Current advances in selenium research and applications

edited by:

Peter F. Surai

Jules A. Taylor-Pickard

Wageningen Academic
Publishers

Selenium-enriched eggs: from niche market to main stream

T.T. Papazyan[1], V.I. Fisinin[2] and P.F. Surai[3-6]
[1]Alltech Russia, Moscow, Russia
[2]All-Russian Institute of Poultry Husbandry, Sergiev Posad, Russia
[3]Avian Science Research Centre, SAC, Auchincruive, Ayr, United Kingdom
[4]Department of Environmental and Evolutionary Biology, University of Glasgow, Glasgow, United Kingdom
[5]Department of Nutrition, Szent Istvan University, Godolo, Hungary
[6]Trakia University, Stara Zagora, Bulgaria

1. Introduction

Chicken's eggs have been used as a food by human beings since antiquity. Compared with the hen's egg, no other single food of animal origin is eaten by so many people all over the world and none is served in such a variety of ways. Its popularity is justified not only because it is so easy produced and has so many uses in cookery, but also because of its nutritive excellence. From a nutritional point of view, wide use of eggs in the human diet is well deserved. Of the three most important dietary essentials – proteins, fats, and carbohydrates – the egg is composed largely of the first two. The nutritive excellence of the egg enhances the value of any food in which it is incorporated. Its wide use in cookery for purposes of leavening, thickening, binding, and emulsifying considerably improves the human diet. Its proteins are highly digestible and remarkably complete, containing the most important essential amino acids. The egg amino acid profile is similar to the ideal balance of amino acids needed by men and women. It also supplies various minerals and contains a range of vitamins. However, egg contribution as a source of minerals in human diet is only about 1-3% of total mineral consumption. Indeed mineral manipulation of the egg is quite difficult task since their delivery to the egg is regulated by different physiological mechanisms making sure that the embryo is not exposed to toxic levels of the minerals in normal physiological conditions. Therefore, it is practically impossible to increase the level of zinc, cupper or iron in the egg to such an extent that they would be considered as an important source of these minerals in the human diet. On the other hand, the situation with Se is different one, since Selenomethionine (SeMet) can be incorporated into egg proteins and Se content of the egg can be manipulated. Indeed, the development of the technology of production of Se-yeast gave an opportunity to substantially increase Se concentration in the egg to such an extent that a single egg can deliver 50% RDA in selenium. In fact, in conditions of global Se deficiency production of Se eggs could be considered as an important step towards solving this problem.

2. Selenium-enriched products

Several important factors must be considered when choosing the best food supplementation strategy for a given population. Such factors are shown in Table 1. In general, main sources of dietary selenium could differ between different countries. For example, in the UK meat and meat products provide 32% daily Se consumption and dairy products and eggs are responsible for 22% Se consumption (BNF, 2001). In contrast, in Russia about 50% Se in the diet originates from bread and cereals and meat, milk and eggs provide about

Table 1. Some characteristics of food choice for selenium-enrichment (adapted from Yaroshenko et al., *2003).*

The food should be	Comments
A part of traditional meals for the population	It would be counter-productive to attempt a change in culturally-based food habits by introducing a new type of food. Emphasis should be given to the possibilities of changing composition of existing foods such as by selenium enrichment.
Consumed regularly in a moderate amount	Since the objective is to deliver the amount of selenium needed to meet RDA it is necessary to choose food which is consumed regularly in moderate amount. Over-supplementation is unnecessary and undesirable.
Consumed by the majority of the population	This is particularly important given that immune function is more likely to be compromised in groups such as children and the elderly.
Affordable	Affordability of food would play an important role in the consumer choice.
Enriched with other health-promoting nutrients that are in short supply in the same population	Examples of minerals critical to health that are frequently deficient include iron and iodine. Vitamin E and lutein are also in short supply in the human diet. This can give a greater improvement in the diet.
Supplying a meaningful amount of the nutrient (e.g. at least 50% RDA)	This is an important point that distinguishes true functional foods from products that include 'tag-dressing' amounts of nutrients for advertising purposes.

20%, 10% and 5% daily Se consumption respectively (Golubkina *et al.*, 2002). In the USA beef, white bread, pork, chicken and eggs account for half of the Se in the diet (Schubert *et al.*, 1987). In Ireland, meat and meat products (30%), bread and rolls (24%), fish/fish products (11%), and milk and yoghurt (9%) were the main contributors to mean daily Se intake (Murphy *et al.*, 2002). In Japan in the mountain community, fish made the largest contribution to dietary selenium intake (48.2% of daily total), followed by eggs (24.3%), and meat (17.0%). In the coastal community, fish accounted for 57.7% of daily total selenium intake, followed by meat (17.5%), and eggs (16.1%). In both districts, the total contribution of rice and wheat products was around 10% (Miyazaki *et al.*, 2004).

Among animal-derived products, the egg is ideally suited to meet the list of requirements mentioned in Table 1. The egg is a traditional and affordable food in most countries and is consumed by people of all ages more or less regularly and in moderation. It is also a very safe vehicle for supplementation and there is an option of simultaneous enrichment of eggs with several important nutrients, including omega-3 fatty acids, vitamin E, carotenoids (Surai and Sparks, 2001; Surai, 2002) and with a single egg it is possible to deliver about 50% of the RDA for selenium. It seems likely that pork, beef, chicken and milk can also be enriched with selenium.

3. Improving the image of the egg

The main problem with eggs' consumption is that the image of the egg in the mind of the consumer is not necessarily always good. Despite the nutritious qualities of the egg, its comparatively high content of cholesterol has been the driving factor causing declining egg consumption for the last 20 years. Indeed, purchases of eggs for household consumption in the UK fell by 54% between 1975 and 1993 and by 9% between 1993 and 2000 (Buttriss, 2002). The problem started when cholesterol was implicated as an important risk factor of coronary heart disease (CHD), the leading cause of death in developed countries. The direct relationship between the levels of plasma cholesterol and atherosclerosis was experimentally demonstrated in an animal model (rabbits) 95 years ago (Anischenkow and Charlatov, 1913). Since that time numerous studies have been devoted to that subject. In particular, a consistent correlation was found between levels of total cholesterol and CHD in populations living in different countries (Keys, 1980). Therefore, dietary cholesterol became the centre of attention because of its association with heart vascular disease development. That information provided the stimulus for mass media blaming cholesterol for many pathological conditions in the human body. Eggs also were included in a category of 'bad food'. Indeed, even today going to a book store in the UK or USA and trying to find a single book describing all benefits of eggs is almost impossible task to accomplish. On the other hand, mass media are promoting cooking without eggs, no egg cooking recipes, etc. Even now, many dieticians and doctors still recommend to lower egg consumption to avoid excess of cholesterol in the diet.

Indeed, it was initially believed that egg consumption was associated with a rise in blood cholesterol (Yaffee *et al.*, 1991) and as a consequence was deleterious to health and life expectancy. The situation deteriorated when problems with egg contamination with *Salmonella* were reported publicly. In the wake of health fears, whole egg consumption in Britain has fallen by almost half, from more than three eggs a week to 1.70 eggs/week. Similar decreases in egg consumption have been reported in other countries, including the US (Stadelman, 1999; Lewis *et al.*, 2000). The proliferation of magazine articles and public statements by organisations such as the American Heart Association relating eggs to blood cholesterol and heart disease caused a downward trend in egg consumption (McIntosh, 2000).

However, our understanding of cholesterol metabolism has substantially improved since the initial furore over cholesterol, food animal products and heart disease. Knowledge of reverse cholesterol transport by HDL from the vessel wall to the liver for the catabolism (Lacko and Pritchard, 1990) was an important milestone changing the current views of cholesterol intake. Dietary cholesterol is not regarded anymore as the major determinant of the cholesterol level in the blood. There are other more important determinants of this parameter such as saturated fat intake. More is also known about the development of coronary heart disease (Shaper, 1987). Furthermore, more detailed analyses of many cholesterol-lowering trials showed that a decreased coronary morbidity did not reflect changes in total mortality (Libbi *et al.*, 2000), which was not changed. Furthermore, after analysing results from 27 studies involving 30,902 person-years of observation, Hooper *et al.* (2001) concluded that alterations of dietary fat intake had a positive effect on cardiovascular events but practically no effect on total mortality. Correlations drawn between nutrient intakes and longevity in the Japanese since WWII illustrate this point. It was found that sufficient intakes of animal protein and fat are crucial for attaining longevity (Shibata, 2001). It is interesting that low serum cholesterol was deleterious for higher levels of functional capacity and accelerated depressive status in the elderly in the community. High intakes of milk and fats and oils had favourable effects on 10-year (1976-1986) survivorship in 422 urban residents aged 69-71 (Shibata *et al.*, 1992). The survivors revealed a longitudinal increase in intakes of animal foods such as eggs, milk, fish and meat over the 10 years. Furthermore, an increase in total cancer mortality in lung, prostate and colon was observed in men >60 years of age with low plasma cholesterol in Switzerland (Eichholzer *et al.*, 2000). Cholesterol level and mortality rates in the elderly population (over 85 y old) followed for 10 years in the Netherlands with a conclusion that both cancer mortality and mortality from infectious diseases were higher when serum cholesterol was lower. In the study, all causes of mortality were negatively correlated with serum cholesterol level (Weverling-Rijnsburger *et al.*, 2002). Similar results were obtained in another study. Lipid and serum cholesterol concentrations were measured in 3572 Japanese/American men (aged 71-93 years). Changes in these concentrations were recorded over 20 years with all-cause mortality (Schatz *et al.*, 2001). Age-adjusted mortality rates were 68.3, 48.9, 41.1, and 43.3 for the first to fourth quartiles of cholesterol concentrations, respectively. Relative risks for mortality were 0.72, 0.60 and 0.65, in the second, third, and fourth quartiles, respectively, with quartile 1 as reference. These data cast doubt on the scientific justification for lowering cholesterol to very low concentrations in elderly people. Indeed, in a recent review paper of Hamazaki and Okuyama (2007) the same conclusion was drawn: cholesterol-reducing diets might increase the risk of acute myocardial infarction nearly three times. Furthermore, cholesterol lowering with statins does not appear to be a very effective way of reducing CHD mortality (De Lorgeril and Salen, 2007).

Results of many recent studies have shown that large numbers of eggs can be consumed over lengthy periods without adverse changes to plasma cholesterol or other lipid components. Furthermore, it is a general misconception that elevated plasma cholesterol represents the main atherogenic stimulus. It seems likely that the time has come to reconsider the egg's image and to distinguish between scientific fact and conjecture. For example, a study involving 37,850 men and 80,082 women concluded that the consumption of up to one egg per day was unlikely to have a substantial overall impact on the risk of cardiovascular disease or stroke among healthy men and women (Hu *et al.*, 1999). Furthermore, when dietary confounding factors were considered, no association was found between egg consumption at levels up to one egg per day and the risk of coronary heart disease in non-diabetic men and women (Kritchevsky and Kritchevsky, 2000). Conclusions from a review of epidemiological and clinical data published by McNamara (2000b) was that 'for the general population, dietary cholesterol makes no significant contribution to atherosclerosis and risk of cardiovascular disease'. These suggestions are in line with a finding that consumption of three eggs per day for 30 days by pre-menopausal women did not increase the risk of developing an atherogenic lipoprotein profile (Herron *et al.*, 2002). From another analysis of data summarising 166 cholesterol-feeding studies conducted over the past 40 years in 3,500 subjects, it was concluded that there was little justification for restriction in egg consumption for general healthy individuals (McNamara, 2000a). It is interesting to mention that the three countries (France, Mexico and Japan) are characterised by highest egg consumption and lowest CVD-mortalities (De Meester, 2007). Once the public image of the egg is changed for the better, there are many opportunities to produce 'designer eggs' enriched with various nutrients with health-promoting properties.

4. Selenium-enriched eggs as a route toward improving human selenium status

Before the advent of commercially available organic selenium for food animal diets, the main problem as regards the enrichment of eggs with selenium was the low efficiency of transfer of inorganic selenium (selenite or selenate) to the egg. In fact, even high doses of selenite in the diet of laying hens were not able to substantially enrich eggs with this trace element (for review see Surai, 2002; 2006). The concept of producing Se-enriched eggs first originated from the Scottish Agricultural College in 1998 (Surai, 2000). Indeed, a wide introduction of organic selenium in the form of Sel-Plex into poultry diets was a revolutionary decision making it possible to produce eggs containing increased Se concentration. Since the main form of Se in the egg is SeMet and chicken cannot make this essential amino acid, inclusion of sodium selenite into the chicken diet has limited ability to enrich eggs with this element. On the other hand, SeMet from Sel-Plex is effectively transferred to egg yolk and egg albumin giving an opportunity to produce Se-eggs. At that time many publications in the media around the world made the first step towards the commercial production of Se-enriched eggs. Later it was proven that the consumption of such eggs could be a good source of Se for humans (Surai *et al.*, 2004) and could help to solve the global Se deficiency. Today, Se-enriched eggs are produced in more than 25 countries world wide, but the Eastern European countries have progressed the most in this regard (Table 2). For example, Russia keeps a special place being the most advanced country in this business. Indeed, in 2006 Russia produced about 38 billion eggs and more than 20% of poultry farms produce various modified eggs including Se-eggs (Fisinin, 2007). There are more than 20 poultry farms in Russia producing Se-eggs commercially. They are situated in various regions of the country ranging from St. Petersburg up to Siberia and the Far East. Generally they are not competing

Table 2. Some examples of selenium-enriched eggs produced in various countries.

Brand name of Se-eggs	Country
Columbus	UK, Belgium, Netherlands and other countries
Origin	Northern Ireland
Mega-Eggs	Ireland
NutriPlus	Malaysia
LTK Omega Plus	Malaysia
Selenium Plus	Malaysia
TPC Egg with Organic Selenium	Malaysia
Selen Egg	Thailand
Doctor Hen Egg	Thailand
Omax	Thailand
Bounty Eggs	Philippines
Organic Selenium Egg	Singapore
Bon Egg	Columbia
Avinal	Columbia
Mr Egg	Mexico
Heart Beat eggs	New Zealand
Tavas Yumurta	Turkey
Seker Yumurta	Turkey
Selenyum eggs	Turkey
NutriPlus	Portugal
Omega Pluss	Hungary
Welness Tojas	Hungary
Vi Omega-3	Greece
Splepacich Vajec Eggs	Slovakia
Imperial's eggs	Indonesia
Selenium eggs	Korea
Saguna Active eggs	India
Ecoeggs	Australia
Bag of Life (Koshik zhitja)	Ukraine
Eggs for Prince (Kniazivskiye)	Ukraine
Spring of Life (Dzherelo zhitja)	Ukraine
Rejuvenating (Molodiljnije)	Russia
Aksais' sun (Aksaiskoyè solnishko)	Russia
Spring of cheerfulness (Rodnik bodrosti)	Russia
Khokhlatka eggs (KhoKhlatka)	Russia
Cheerful egg (Bodroe)	Russia

Table 2. Continued.

Brand name of Se-eggs	Country
Universal (vSELENskoye)	Russia
Cossack Village Egg (Stanichnije)	Russia
Strong eggs (Silnoye)	Russia
Selena eggs (Selena)	Russia
Aktivita	Russia
Dr. Selenium	Russia
Oval Wonder	Russia
Tomorrow's eggs	Russia
Mettlesome eggs (Molodetskoye)	Belarus

with each other on the local markets. In most instances, these eggs are sold with distinguishable names and brands including 'Rejuvenating', 'Aksais's sun', 'Spring of Cheerfulness', 'Universal', 'Cossack Village Eggs', 'Oval Wonder', 'Strong eggs', 'Activita', 'Selena', 'Healthy Selenium'. The level of Se delivered in a single egg varies from 20 up to 35 μg. In many cases eggs are simultaneously enriched with vitamin E, however, as a rule, the amount of vitamin E delivered from a single egg is less than 30% RDA. Prices for Se-enriched eggs vary and are usually higher by 10-50% in comparison with normal table eggs. The level of production of Se-eggs as a percentage of total egg production on these farms varied from 1 to approximately 20%.

It seems that Se in eggs is highly available. For example, a recent clinical trial conducted in the Ukraine showed that consumption of two Se-enriched eggs per day for eight weeks significantly increased the Se level of the plasma of volunteers (Surai *et al.*, 2004). In fact sixty volunteers (30 in control and 30 in experimental group) successfully finished the trial. Eggs consumed in the control group contained 7-9 μg Se/egg and experimental eggs were enriched with selenium (28-32 μg Se/egg). Blood was collected before the beginning and at the end of experimental period and Se was determined in plasma by hydride generation atomic absorption spectrometry with fluorometric detection. The level of selenium in plasma of volunteers living in the Kiev area of Ukraine (0.055-0.081 μg /ml) was on the low side of the physiological range and was somehow lower than we reported earlier in volunteers in Scotland (Surai, 2000). Consumption of commercially available eggs for eight weeks only slightly increased Se in plasma, which reached physiological level (0.075-0.085 μg/ml).

In contrast, consumption of two eggs daily, which together delivered the daily requirement of 55-65 μg Se, for eight weeks, was associated with a significant increase in Se concentration in plasma. Plasma Se reached 0.09-0.14 μg/ml, indicating improving Se status of volunteers (Surai *et al.*, 2004). This is the first clinical trial to prove that selenium-enriched eggs could be used as an important vector to improve selenium status in countries with low Se consumption like Scotland or Ukraine. Se availability from eggs for human needs further elucidation and effect of different dietary sources of Se on its concentration in plasma probably depends on the Se status of the human. After the successful clinical trial with Se-enriched eggs in Ukraine Se-egg production has been developed by the Langut Ukraine, a company located in the Kiev region. The egg under the brand 'Bag of Life' and a trade mark 'Eggs from a good hen' are produced at the level of 1.2 million eggs daily and sold all over the Ukraine. In fact, all of the eggs which are produced by the company are Se-enriched. A single egg delivers about 30-35 μg Se (50% RDA), about 15-20 mg vitamin E (100% RDA) and is also enriched with natural carotenoids. This development is very important for this region. From the one hand Se deficiency was documented in people working in Chernobyl area (Tutelyan *et al.*, 2002; Golubkina *et al.*, 2002). On the other hand selenium and other antioxidants can be especially beneficial for people living in radionuclide-contaminated areas of the Ukraine.

In the UK the only designer egg available through the major supermarkets is the 'Columbus' egg produced by the Belgium company Belovo. These eggs, enriched in n-3 fatty acids and vitamin E, first appeared in Belgium in 1997, and since then they have been sold in the UK (1998), Netherlands (1999) and India, Japan and South Africa (2000). Currently, production of the Columbus egg exceeds 50 million eggs per year in Europe. To satisfy consumer demand in the UK, free range Columbus eggs enriched with n-3 PUFAs, vitamin E and selenium are also on the supermarket shelves. These eggs are characterised by a balanced nutritional lipid composition (C18, n-6: n-3=1: 1) and a favourable structural lipid ratio (long-chain PUFA, n-6: n-3 = 1: 3). When fed to selected groups of people, Columbus eggs have been shown to improve the circulating cell membrane fatty acid composition by favourably altering the n-6: n-3 ratio (De Meester *et al.*, 1998; De Meester, 2007). The level of alpha-linolenic acid in Columbus eggs is about 12.6% while DHA comprises about 2% of total fatty acids in the egg yolk. Therefore, these eggs could adjust a diet toward recent nutritional recommendations regarding dietary fatty acid profiles. In particular it is recommended linoleic acid: alpha-linolenic acid ratio in the diet to be 5: 1-10: 1 with n-3 PUFA to provide 0.4-2% of total energy (FAO, 1998). Indeed a concept of producing eggs similar to the composition of those in wild developed by the company is proven to be successful. In fact a combination of omega-3 fatty acids and antioxidants in the same egg is shown to be beneficial (Surai, 2002).

It is interesting to note that practically all of the aforementioned Se-eggs are produced using Se-yeast in the form of Sel-Plex as a major source Se for laying hens at the level of 0.3-0.5 ppm. One important advantage for Russia and the Ukraine in terms of Se-egg production is that they do not need to comply with EU feed additive legislation for local use and they also have strong marketing support. An egg is a safest way of Se delivery for human. For example, Se-enriched eggs, as a rule, contain up to 30 μg Se per egg. Since maximum safe dietary Se intake (mean NOAEL: no observed adverse effect level) is 819 μg (Whanger, 2004), therefore to have any detrimental effect from Se overdose one must consume more than 25 eggs a day for a long period of time. If we take into account maximum safe dietary Se intake identified by Food Nutrition Board (2000) to be 400 μg, one can consume 13 eggs a day for a long period of time, a situation difficult to imagine. In most of European countries egg consumption is less than 1 egg/day. Therefore, the safety margin here is more than 10-fold.

Our observations with Se-egg production in various countries indicate the following:
1. Cost involved in Se-egg production does not exceed 2% of total feed cost.
2. Sel-Plex supplementation of the laying hens is associated with increased egg production, better shell quality, internal egg quality (Hough Units) and improved FCR. These parameters pay money back and give profit at the level of 1: 3-5. Therefore a label 'Se-enriched' is usually free of charge and can be used as an effective marketing tool for egg promotion.
3. Additional inclusion of Se to already existing modified eggs (omega-3, vitamin E-enriched, iodine-enriched, etc.) can further enhance their quality and marketing potential without substantial increase in price.
4. Labelling regulations differ substantially from country to country, however, two-fold increase in Se content of the egg would fit to 'Se-enriched' category of the most European and other countries.
5. Some countries (e.g. Eastern European and Asian) allow claiming health benefit of Se, but in most of countries it is only possible to put level of Se on the label and give a comparison to RDA. It seems likely, that even such a labelling would be a great advantage for producers.

The prospects for increased production of Se eggs in Europe are great and a major limitation in Se-egg production is a lack of public knowledge concerning the beneficial effects of Se in relation to human health. Indeed, the companies producing Se-eggs should invest more into the public education to widen the market for Se-eggs. It is important to mention that in many countries there are several different competitive companies producing Se-enriched eggs. For example in Russia Seimovskaya poultry farm (Nizni Novgorod region) produces about 65,000 Se-enriched eggs per day, while Magnitogorskaya (Magnitogorsk city), Aksaiskaya (Rostov region), Voktinskaya (Izhevsk region) and Volzhaninskaya (Yaroslavl region) poultry farms produce 40,000; 30,000; 15,000 and 10,000 Se-enriched eggs daily. In Belarus, Soligorskaya (Minsk region) poultry farm produces about 40,000 Se-enriched eggs daily. Se concentration in those eggs in Russia and Belarus varies in a range of 20-30 μg/egg. Similar range of Se in Se-enriched eggs can be found in other countries with a target to achieve a 50% RDA in Se with a single egg. There is also a possibility to produce eggs with much higher Se content. For example, Combs (2000a) reported that using selenium in the form of high-quality Se-enriched yeast in the chicken diet at the level 1.2 ppm it is possible to achieve Se content in the egg up to 200 μg. If egg selenium content is enhanced along with increased levels of omega-3 PUFAs and vitamin E (Columbus) or vitamin E and specific carotenoids (Super eggs, Surai, 2001) in levels comparable with RDA, this could further widen opportunities for producers and consumers to meet specific nutrient demands that aid in maintaining a healthy life style. There is also an opportunity to produce Se-enriched quail eggs which can already be found on supermarket shelves in Ukraine and Belarus.

5. Selenium-enriched eggs as functional food

The concept of healthy food additives arrived from Japan in the 1970s and the term 'Functional Foods' appeared in 1984 (Harris, 2000). At this time consumers began to view food from a radically different point. This 'changing face' of food led to the development of a new area in the food and nutrition sciences known as functional foods (Hasler, 2000). The Food and Nutrition Board of the National Academy of Sciences defines a functional food as one that encompasses potentially healthy products providing health benefits beyond that of the traditional nutrients it contains (Milner, 2000). The term 'nutraceutical' was introduced in 1989 by the Foundation for Innovation in Medicine and defined as 'any substance that may be considered a food or part of a food and provides prevention or/and treatment of disease' (Andlauer and Furst, 2002). Therefore, nutraceuticals may range from isolated nutrients, dietary supplements and diets to genetically engineered 'designer' foods, herbal products and processed products such as cereals, soups and beverages.

Indeed, the ongoing research will lead to a development of a new generation of foods, which will connect food and drug into the same category. Today public health authorities consider disease prevention and treatment with nutraceuticals as a powerful instrument in maintaining health and to act against nutritionally induced acute and chronic diseases, thereby promoting optimal health, longevity and quality of life (Andlauer and Furst, 2002). This is in agreement with the data of the 1998 USA study from written questionnaires, completed by 2,074 respondents indicating that most shoppers believe foods can offer benefits beyond basic nutrition to functional nutrition for disease prevention and health enhancement (Gilbert, 2000). However, a recent USA survey reported that taste is the primary influence on food choice, followed by cost (Glanz *et al.*, 1998). Today, functional foods have received substantial attention (Mazza, 1998; Reilly, 1998) and represent one of the fastest growing segments of the world food industry (Harris, 2000). For example, recently published Dictionary of Nutraceuticals and Functional Foods (Eskin and Tamir, 2006) provides science-based information on over 470 nutraceutical and functional foods products and compounds with information on the product or compound role in the promotion of health or the prevention of disease. Many progressive nutritionists and healthcare professionals have responded to the growing interest in natural products by emphasising the roles of proper diet and nutrition, and prescribing the 'nutraceutical' benefits of many foods.

There are three major reasons for the increased interest in functional foods (Milner, 2000):
- increased health care costs;
- recent legislation; and
- scientific discoveries.

Recently, six major targets in relation to functional food science have been identified (Roberfroid, 2000):
- gastrointestinal functions;
- redox and antioxidant systems;
- metabolism of the macronutrients;
- development in foetal and early life;
- xenobiotic metabolism and its modulation;
- mood and behaviour or cognition and physical performance.

In the same review the author has stated that the 'health benefit of a functional food will be limited if the food is not part of the diet'.

European legislation does not consider 'functional foods' or 'nutraceuticals' as specific food categories. There is not, as such, a regulatory framework for 'functional foods' or 'nutraceuticals' in EU Food Law. The rules to be applied are numerous and depend on the nature of the foodstuff. The rules of the General Food Law Regulation, including responsibility for food safety, traceability, recall and notification, definitely are applicable to all food (Coppens *et al.*, 2006). Therefore, the cornerstone of EU legislation on food products, including functional foods and nutraceuticals is 'safety'. As mentioned above, nutraceutical ingredients and functional foods, legally defined as natural substances that may be used individually, in combination, or even added to food or beverage for a particular technologic purpose or health benefits. They must have an adequate safety profile demonstrating the safety for consumption by humans. Indeed, risk of toxicity or adverse effects of many medical drugs led scientists and medical doctors to consider safer nutraceutical and functional food based approaches for health management. In fact, the option of health and disease management by natural means has been embraced by a large fraction of the world population (Bagchi *et al.*, 2004; Bagchi, 2006).

Se-egg is perfectly fitted into the category of functional/nutraceutical food:
1. A single egg can deliver 50% RDA in Se and since most of the European countries are Se-deficient (Surai, 2006), this could have additional benefits, beyond those provided by normal eggs.
2. Eggs are an essential parts of many different foods and dishes and therefore could enhance their quality beyond nutritive value.
3. Se-enriched eggs could have a substantial effect of gastro-intestinal functions (one of the direction of functional food mentioned above) providing Se for GI-GSH-Px, which is responsible for prevention of oxidised lipid absorption and probably protecting against heart diseases and cancer. Furthermore, Se delivered with eggs could have beneficial effect on antioxidant-prooxidant balance in the intestine improving general health (Surai, 2006).

6. Conclusions

Analysis of literature presented above clearly indicate that new trends in the egg production are associated with quality issues. Indeed, for many years animal industry was driven mainly by consumer demands on quantity and price. Quality issues were overshadowed by increasing demands. However, time has come to reconsider sèveral important issues. Indeed, decreased Se levels in feeds and foods in many cases reflect consequences of our agricultural practises. For example, usage of inorganic fertilisers rich in sulphur and phosphorus interferes with Se assimilation from soil as well as soil acidification decreases Se availability. 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 back to nature. Therefore Se-enrichment of eggs, is nothing else but production of naturally-designed food ingredients. Indeed, production and commercialisation of such organic Se sources as selenised yeast (for example Sel-Plex^{TM}) opened a new era in Se supplementation of animals and gave a real chance for producers to meet growing requirements of consumers. What is more, production of these kind of animal-derived foodstuffs is a natural way to health promotion.

References

Anitschenkow, N. and Chalatow, S. (1913). Uber experimentelle Cholester-insteatose und ihre Bedeutung fur die Entsteihung einiger pathologischer Prozesse. *Zentralblatt Fur Allgemeine Pathologie* 24: 1-9.

Andlauer, W. and Fürst, P. (2002). Nutraceuticals: a piece of history, present status and outlook. *Food Research International* 35: 171-176.

Bagchi, D. (2006). Nutraceuticals and functional foods regulations in the United States and around the world. *Toxicology* 221: 1-3.

Bagchi, D., Preuss, H.G. and Kehrer, J.P. (2004). Nutraceutical and functional food industries: aspects on safety and regulatory requirements. *Toxicology Letters* 150: 1-2.

British Nutrition Foundation. (2001). Selenium and Health. Briefing paper, July 2001.

Buttriss J. (2002). Findings of the national food survey for 2000. *British Nutrition Foundation Bulletin* 27: 37-40.

Coppens, P, da Silva, M.F. and Pettman, S. (2006). European regulations on nutraceuticals, dietary supplements and functional foods: a framework based on safety. *Toxicology* 221: 59-74.

De Lorgeril, M. and Salen, P. (2007). Dietary prevention of coronary heart disease. In: *Wild-Type Food in Health Promotion and Disease Prevention. The Columbus Concept.* (Eds. De Meester, F. and Watson, R.), Humana Press, New Jersey, pp. 227-242.

De Meester, F., Stannard, J., Remacle, C., D'Hollander, F., Goerminne, X. and Erpicum, T. (1998). Columbus, the natural original egg a model for healthy animal-derived food *Leatherhead Food RA Food Industry Journal* 1: 289-300.

De Meester, F. (2007). Wild-Type Land-Based Food in health promotion and Disease prevention. In: *Wild-Type Food in Health Promotion and Disease Prevention. The Columbus Concept* (Eds. De Meester, F. and Watson, R.), Humana Press, New Jersey, pp. 3-20.

Eichholzer, M., Stahelin, H.B., Gutzwiller, F., Ludin, E. and Bernasconi, F. (2000). Association of low plasma cholesterol with mortality for cancer at various sites in men: 17-y follow-up of the prospective Basel study. *American Journal of Clinical Nutrition* 71: 569-574.

Eskin, N.A.M. and Tamir, S. (2006). *Dictionary of Nutraceuticals and Functional Foods*, CRC Press, Boca Raton, USA.

Fisinin, V.I. (2007). Research and commercial experience of the world and Rissian poultry production. In: *Proceedings of the 4th International Conference on Poultry Production*, Moscow, February 5-7, pp.10-33.

Food and Agriculture Organization/World Health Organization (1998). General conclusions and recommendations of the consultation. Expert Consultation on Fats and Oils in Human Nutrition'. Rome, FAO, pp. 3-9.

Food and Nutrition Board, Institute of Medicine (2000). Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids 2000. National Academy Press Washington, DC.

Gilbert, L.C. (2000). The functional food trend: what's next and what Americans think about eggs. *Journal of the American College of Nutrition* 19 (5 Suppl.): 507S-512S.

Glanz, K., Basil, M., Maibach, E., Goldberg, J. and Snyder, D. (1998). Why Americans eat what they do: taste, nutrition, cost, convenience, and weight control concerns as influences on food consumption. *Journal of the American Dietetic Association* 98: 1118-1126.

Golubkina, N.A., Slkalniy, A.V., Sokolov, Y.A. and Schelkunov, L.F. (2002). *Selenium in Medicine and Ecology*. KMK, Moscow

Hamazaki, T. and Okuyama, H. (2007). The Japanese experience: High cholesterol is not an important risk factor of all-cause mortality. In: *Wild-Type Food in Health Promotion and Disease Prevention. The Columbus Concept,* (Eds. De Meester, F. and Watson, R.), Humana Press, New Jersey, pp. 21-28.

Harris, C. (2000). Meat products are perfect as functional foods. *Meat Processing* Jan/ Feb. p. 19.

Hasler, C.M. (2000). The changing face of functional foods. *Journal of the American College of Nutrition* 19 (5 Suppl): 499S-506S.

Herron, K.L., Vega-Lopez, S., Conde. K., Ramjiganesh, T., Roy, S., Shachter, N.S. and Fernandez; M.L. (2002). Pre-menopausal women, classified as hypo- or hyperresponders, do not alter their LDL/HDL ratio following a high dietary cholesterol challenge. *Journal of the American College of Nutrition* 21: 250-258

Hooper, L., Summerbell, C.D., Higgins, J.P., Thompson, R.L., Capps, N.E., Smith, G.D., Riemersma, R.A. and Ebrahim, S. (2001). Dietary fat intake and prevention of cardiovascular disease: systematic review. *British Medical Journal* 322: 757-763.

Hu, F.B., Stampfer, M.J., Rimm, E.B., Manson, J.E., Ascherio, A., Colditz, G.A., Rosner, B.A., Spiegelman, D., Speizer, F.E., Sacks, F.R., Hennekens, C.H. and Willett, W.C. (1999). A prospective study of egg consumption and risk of cardiovascular disease in men and women. *Journal of the American Medical Association* 281: 1387-1394

Keys, A. (1980). *Seven Countries. A Multivariate Analysis of Death and Coronary heart Disease.* Harvard University Press, Cambridge, MA

Kritchevsky, S.B. and Kritchevsky, D. (2000). Egg consumption and coronary heart disease: an epidemiologic overview. *Journal of the American College of Nutrition* 19 (5 Suppl): 549S-555S.

Lacko, A.G. and Pritchard, P.H. (1990). International Symposium on Reverse Cholesterol Transport. Report on a meeting. *Journal of Lipid Research* 31: 2295-2209.

Lewis, N.M., Seburg, S. and Flanagan, N.L. (2000). Enriched eggs a source of n-3 polyunsaturated fatty acids for humans. *Poultry Science* 79: 971-974.

Libby, P., Aikawa, M. and Schonbeck, U. (2000). Cholesterol and athesosclerosis. *Biochemica et Biophysica Acta* 1529: 299-309.

Mazza, G. (1998). *Functional foods. Biochemical and processing aspects.* Lancaster-Basel, Technomic Publishing Co. Inc.

McIntosh, W.A. (2000). The symbolization of eggs in American culture: a sociologic analysis. *Journal of the American College of Nutrition* 19 (5 Suppl): 532S-539S.

McNamara, D.J. (2000b). Dietary cholesterol and atherosclerosis. *Biochimica et Biophysica Acta* 1529: 310-320.

McNamara, D.J. (2000a). The impact of egg limitations on coronary heart disease risk: do the numbers add up? *Journal of the American College of Nutrition* 19 (5 Suppl): 540S-548S.

Milner, J.A. (2000). Functional foods: the US perspective. *American Journal of Clinical Nutrition* 71: 1654S-1659S.

Miyazaki, Y., Koyama, H., Sasada, Y., Satoh, H., Nojiri, M. and Suzuki, S. (2004). Dietary habits and selenium intake of residents in mountain and coastal communities in Japan. *Journal of Nutritional Science and Vitaminology* 50: 309-319.

Murphy, J., Hannon, E.M., Kiely, M., Flynn, A. and Cashman, K.D. (2002). Selenium intakes in 18-64-y-old Irish adults. *European Journal of Clinical Nutrition* 56: 402-408.

Reilly, C. (1998). Se: A new entrant into the functional food arena. *Trends in Food Science and Technology* 9: 114-118.

Roberfroid, M.B. (2000). Concepts and strategy of functional food science: the European perspective. *American Journal of Clinical Nutrition* 71: 1660S-1664S.

Schatz, I.J., Masaki, K., Yano, K., Chen, R., Rodriguez, B.L. and Curb, J.D. (2001). Cholesterol and all-cause mortality in elderly people from the Honolulu Heart Program: a cohort study. *Lancet* 358: 351-355.

Schubert, A., Holden, J.M. and Wolf, W.R. (1987). Selenium content of a core group of foods based on a critical evaluation of published analytical data. *Journal of the American Dietetic Association* 87: 285-299.

Shaper, A.G. (1987). Environmental factors in coronary heart disease: diet. *European Heart Journal* 8 (Suppl E): 31-38.

Shibata, H. (2001). Nutritional factors on longevity and quality of life in Japan. *The Journal of Nutrition, Health & Aging* 5: 97-102.

Shibata, H., Nagai, H., Haga, H., Yasumura, S., Suzuki, T. and Suyama, Y. (1992). Nutrition for the Japanese elderly. *Nutrition and Health* 8: 165-175.

Stadelman, W.J. (1999). The incredibly functional egg. *Poultry Science* 78: 807-811.

Surai, P.F. (2000). Organic selenium: benefits to animals and humans, a biochemist's view. In: *Biotechnology in the Feed Industry. Proceedings of Alltech's 16th Annual Symposium* (Eds. Lyons, T.P. and Jacques, K.A.), Nottingham University Press, Nottingham, UK, pp. 205-260.

Surai, P.F. (2001). The 'super-egg'. *Biological Sciences Review* 13: 9-12.

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

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

Surai, P.F. and Sparks, N.H.C. (2001). Designer eggs: from improvement of egg composition to functional food. *Trends in Food Science and Technology* 12: 7-16.

Surai, P.F., Yaroshenko, F.O., Yaroshenko, Y.F., Karadas, F. and Sparks, N.H.C. (2004). Consumption of selenium-enriched eggs improves selenium status in human volunteers. *Proceedings of the XXII World's Poultry Congress*, Turkey (In press).

Tutelyan, V.A., Kniazhev, V.A., Hotimchenko, S.A., Golubkina, N.A., Kushlinskiy, N.I. and Sokolov, Y.A. (2002). *Selenium in human body: metabolism, antioxidant properties, role in cancerogenesis*. Russian Academy of Medical Sciences, Moscow.

Weverling-Rijnsburger, A.W., Blauw, G.J., Lagaay, A.M., Knook, D.L., Meinders, A.E. and Westendorp, R.G. (1997). Total cholesterol and risk of mortality in the oldest old. *Lancet* 350: 1119-1123.

Whanger, P.D. (2004). Selenium and its relationship to cancer: an update dagger. *British Journal of Nutrition* 91: 11-28.

Yaffee, M., Schutz, H., Stone, J., Bokhari, S. and Zeidler, G. (1991). Consumer perception and utilization of eggs and egg products. *Poultry Science* 70 (Suppl.1): 88.

Yaroshenko F.A., Dvorska J.E., Surai P.F. and Sparks N.H.C. (2003a). Selenium-enriched eggs as a source of selenium for human consumption. *Applied Biotechnology, Food Science and Policy* 1: 13-23.