, the proportion of DHA in the total lipid of the yolk was three to five times greater for chickens compared to turkey.

When turkey semen was compared with chicken semen, the following differences were observed:

- Lower proportion of arachidonic (20:4n-6) and docosatetraenoic (22:4n-6) fatty acids in spermatozoa
- Higher superoxide dismutase (SOD) activity in seminal plasma, but lower SOD and GSH-Px activity in spermatozoa
- Higher total antioxidant activity of seminal plasma

Therefore, different antioxidant and fatty acid profiles of turkey tissues in comparison to those in chicken suggest different mechanisms and efficiency of antioxidant-prooxidant balance regulation. Clearly, more research should be done in this exciting area.

It seems likely, that based on the information available, in comparison to chickens, higher doses of vitamin E and probably selenium in organic form would be necessary to include in turkey diet to maintain productive and reproductive performance of turkey in commercial conditions.

Introduction

The animal body is under constant attack from free radicals, formed as a natural consequence of the body's normal metabolic activity and as part of the immune system's strategy for destroying invading microorganisms. It has been calculated that about 2 $x10^{10}$ molecules of reactive oxygen species (ROS) are generated per cell per day (Surai, 2006) In stress conditions this rate is substantially increased.

During evolution, living organisms have developed specific antioxidant protective mechanisms to deal with ROS. Therefore, the presence of natural antioxidants in living organisms is the major factor that enables their survival in an oxygen-rich environment. These mechanisms are described by the general term "antioxidant system" (Surai, 2002). It is diverse and is responsible for the protection of cells from the actions of ROS. This system includes:

- natural fat-soluble antioxidants (vitamins A, E, carotenoids, ubiquinones, etc.);
- water-soluble antioxidants (ascorbic acid, uric acid, taurine, etc.)
- antioxidant enzymes: glutathione peroxidase (GSH-Px), catalase (CAT) and superoxide dismutase (SOD).
- thiol redox system consisting of the glutathione system (glutathione/glutathione reductase/glutaredoxin/glutathione peroxidase and a thioredoxin system (thioredoxin/thioredoxin peroxidase/thioredoxin reductase).

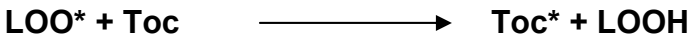
The protective antioxidant compounds are located in organelles, subcellular compartments or the extracellular space, enabling maximum cellular protection to occur. The antioxidant system of the living cell includes three major levels of defence.
The first level is based on the activity of superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and catalase which, together with metal-binding proteins, are responsible for prevention of free radical formation and keep this process under control. The second level of antioxidant defence is based on chain-breaking antioxidants (vitamins E, C, carotenoids, etc.) and is responsible for restriction of chain formation and propagation. The third level of defence is based on the activity of specific enzymes, responsible for repairing or removal of damaged molecules from the cell.

Natural antioxidants in turkey diets and supplements

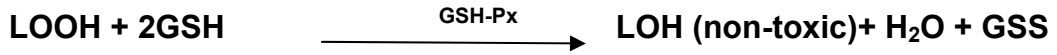
The diet provides a range of natural compounds possessing antioxidant activity. For example, vitamin E comprises of 8 compounds: 4 tocopherols and 4 tocotrienols. The carotenoid family includes more than 600 compounds and there are more than 8,000 flavonoids. However, in the body, all antioxidants are working in concert as a team, the "antioxidant system", responsible for prevention of the damaging effects of free radicals and toxic products of their metabolism. In this team, every member has its own job to do and they are

located in various parts of the cell in such a way to provide a maximal efficiency of antioxidant protection.

It is well known that vitamin E is the major antioxidant in biological systems, providing antioxidant defences at the membrane level. It can be found in practically all feed ingredients in varying concentrations. Vegetable oils are the richest source of vitamin E. However, because the oil refining process removes most of the vitamin E, commercially used oils (soya, maize, sunflower) are not high in this vitamin. The vitamin E requirement of poultry is in the range of 5-20 ppm. It is a general practice in poultry production to add vitamin E as a part of premixes. The level of supplementation varies substantially depending on country and conditions, but for commercial turkey breeders vitamin E supplementation is about 90-100 ppm. Vitamin E is not toxic for poultry and high doses (250-500 ppm) can be used for improvement of meat quality during storage and to maintain egg production during heat stress. Recently, it has been shown that vitamin E can be effective only in an optimal balance with selenium (Se). Indeed, vitamin E, the most effective natural free radical scavenger identified to date, is the main chain breaking antioxidant in the cell.



Thus, vitamin E breaks the chain reaction of lipid peroxidation by removing lipid peroxyl radicals (LOO*). However, hydroperoxides (LOOH), produced in the reaction of vitamin E with the peroxyl radical, are toxic and if not removed, impair membrane structure and functions (Surai, 2002). In fact, lipid hydroperoxides are not stable and in the presence of transition metal ions can decompose producing new free radicals and cytotoxic aldehydes. Therefore, hydroperoxides have to be removed from the cell in the same way as H_2O_2, but catalase is not able to detoxify these compounds and only Se-dependent GSH-Px can deal with them, converting hydroperoxides into non-reactive products as follows:



Thus, vitamin E performs only half the job of preventing lipid peroxidation by scavenging free radicals and forming hydroperoxides. The second part of this important process of antioxidant defence is due to Se-GSH-Px. It is necessary to underline, that vitamin E and Se work in tandem; and even very high doses of dietary vitamin E cannot replace Se, which is needed (in the form of GSH-Px and thioredoxin reductase) to complete the second part of antioxidant defence as mentioned above. Thus, Se as an integral part of the GSH-Px and thioredoxin reductase, belongs to the first and second levels of antioxidant defence.

Se is considered to be an integral part of at least 25 selenoproteins expressed in various tissues of human and animals. It has been proven that Se participates in regulation of major physiological functions in human and animals including growth, development, spermatogenesis and embryonic development. Se can be found in major feed ingredients, but its concentration varies substantially and in many areas of the world, including Europe, Se concentration in grains is <0.1 ppm. The Se requirement of poultry is 0.1-0.2 ppm but common Se supplementation is in the range of 0.1-0.3 ppm. The legal

limit in EU countries is 0.5 ppm of total (feed derived+ supplemental) Se, while in the USA the supplemental Se level is restricted to 0.3 ppm. For the last few years it has been proven that a replacement of sodium selenite by organic Se in the form of Se-yeast is associated with increased fertility and hatchability in breeders, better FCR, lower mortality decreased drip loss in broilers (Surai, 2006). Analysis of current literature indicates that optimal Se supplementation in the form of Sel-Plex for breeders is 0.3 ppm. The same level of supplementation can be used for other categories of poultry. Our data on the Se content in the egg of wild birds indicate that the level of this element in chicken egg is 2-5-fold lower than that in eggs of many avian species in the wild. This raises the question of whether the current level of Se in the chicken egg is adequate or if it needs to be increased.

Recently, carotenoids have been included into the antioxidant family. In poultry production two major diets are used. They are the soya-maize based diet containing comparatively high levels of carotenoids and the wheat-barley-based diet that has a low carotenoid content. Lutein and zeaxanthin are major feed-derived carotenoids. There is no requirement for carotenoids established in poultry. However, there are some data indicating that carotenoids could have a role in chicken embryonic development. In wild birds, the egg yolk of many species contains 3-10-fold higher carotenoid concentration than in eggs of commercial chickens. Carotenoids have immunomodulating properties. Moreover, during embryonic development a portion of the carotenoids in egg yolk are used by the embryo, presumably in antioxidant reactions. However, whether birds have an absolute need for carotenoids remains to be established.

The roles of flavonoids and various flavonoid-containing compounds (herbs, plant extracts, etc) are not well understood and need further research. In particular, recently the idea of antioxidant-prooxidant balance in the digestive tract as a major determinant of human and animal health was put forward (Surai et al., 2003; 2004) and some important features of this balance in the chicken were investigated (McLean et al., 2005). Indeed, many antioxidant compounds such as flavonoids, which are not well absorbed can have profound health-promoting effects in the digestive tract preventing possible damage to enterocytes by various harmful compounds of the feed, including oxidised fat, mycotoxins and others. Recently, substantial attention was given to the microbial balance in the digestive tract and the possibilities for their regulation by various nutritional means, including mannan oligosccharides. It seems likely that antioxidant-pro-oxidant balance is the second part of the same equation. On the one hand, the bacterial population in the digestive tract depends on the diet used. On the other hand, bacteria can affect the antioxidant-prooxidant balance by triggering immune cell to produce free radicals.

Natural antioxidants and turkey semen production and quality

Since all avian species are characterized by the presence of high concentrations of PUFA in the spermatozoa, lipid peroxidation is also a common process for spermatozoa of other avian species. For example, incubation of turkey semen in presence of Fe^{2+} was found to induce lipid peroxidation and MDA accumulation (Surai, 1983; 1984). This was confirmed by Cecil and Bakst (1993) who showed that during aerobic storage of turkey

spermatozoa lipid peroxidation increased with time and depended on incubation temperature. The authors also concluded that turkey spermatozoa underwent lipid peroxidation more readily than that reported for spermatozoa from other species. In a preliminary study with turkey semen, Donoghue and Donoghue (1997) showed that MDA concentrations were 10-fold higher for the older toms (56 wk of age) than for younger toms (30 wk of age).

In turkey spermatozoa incubated at 37°C in the presence of exogenous Fe^{2+}, a significant decrease in PS (by 47%) and PE (by 35%), the two most unsaturated lipid fractions of avian spermatozoa, was observed (Surai *et al.*, 1998a; Maldjian *et al.*, 1998). Storage of diluted turkey semen for 48h at 4°C was also associated with a decrease in total phospholipid content and of PC and, to lesser extent, of Sph, PS and PI (Douard *et al.*, 2000). The significance of the decreased concentration of these phospholipids needs further investigation. However PS appears to be an important phospholipid fraction in avian spermatozoa having the highest degree of unsaturation (Surai *et al.*, 1997a; Surai *et al.*, 2000). Storing turkey semen for 48 h at 4°C did not significantly affect the fatty acid profile nor the level of free cholesterol, but the motility, viability and morphological integrity of spermatozoa significantly decreased (Douard *et al.*, 2000). In contrast, as a result of lipid peroxidation in turkey spermatozoa during 1 h sperm incubation at 37°C in the presence of Fe^{2+}, there was a significant decrease in the levels of the main PUFAs: 22:4n-6, 20:4n-6, 22:6n-3 and 22:3n-9 (Surai *et al.*, 1998a; Maldjian *et al.*, 1999).

Antioxidant system of turkey semen based on antioxidant enzymes as well as on vitamin E. Our recent data indicate that in seminal plasma of 5 avian species, KCN inhibited 100% of SOD activity, reflecting the presence of only Cu,Zn-SOD (Surai *e*t al., 1998). In the seminal plasma, the highest SOD activity was recorded in turkey and guinea fowl and the lowest activity was found in duck. Therefore, when expressing SOD activity as per mg seminal plasma protein avian species can be placed in the following descending order guinea fowl>chicken>goose>duck>turkey. In contrast, expressing SOD activity in the spermatozoa, the studied species are in opposite order: goose>duck>chicken=guinea fowl>turkey. In seminal plasma total GSH-Px activity was the highest in turkey and lowest in duck and goose (Surai *et al.*, 1998). In contrast in spermatozoa, the highest GSH-Px activities were found in goose and duck and much lower GSH-Px activity was recorded in the guinea fowl, turkey or chicken. A comparison of antioxidant activities of seminal plasma from boar, ram, human, turkey and chicken showed that human and turkey seminal plasma displayed the highest and that of chicken the lowest protective effect against peroxidation (Surai *et al.*, 1998d).

Vitamin E was first detected in turkey semen in 1981 and it has been shown that most α-tocopherol is located in the cells and only a very low concentration of this vitamin was detected in the seminal plasma (Surai, 1981). The increased vitamin E concentration in turkey spermatozoa was associated with improved motility, viability and fertilizing ability after artificial insemination (Surai, 1983; 1991). For example, inclusion of increased vitamin E doses in the turkey diet was shown to increase α-tocopherol concentration in spermatozoa (Surai, 1983; Surai and Ionov, 1992a; 1992b). It has been shown that turkey spermatozoa enriched with vitamin E released less GOT into the medium during sperm storage compared to the control group (Surai, 1982a). Even during sperm cryopreservation a protective effect of increased vitamin E concentration in the

spermatozoa was observed (Surai, 1988). It was not clear if the stabilising effect of vitamin E was due to prevention of lipid peroxidation. Therefore, in the next experiment it was shown that an increased level of vitamin E in the turkey spermatozoa was associated with a reduction in susceptibility to Fe^{2+}-induced lipid peroxidation (Surai, 1984). This effect of vitamin E was confirmed with chicken semen (Surai *et al.*, 1997a). For inhibition of lipid peroxidation in the spermatozoa the efficiency of vitamin E, incorporated into the sperm membranes as a result of its increased level in the diet, was almost 500 times higher when compared to α-tocopherol inclusion in the diluent (Surai, 1991). Similar increased efficiency of prevention of lipid peroxidation in the chicken spermatozoa as a result of increased vitamin E concentration in the cells compared to it's incorporation into the incubation medium has been recorded recently (Surai *et al.*, 2000a). Therefore, a prevention of lipid peroxidation could be an important mechanism of stabilizing effect of vitamin E on sperm membranes.

Thus, it has been suggested that vitamin E plays a role as a biological stabilizer of sperm plasma membrane (Surai, 1989; 1999). Increasing the α-tocopherol content of the membrane has been shown to stabilize them, making spermatozoa more resistant to the 'unnatural' stresses incurred during artificial insemination, short-term storage and cryopreservation (Surai, 1992; Surai and Ionov, 1992a). It is notable that in experiments with turkeys, the best results were obtained when vitamin E dietary supplementation was increased from 20 to 80 mg/kg (Surai, 1983; 1991). In this regard it is interesting that recommendations by Cuddy Farms for vitamin E supplementation of breeding toms was 90 mg/kg (Surai, 1999).

The protective effect of vitamin E was associated with prevention of PUFA oxidation. For example, inclusion of α-tocopherol into the incubation medium for turkey semen completely prevented loss of 22:6n-3, 22:5n-3 and 22:4n-6 due to peroxidation. Therefore, the PL fatty acid profile of the spermatozoa incubated in the presence of vitamin E (200 ppm) was similar to that of the control before incubation. However, it was not possible to achieve 100% protection from peroxidation, since the level of 20:4n-6 was still lower ($P<0.01$) compared to the non-incubated spermatozoa (Surai *et al.*, 1998a; Maldjian *et al.*, 1998). In addition, PE and PS were the PL fractions that were the most affected during induced peroxidation. Again inclusion of vitamin E into incubation medium prevented changes in PE and PS proportions in the turkey spermatozoa due to lipid peroxidation. Similarly, addition of the antioxidants vitamin E, BHT, and "Tempo" to extended turkey semen improved sperm survival, membrane integrity, and reduced the loss of motility after a 48 hour storage period (Donoghue and Donoghue, 1997). In the same experiment, ascorbic acid was not shown to have any effect of sperm storability

Natural antioxidants and turkey embryo development

Our early observations indicated that the levels of α-tocopherol in the egg yolk of quail, pigeon, chicken, muscovy ducks, Ukrainian white ducks, pheasant, goose and turkey were (μg/g) 252.4; 162.1; 110.3; 66.8; 54.6; 45.7; 45.6 and 34.9 respectively (Ionov *et al*., 1994a). Similar levels of vitamin E in turkey eggs (42.2 - 45.7 μg/g) were found by Trefny *et al*. (1989). Our recent work has

shown that the chicken displayed a much greater efficiency in incorporating α-tocopherol from the parental diet into the yolk by comparison with the turkey, duck and goose (Surai *et al*., 1998). Thus, in spite of similar concentrations in the respective diets, the resultant concentration of α-tocopherol in the yolk of the chicken egg was four to five times greater than observed for the other three species

When compared with the other avian species which have been examined, the turkey accumulates relatively low levels of tocopherols in its tissues (Soto-Salanova *et al*., 1993; 1995; 1996) and egg yolk (Surai *et al*., 1998). The tocopherol accumulation in the turkey embryonic liver started after day 22 of embryo development (Surai *et al*., 1999b), e.g. simultaneously with lipid absorption from the residual yolk (Ding *et al*., 1995). In the YSM this process started earlier which means that, as in the chicken (Surai *et al*., 1996) the YSM absorbs tocopherols from the residual yolk and then transfers them to the embryonic liver. Similarly, in the other tissues α-tocopherol accumulation takes place during the last week of embryonic development. The level of vitamin E in the embryonic brain was much lower compared to those of the other tissues studied, a finding consistent with observations with chickens (Surai *et al*., 1996; 1999d). Thus, the accumulation of vitamin E in the turkey embryonic tissues reaches the maximum just after hatching (Surai *et al*., 1999b) similar to that in the chicken.

Therefore, 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 (Surai and Ionov, 1994), goslings and ducklings (Surai *et al*., 1993) and more than 50 times in turkeys (Soto-Salanova *et al*., 1993). Marusich *et al*. (1975) suggested that the low levels of vitamin E in the liver of turkey poults resulted from the inefficient intestinal absorption of vitamin E, which can be explained as a result of low pancreatic lipase activity (Sell *et al*., 1991) and restricted bile production (Freeman, 1976) as well as of greater (compared to chicken) production and excretion of tocopheryl glucuronides (Sklan *et al*., 1982).

Evidence is accumulating to support the hypothesis that the vitamin E status of turkey poults may be inadequate during the first 3 weeks after hatching (Sell, 1996). A variety of approaches aimed at improving the vitamin E status of turkey poults have, in fact, been investigated; these have included dietary supplementation of the poults with high levels of α-tocopherol (Applegate and Sell, 1996), bile salts (Soto-Salanova *et al*., 1993), and fat (Soto-Salanova and Sell, 1995), as well as vitamin E injection (Soto-Salanova and Sell, 1996) and alterations in provision of n-6 and n-3 polyunsaturated fatty acids (Applegate and Sell, 1996). When d-α-tocopherol was added in the drinking water, there was a temporary increase of α-tocopherol in tissues and a decreased susceptibility of red blood cells to hemolysis (Soto-Salanova, 1998). Moreover, day-old chickens were treated with 3.25 mg vitamin E/bird/day per os, via the drinking water, for two weeks. The vitamin E content of both the liver and the blood plasma was significantly higher in the treated chickens than in the

untreated controls (Mezes, 1994). However all those attempts were not able to reverse that process and only slowed down the vitamin E depletion. Nevertheless, our observation with chickens indicate that increased vitamin E supplementation as well as inclusion of organic selenium in the maternal diet could substantially improve the situation (Surai, 2000). Therefore, maternal diet plays a crucial role in maintaining physiological levels of vitamin E in the chicken tissues during first 10 days of postnatal development.

Conclusions

Natural antioxidants play important roles in maintaining turkey health, their productive an reproductive performance. There are species-specific differences in antioxidant metabolism in poultry, In particular, turkey are characterized by decreased efficiency of vitamin E and carotenoid transfer from the diet to the egg an further to the developing embryo. Furthermore, turkey tissues including muscles contain lower vitamin E concentration than chicken tissues when the similar vitamin E levels are in both diets. However, molecular mechanisms of such differences are not clear at present and need further elucidation.

References

Applegate, T.J. and Sell, J.L. (1996). Effect of dietary linoleic to linolenic acid ratio and vitamin E supplementation on vitamin E status of poults. *Poultry Science* 75: 881-890.

Cecil, H.C. and Bakst, M.R. (1993). In vitro lipid peroxidation of turkey spermatozoa. *Poultry Science* 72: 1370-1378.

Ding, S.T., Nestor, K.E. and Lilburn, M.S. (1995). The concentration of different lipid classes during late embryonic development in a randombred turkey population and a subline selected for increased body weight at sixteen weeks of age. *Poultry Science* 74: 374-382.

Donoghue, A.M. and Donoghue, D.J. (1997). Effects of water- and lipid-soluble antioxidants on turkey sperm viability, membrane integrity, and motility during liquid storage. *Poultry Science* 76: 1440-1445

Douard, V., Hermier, D. and Blesbois, E. (2000). Changes in turkey semen lipids during liquid in vitro storage. *Biology of Reproduction* 63: 1450-1456.

Freeman, C.P. (1976). Digestion and absorption of fat. In: *Digestion in the fowl*, Edited by Boorman, K.N. and Freeman, C.P., British Poultry Science Ltd., Edinburgh, pp. 117-142.

Ionov, I., Surai, P. and Sakhatsky, N. (1994a) Vitamins A and E content in avian egg yolk. *Journal fur Ornithologie* 135: 102.

Maldjian, A., Cerolini, S., Surai, P.F. and Speake, B.K. (1998). The effect of vitamin E, green tea extracts and catechin on the in vitro storage of turkey spermatozoa at room temperature. *Poultry and Avian Biology Reviews* 9: 143-151.

Marusich, W.L., DeRitter, E., Ogrinz, E.F., Keating, J., Mitrovic, M. and Bunnel, R.H. (1975). Effect of supplemental vitamin E on control of rancidity in poultry meat. *Poultry Science* 54: 831-844.

Mezes, M. (1994). Effect of vitamin E treatment on early postnatal changes of vitamin E status of chicken. *Acta Veterinaria Hungarica* 42: 477-480.

McLean J. A., Karadas F., Surai P.F., Speake B.K., McDevitt R.M. and Sparks N.H.C. (2005). Comp. Biochem. Physiol. 141B: 366-372.

Sell, J.L. (1996). Recent developments in vitamin E nutrition of turkeys. *Animal Feed Science and Technology* 60: 229-240.

Sell, J.L, Amgel, C.R., Piquer, F.J., Mallarino, E.G. and Al-Batshan, H.A. (1991). Development patterns of selected characteristics of the gastrointestinal tract of young turkeys. *Poultry Science* 70: 1200-1205.

Sklan, D., Bartov, I., and Hurwitz, S. (1982). Tocopherol absorption and metabolism in the chick and turkey. *The Journal of Nutrition* 112: 1394-1400.

Soto-Salanova, M.F. (1998). Vitamin E in young turkeys: A reassessment of the requirement. *Turkeys*. 45: 18-20.

Soto-Salanova, M.F. and Sell, J.L. (1995). Influence of supplemental dietary fat on changes in vitamin E concentration in livers of poults. *Poultry Science* 74: 201-204.

Soto-Salanova, M.F. and Sell, J.L. (1996). Efficacy of dietary and injected vitamin E for poults. *Poultry Science* 75: 1393-1403.

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.

Surai, P.F. (2002). Natural Antioxidants in Avian Nutrition and Reproduction. Nottingham University Press, Nottingham.

Surai, P.F. (2006). Selenium in Nutrition and Health. Nottingham University Press, Nottingham.

Surai, K.P., Surai, P.F., Speake, B.K. and Sparks, N.H.C. (2003). Nutritional Genomics and Functional Foods 1: 51-70.

Surai, K.P., Surai, P.F., Speake, B.K. and Sparks, N.H.C. (2004). Current Topics in Nutraceutical Research 2: 27-46.

Surai, P.F. (1983b). Stabilising effect of vitamins A and E on turkey sperm membranes. *Ptitsevodstvo* (Kiev) 36: 49-52.

Surai, P.F. (1984). Lipid peroxidation in turkey semen. *Ptitsevodstvo* (Kiev) 37: 58-59.

Surai, P.F. (1981). Fat-soluble vitamins in turkey sperm. *Proceedings of 2nd Conference of Young Scientists*. Zagorsk, USSR, pp. 55-56.

Surai, P.F. (1983a). Biochemical and functional changes in turkey tissues and sperm as a function of the levels of vitamins E and A in feed. *PhD Thesis*. Ukrainian Poultry Research Institute, Borky, Ukraine.

Surai, P.F. (1991). Nutritional and Biochemical Aspects of Vitamins in Poultry. *Doctor Science (DSc) Thesis*. Ukrainian Poultry Research Institute, Borky, Ukraine.

Surai, P.F. (1983b). Stabilising effect of vitamins A and E on turkey sperm membranes. *Ptitsevodstvo* (Kiev) 36: 49-52.

Surai, P.F. (1984). Lipid peroxidation in turkey semen. *Ptitsevodstvo* (Kiev) 37: 58-59.

Surai, P.F. (1988). A protective effect of fat-soluble vitamins during turkey sperm cryopreservation. *Abstracts of International Conference on Achievements and Prospects of the Development of Cryobiology and Cryomedicine*, Ukraine, Kharkov, pp. 213-214.

Surai, P.F. (1989). Relations between vitamin E concentration in poultry spermatozoa and some semen biochemical and physiological characteristics. *Proceedings of the 8th International Symposium on Current Problems of Avian Genetics*, Smolenice, Czechoslovakia, pp. 171-173.

Surai P.F. (1992). Vitamin E feeding of poultry males. *Proceedings of the XIX World's Poultry Congress*, Amsterdam The Netherlands, Vol. 1, pp. 575-577. Surai P.F. (1999). Vitamin E in avian reproduction. *Poultry and Avian Biology Reviews* 10: 1-60.

Surai, P.F. (2000). Effect of 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.

Surai, P. and Ionov, I. (1992). Some biochemical aspects of hypervitaminosis E in hens. *Proceedings of XIX World's Poultry Congress*, Amsterdam The Netherlands, Vol. 1, pp. 578-581.

Surai, P. and Ionov, I. (1992a). Vitamin E in fowl sperm. *Proceedings of the 12th International Congress on Animal Reproduction*, The Huge, The Netherlands, Vol. 1, pp. 535-537.

Surai, P.F. and Ionov, I. (1994). Vitamin E in the liver of developing avian embryos. *Journal fur Ornithologie*. 135: 85

Surai, P.F., Ionov, I.A., Sakhatsky, N.I. and Kuklenko, T.V. (1993). Vitamins A and E content in poultry meat and its quality. *Proceedings of the 11th European Symposium on the Quality of Poultry Meat*, France, Tours, pp. 455-459.

Surai, P.F., Cerolini, S., Maljian, A., Noble, R..C., Speake, B.K. (1998a). Effect of lipid peroxidation on the phospholipid and fatty acid composition of turkey spermatozoa: a protective effect of vitamin E. *Proceedings of the 50th International Congress on Animal Reproduction*, Milano, p. 603

Surai, P.F., Kutz, E., Wishart, G.J., Noble, R.C. and. Speake, B.K. (1997a). The relationship between the dietary provision of α-tocopherol and the concentration of this vitamin in the semen of chicken: effects on lipid composition and susceptibility to peroxidation. *Journal of Reproduction and Fertility* 110: 47-51.

Surai P.F., Brillard J-P., Speake B.K., Blesbois E., Seigneurin F. and Sparks N.H.C. 2000. Phospholipid fatty acid composition, vitamin E content and susceptibility to lipid peroxidation of duck spermatozoa. *Theriogenology* 53: 1025-1039.

Surai, P.F., Cerolini, S., Maljian, A., Noble, R..C., Speake, B.K. (1998a). Effect of lipid peroxidation on the phospholipid and fatty acid composition of turkey spermatozoa: a protective effect of vitamin E. *Proceedings of the 50th International Congress on Animal Reproduction*, Milano, p. 603.

Surai, P.F., Blesbois, E., Grasseau, I., Ghalah, T., Brillard, J-P.,Wishart, G., Cerolini, S. and Sparks, N.H.C. (1998). Fatty acid composition, glutathione peroxidase and superoxide dismutase activity and total antioxidant activity of avian semen. *Comparative Biochemistry and Physiology* 120B: 527-533.

Surai, P.F., Sparks, N.H.C. and Noble, R.C. (1999b). Antioxidant systems of the avian embryo: tissue-specific accumulation and distribution of vitamin E in the turkey embryo during development. *British Poultry Science* 40: 458-466.

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 Biochysica Acta* 1304: 1-10.

Surai, P.F., Speake, B.K., Noble, R.C. and Sparks, N.H.C. (1999d). Tissue-specific antioxidant profiles and susceptibility to lipid peroxidation of the newly hatched chick. *Biological Trace Element Research* 68: 63-78.

Surai, P.F., Noble, R.C., Sparks, N.H.C. and Speake, B.K. (2000a). Effect of long-term supplementation with arachidonic and docosahexaenoic acids on sperm production in the broiler chicken. *Journal of Reproduction and Fertility* 120: 257-264.

Surai, P.F., Maldjian, A., Cerolini, S. and Sparks, N. (1998d). Species-specific protective effect of seminal plasma against lipid peroxidation in an *in vitro* system. *Final Programme and Book of Abstracts of 8th International Symposium on Spermatology*, Montreal, Canada, p.69.

Surai, P., Ionov, I., Kuchmistova, E., Noble, R.C. and Speake, B.K. (1998). The relationship between the levels of α-tocopherol and carotenoids in the maternal feed, yolk and neonatal tissues: Comparison between the chicken, turkey, duck and goose. *Journal of the Science of Food and Agriculture* 76: 593-598.

Trefny, D., Sova, Z., Mader, P. (1989). Vitaminy A, E, karotenoidy a cholesterol jaka ukazatele biologicke hodnoty krutich nasadovych valec. *Sbornik Vysoke Skoly Semed v Praze. Fakultet Agronomy R. B.* 50: 19-28.