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The selenium intake of the female chicken influences the selenium status of her progeny

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Abstract

The primary purpose of this study is to determine the extent to which the effects of dietary supplementation of the female chicken with selenium (Se) continue into the next generation. An additional aim is to compare the relative effectiveness of pre-hatch (from the hen's diet) with that of post-hatch (from the progeny's diet) supplementation with Se on the Se status of the chick during the first 4 weeks of post-hatch life. Hens were maintained on control or Se-supplemented diets, respectively containing 0.027 and 0.419 μg Se/g of feed. The high-Se diet elevated the Se content of the hens' eggs by 7.1-fold. At hatch, the concentrations of Se in the liver, breast muscle and whole blood of the chicks originating from the high-Se parents were, respectively, 5.4-, 4.3- and 7.7-fold higher than the values in the chicks of the low-Se parents. When the offspring from the two parental groups were both maintained on the low-Se progeny diet, the tissue Se concentrations in chicks originating from the high-Se hens remained significantly higher for 3–4 weeks after hatching, compared with the values in chicks from the low-Se hens. Similarly, tissue glutathione peroxidase activity remained significantly higher in chicks from the high-Se hens for 2–4 weeks post-hatch. Thus, the effects of maternal Se supplementation persist in the progeny for several weeks after hatching. However, when chicks hatching from low-Se eggs were placed on a high Se diet, their tissue Se concentrations at 7 days of age were markedly higher than the values in chicks from high-Se eggs placed on the low-Se diet.

Keywords: Antioxidants; Chicken; Egg; Glutathione peroxidase; Maternal effects; Selenium; Selenoproteins; Yolk

1. Introduction

The avian egg contains a wide range of nutrients to support the growth and development of the embryo to the time of hatch. However, the contribution made by the egg contents to the viability of the offspring is not confined to the embryonic period. Most notably, the residual yolk that is retracted into the body of the hatching chick continues to contribute to the general nutrition of the neonate for several days of post-hatch life (Speake et al., 1998). Other, more specific, examples of sustained maternal influences on neonatal function include yolk-derived antibodies that provide the progeny with passive immunity (Kowalczyk et al., 1985), and yolk-derived steroid hormones that regulate the development and behavior of the chick in some species (Schwabl, 1993).

Included among the many micronutrients that the female deposits into the egg are a number of compounds, such as vitamin E, carotenoids and selenium (Se), that provide the embryo with an integrated antioxidant system (Surai, 2002). In addition to protecting the embryonic tissues from the damaging effects of free radicals and reactive oxygen species that are inevitably generated by aerobic metabolism (Surai, 2000; Surai et al., 1996, 1999), these antioxidants also stimulate the development and function of the avian immune system (Marsh et al., 1986; Haq et al., 1996; Blount et al., 2003). During embryonic development, antioxidants are absorbed from the yolk (and also from the albumen in the case of Se) and distributed among the differentiating tissues (Gaál et al., 1995; Surai et al., 1996). However, the beneficial effects of egg-derived antioxidants do not necessarily stop when the chick hatches since these compounds may be retained to varying extents in the tissues of the chick for several days after it emerges from its shell (Surai, 2000; Karadas et al., 2005). The rate of post-hatch depletion of egg-derived vitamin E,

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carotenoids and Se from a tissue will depend on various factors including their utilization in redox reactions and/or their influx/efflux from the cells. During this time, the egg-derived antioxidants of the neonatal tissues will be replaced by vitamin E, carotenoids and Se provided from the diet of the chick. The effectiveness of this replenishment will depend, for example, on the concentrations of antioxidants in the dietary items selected by the chick and the efficiency of their digestion and absorption by the neonatal intestinal tract (Surai, 2002).

For a species such as the chicken, which produces precocial hatchlings, the role of antioxidants is likely to be particularly crucial during the hatching and early post-hatch periods due to the conjunction of two developmental features at this stage. Firstly, the rate of aerobic metabolism accelerates dramatically during hatching to meet the needs of locomotion and endothermy (Hohtola and Visser, 1998). Together with the sudden exposure of the chick to atmospheric oxygen, this is highly likely to stimulate the generation of reactive oxygen species. Secondly, the cell membrane phospholipids of several tissues, including the brain and skeletal muscle, are especially enriched in the omega-3 fatty acid, docosahexaenoic acid, by the end of the embryonic period (Speake and Wood, 2005). Since this highly unsaturated fatty acid is a prime target for peroxidative attack, its presence may promote the susceptibility of the tissues to the damaging effects of reactive oxygen species (Surai et al., 1996).

The question arises as to the most effective way for the newly hatched chick to achieve an effective antioxidant defense. Perhaps the most obvious strategy is via post-hatch nutrition, so that antioxidants are acquired from the chick's diet contemporaneous with the critical period of oxidative stress. The effectiveness of this direct approach would depend on the efficiency of absorption and on the time needed to accumulate sufficient levels of antioxidants in the tissues. Alternatively, the antioxidant system could be established in advance during the embryonic period, utilizing the micronutrients present in the egg, and ultimately dependent on the maternal diet. Although this strategy would provide the newly hatched chick with a pre-established antioxidant system, its efficacy would diminish with post-hatch age as the egg-derived antioxidants are depleted from the tissues. In reality, both systems are likely to operate together, particularly in species where the mother and her chicks consume similar diets. In this scenario, it might be envisaged that the effects of maternal diet would initially predominate, whereas the diet of the progeny would assume increasing importance with age.

We have recently evaluated the relative importance of pre-hatch (from the hen's diet) vs. post-hatch (from the progeny's diet) supplementation with carotenoids in determining the carotenoid status of the chicken during the first 4 weeks of post-hatch life (Karadas et al., 2005). It was demonstrated that maternal diet is the main determinant of the progeny's carotenoid status for at least 7 days after hatching, whereas the effects of the post-hatch diet only begin to predominate at some stage between 7 and 14 days. Hence, the maternal intake of carotenoids is the most effective way influence the concentration of these lipid-soluble antioxidants in the tissues of the offspring during the critical period of early post-hatch life.

The present report is concerned with the trace element Se, an essential component of the antioxidant enzyme glutathione peroxidase (GPX). Se is present in GPX as a constituent of the amino acid selenocysteine, located at the active site of the enzyme where it plays a pivotal role in a redox reaction (Hatfield and Gladyshev, 2002). The GPX family of enzymes are crucial players in the integrated antioxidant system, neutralizing potential threats to the integrity of cellular macromolecules by eliminating hydrogen peroxide and detoxifying lipid hydroperoxides (Brigelius-Flohe, 1999). Se derived from the diet of the female bird is deposited in the egg and is distributed among the developing tissues during embryogenesis (Gaál et al., 1995; Surai, 2000; Paton et al., 2002). Consequently, GPX is expressed in the chicken embryo in a tissue- and stage-specific manner (Wilson et al., 1992; Gaál et al., 1995; Surai, 1999). Supplementary Se in the diet of the hen was shown to increase the concentration of this element in the egg and in the tissues of the chick at hatch, and to elevate the expression of GPX, while reducing the generation of lipid peroxides in the liver of the day-old chick (Surai, 2000; Paton et al., 2002).

The present study was designed to determine the extent to which the effects of maternal Se supplementation, as evident in the day-old chicks (Surai, 2000; Paton et al., 2002), are sustained into the post-hatch life of the progeny. The relative effectiveness of pre-hatch vs. post-hatch Se supplementation in optimising the Se status of the progeny was also evaluated. Some preliminary aspects of this work have been reported in the form of a conference abstract (Pappas et al., 2005a).

2. Materials and methods

2.1. Dietary treatments

Domestic chickens (*Gallus gallus*) of the Hubbard–ISA broiler breeder strain were maintained from 39 weeks of age on either a control diet formulated for broiler breeders or on the same diet supplemented with additional Se from a yeast source, Sel-Plex® (Alltech Inc, Nicholasville, KY, USA). The control diet for the hens consisted of (wt.%) wheat (56.4), soybean meal (20.8), oat hulls (7.4), soya oil (5.5), limestone (7.9), monodical phosphate (1.0), NaCl (0.3), methionine (0.2) and Se-free vitamin–mineral premix (0.5). In contrast to commercial practice, no supplementary Se was added to the control diet, thus providing a low-Se basal diet containing only the Se that is endogenous to the wheat, soybean meal and oat hulls of the feed (Pappas et al., 2005b). The supplemented diet contained Sel-Plex® at 0.02% (w/w) of the feed. This supplement provides Se in the organic form, with selenomethionine, selenocystine, selenocysteine, selenocystathione and methylselenocysteine respectively forming 50%, 15%, 15%, 10% and 10% (w/w) of the total (Mahan, 1999). The Se contents of the control and supplemented diets were (μg/g) 0.027 and 0.419, respectively, measured as described below. The supplemented diet thus provided 15.5 times more Se than