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Nutritional composition of novel nutraceutical egg products developed with omega-3-rich oils

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ABSTRACT

The ω-3 fatty acids (ω-3 FAs)-fortified eggs are typically developed through alteration of hen feed. The present study aimed at creating ω-3 FAs-fortified egg products via processing. Novel, nutritionally-enhanced egg products were developed by substituting cholesterol-containing yolk with ω-3 FAs-rich flaxseed, menhaden, algae, or krill oil. Experimental egg products (egg whites, ω-3 oils, and annatto), whole egg, and liquid egg product (Egg Beaters™) were microwave-cooked, analyzed, and compared. Protein, fat, and moisture contents of experimental egg products matched ($P > 0.05$) whole egg. Cholesterol was the highest ($P < 0.05$) in whole egg (1.35 g/100 g, dry weight basis); while it ranged 0.01–0.24 g/100 g (dry weight basis) in experimental egg products. On a per egg basis, one whole egg contained 216 mg; while experimental egg products ranged 1–38 mg. The total ω-3 FAs content was the lowest ($P < 0.05$) in whole egg (5.9% of total FAs) and the highest ($P < 0.05$) in experimental egg products developed with krill oil (46.5%), followed by flax (43.1%), algae (DHASCO-42.5% and DHAS-39.5%), and menhaden oil (27.6%). The essential amino acid (EAA) content of experimental egg products was similar ($P > 0.05$) to whole egg except methionine, phenylalanine, and valine were generally greater in experimental egg products. Experimental egg products also had similar ($P > 0.05$) content of non-EAA to whole egg except alanine and glutamic acid were higher ($P < 0.05$); while arginine and cysteine were generally lower and higher in experimental egg products, respectively. However, total EAA, total non-EAA, and the ratio of total EAA to total AA were similar ($P > 0.05$) between experimental egg products and whole egg. Whole egg contained more ($P < 0.05$) Ca, P, and Fe, but less Mg than experimental egg products.

1. Introduction

The egg is one of the best and most inexpensive sources of high quality protein and contains a balanced distribution of various minerals and vitamins. For the last decade, American egg consumption has exceeded six billion dozen eggs per year, rendering eggs a staple food (USDA, 2009a). Eggs supply the human diet with all nine essential amino acids (EAA), making them an excellent source of high biological value (BV). The egg is frequently used as a reference for comparing the protein quality of other foods (Herron & Fernandez, 2004). However, one egg contains about 200 mg of cholesterol (Weggemans, Zock, & Katan, 2001), which nearly meets the dietary intake limit established by the American Heart Association at ≤300 mg/day. Dietary cholesterol increases serum total and LDL-cholesterol concentrations, which are risk factors for cardiovascular disease (CVD) (Howell, McNamara, Tosca, Smith, & Gaines, 1997). Furthermore, about half of the total fat in egg is saturated fat, another contributor to CVD (Hu et al., 1999). Fat, including cholesterol and saturated fat, is contained within the yolk; while egg white contains a negligible amount of fat.

Omega-3 fatty acids (ω-3 FAs) have demonstrated cardio-protective benefits. In addition to the reduction of CVD, consumption of ω-3 FAs decreases blood pressure, triglyceride, and inflammatory markers, improves endothelial function, reduces platelet aggregation and vasoconstriction, and decreases risk of sudden cardiac death (Juturu, 2008). Fish are the major dietary source of ω-3 FAs. Sources of plant-derived ω-3 FAs include flaxseed, walnuts, canola, soybean, and algae. Populations with total fat intake greater than 30% of total energy predominantly from fish and plant oils maintain low mortality from CVD (Psota, Gebauer, & Kris-Etherton, 2006).

Despite ω-3 FAs intake being beneficial to human health, the American diet is typically low in these essential nutrients (Arterburn et al., 2008). This has stimulated the progressive development of "nutraceutical/functional foods" or those containing added, technologically developed ingredients that have specific health benefits (Siro, Kapolna, Kapolna, & Lugasi, 2008). The ω-3

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FAs-fortified food products provide a means to achieve desired health effects of these nutrients without the ingestion of dietary supplements, medications, or a major change in dietary habits.

Dietary manipulation of the ω-3 FAs content of hens' diets has resulted in the production of eggs containing ω-3 FAs (Ferrier et al., 1995). In acceptability studies, U.S. consumers responded positively to ω-3-fortified eggs (Scheideler, Froning, & Cuppett, 1997). Eggs are not naturally rich in ω-3 FAs, although adding ω-3-rich ingredients such as flaxseed, algae, kelp, fish, and canola oils to chicken feed produces eggs with three or more times the normal amount of ω-3 FAs. However, even a three-fold increase should be considered relatively small, particularly when compared with the recommended daily intake for ω-3 FAs established by the governments of Canada, Scandinavia, and Britain, which recommend between 1000 and 2000 mg/day. The U.S. has not yet set recommendations for ω-3 FAs. In addition, consumers may be reluctant to consume eggs as a source of ω-3 FAs due to their high cholesterol and saturated fat contents (Hu et al., 1999; Weggemans et al., 2001). Arantes da Silva et al. (2009) incorporated ω-3 FAs into egg yolks by adding flaxseed to the feed. Although some treatments showed an increase in ω-3 FAs, there was no difference in cholesterol. Thus, even though nutritionally-enhanced eggs via alteration of hens' diets may contain more ω-3 FAs (within chicken's physiological limitations), their cholesterol content remains unchanged.

There are many commercially available liquid egg and egg substitute products such as Egg Beaters™ that are void of cholesterol. While these products remain relatively high in protein and low in calories, they often do not gain consumer acceptability due to their sensory quality when compared to whole egg (Leutzinger, Baldwin, & Cotterill, 1977). In addition, these products do not contain ω-3 FAs; and therefore, lack the potential health/nutraceutical and marketing benefits.

We hypothesize that experimental egg products rich in ω-3 FAs and low in cholesterol, but with other essential nutrients comparable to whole egg, can be developed via processing of eggs, rather than by enhancing chicken feed. Therefore, the objective of this study was to determine nutritional composition with emphasis on cholesterol and ω-3 FAs contents, amino acid profile (AAP), and mineral profile (MP) of nutritionally-enhanced cooked egg products developed by the removal of cholesterol-containing yolk and addition of ω-3 FAs from flaxseed, menhaden, krill, or algae oils. The cholesterol and ω-3 FAs contents, AAP, and MP of the experimental cooked egg products were compared to those of whole egg, as well as a liquid egg product (i.e., Egg Beaters™).

2. Materials and methods

2.1. Development of experimental egg products

Fresh, store brand eggs were purchased from a local chain grocery store. For comparison, top national brand liquid egg product (hereafter called "Egg Beaters™") was also purchased from the same store. The eggs and Egg Beaters™ were stored under refrigeration temperature and the storage time did not exceed three days. The development of experimental egg products along with their comparison with cooked whole egg and Egg Beaters™ in terms of instrumental quality (texture, color, etc.) has been previously reported (Kassis, Drake, Beamer, Matak, & Jaczynski, 2010). The experimental egg products consisted of fresh egg white, freeze-dried egg white, non-iodized salt (NaCl), annatto, and the different ω-3 oils. The egg whites were manually separated from whole eggs. Egg yolks were not used in this study. Care was taken to remove chalazae membranes from egg whites. Annatto (cheese coloring CM500A) was obtained from Grape and Granary (Akron, OH). Annatto is a plant-derived yellow pigment with amphiphilic properties allowing for simultaneous water- and lipid-solubility. Therefore, annatto was used to obtain the color of the experimental egg products that would resemble the color of mixed (i.e., egg yolk and white mixed together) cooked whole egg. The following ω-3 oils were used in the formulation of experimental egg products:

1) Flaxseed oil was obtained from Jedwards International, Inc. (Quincy, MA).
2) Menhaden oil (Omega Pure 8042TE) was obtained from Omega Pure (Reedsville, VA).
3) Algae oil (DHAS) was obtained from Martek Biosciences (Columbia, MD).
4) Algae oil (DHASCO) was obtained from Martek Biosciences (Columbia, MD).
5) Krill oil (4225F) was obtained from Enzymotec USA, Inc. (Springfield, NJ).

The experimental egg products were formulated to achieve moisture, crude protein, and total fat that would be similar ($P > 0.05$) to the proximate composition of whole egg. An optimization spreadsheet was set up and preliminary experiments were conducted to meet this objective (data not shown). The optimized composition of the experimental egg products containing all of the above alternative oils except the DHASCO algae oil was as follows:

1) 430 ml of fresh egg whites.
2) 50 ml of alternative oil (4 alternative oils listed above).
3) 15 g freeze-dried egg whites.
4) 5 g non-iodized salt (NaCl).
5) 750 μl annatto.

The DHAS algae oil contained lecithin, but DHASCO algae oil did not. The DHAS oil is a cheaper, but less concentrated source of algal DHA than DHASCO. This is why both oils were used in the present study. The composition of experimental egg products containing the DHASCO algae oil included 420 ml of fresh egg whites, 40 ml of DHASCO oil, 20 g of soybean lecithin (catalog number 03376-250, Fisher Scientific, Fairlawn, NJ), 15 g of freeze-dried egg whites, 5 g of non-iodized salt (NaCl), and 750 μl of annatto. It was found in the preliminary experiments that 20 g of soybean lecithin prevented phase separation and following cooking the resultant gels developed with the DHASCO oil were uniform (data not shown). The preliminary experiments also showed that experimental egg products containing menhaden, flaxseed, or krill oils did not exhibit phase separation; and therefore, lecithin was not added. The same fresh egg white was used for freeze-drying (VirTis Genesis 35SQ Super XL freeze-dryer, Virtis, Gardiner, NY) as the fresh egg white used in the development of experimental egg products. The freeze-dried egg white was added in order to increase crude protein content in the experimental egg products so that it would be similar ($P > 0.05$) to that of whole egg (i.e., egg yolk and white mixed together). Final volume was approximately 500 ml.

2.2. Mixing and cooking of experimental egg products, mixed whole egg, and Egg Beaters™

The 500 ml of experimental egg products, mixed whole egg (i.e., egg yolk and white), or Egg Beaters™ was mixed in a 1 L beaker. However, approximately 18 h prior to addition of the other ingredients, the 15 g of freeze-dried egg whites were added to the 430 ml of fresh egg whites (or 420 ml when the DHASCO algae oil was used) and held under refrigeration. Mixing was not used during these 18 h. It was determined in the preliminary experiments that this procedure allowed hydration of freeze-dried egg whites and following cooking the resultant gels were uniform (data not