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Development of nutraceutical egg products with omega-3-rich oils

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ABSTRACT

Novel, nutritionally-enhanced egg products were developed by substituting saturated fat and cholesterol-containing yolk with omega-3 fatty acids-rich (ω-3 FA) flaxseed, menhaden, algae, and krill oils. The ω-3 FA-fortified eggs are typically developed through alteration of hen feed. However, the present study aimed at creating such a product via processing. Experimental egg products were developed to match composition, color, and texture of hen eggs (mixed whole egg). Experimental egg products, mixed whole egg, and liquid egg product (Egg Beaters™) were cooked, analyzed, and compared. Moisture, protein, and fat content of experimental egg products matched ($P > 0.05$) whole egg. The L^* (lightness) for experimental egg products was generally similar to mixed whole egg except when krill oil was added. Experimental egg products had higher ($P < 0.05$) a^* and b^* than mixed whole egg and Egg Beaters™, indicating more redness and yellowness, respectively. Texture profile analysis (TPA) values (hardness, springiness, cohesiveness, gumminess, chewiness, and resilience) revealed that experimental egg products had similar ($P > 0.05$) and greater ($P < 0.05$) textural properties when compared to mixed whole egg and Egg Beaters™, respectively. Fundamental torsion test confirmed that experimental egg products and mixed whole egg had generally similar texture, but were firmer ($P < 0.05$) than Egg Beaters™. Kramer shear test indicated a trend ($P > 0.05$) of slightly firmer texture for experimental egg products than Egg Beaters™.

1. Introduction

The egg is one of the best and most inexpensive sources of high quality protein and contains a balanced distribution of various vitamins and minerals relative to its low calorie content. For the last decade, American egg consumption has exceeded six billion dozen eggs per year, rendering eggs an important staple food in most households (USDA, 2009a). Eggs supply the diet with essential nutrients such as folate, selenium, iron, and vitamins A and B-12. They are also one of the few exogenous sources of vitamins K and D as well as one of the few food sources that contain high concentrations of choline, a nutrient that is essential for normal brain development (Herron & Fernandez, 2004). However, one egg also contains approximately 200 mg of cholesterol (Weggemans, Zock, & Katan, 2001), which nearly meets the dietary cholesterol intake limit established by the American Heart Association at ≤ 300 mg/d. Dietary cholesterol increases serum total and LDL-cholesterol concentrations, which are established risk factors for cardiovascular disease (CVD) (Howell, McNamara, Tosca, Smith, & Gaines, 1997). Furthermore, approximately half of the total fat content in an egg is saturated fat, another contributor to CVD (Hu et al., 1999).

Omega-3 polyunsaturated fatty acids (ω-3 PUFA) are one of a number of dietary components that have demonstrated cardioprotective benefits. In addition to the reduction of CVD, consumption of ω-3 PUFA decreases blood pressure, triglycerides, and inflammatory markers, improves endothelial function, reduces platelet aggregation and vasoconstriction, and decreases risk of sudden cardiac death (Juturu, 2008). Fish, including farm-raised fish and their wild counterparts, are the major dietary sources of the longer-chain ω-3 PUFA. Sources of plant-derived ω-3 PUFA include flaxseed, flaxseed oil, walnuts, canola oil, soybean, and algae oil. 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).

However, despite of the fact that adequacy of ω-3 PUFA intake is beneficial to human health, the American diet is typically low in this nutrient (Arterburn et al., 2008). This has allowed for the progressive production of "nutraceutical/functional foods". Nutraceutical (often referred to as functional) food products contain added, technologically developed ingredients that have specific health benefits (Siro, Kapolna, Kapolna, & Lugasi, 2008). The ω-3 PUFA-fortified food products provide a means to achieve desired biochemical effects of these nutrients without the ingestion of dietary supplements, medications, or a major change in dietary habits.

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Dietary manipulation of the ω-3 PUFA content of hens' diets has resulted in the production of eggs containing ω-3 PUFA (Ferrier et al., 1995). In acceptability studies, U.S. consumers responded positively to ω-3- fortified eggs (Scheideler, Froning, & Cuppett, 1997). However, consumers may be reluctant to consume eggs as a source of ω-3 PUFA due to their high cholesterol and saturated fat contents (Hu et al., 1999; Weggemans et al., 2001). Furthermore, adding ω-3-rich ingredients such as flaxseed, algae, kelp, fish oil, and canola oils to chicken feed produces eggs with three or more times the normal amount of ω-3 PUFA; however, an egg is not naturally rich in ω-3 FA. Therefore, even a three-fold increase should be considered relatively small, particularly when compared with the recommended daily intake for ω-3 PUFA by the governments of Canada, Scandinavia, and Britain, which recommend between 1000 and 2000 mg/d. The U.S. has not yet set a recommended daily intake for ω-3 PUFA.

Silva et al. (2008) demonstrated incorporation of ω-3 PUFA into quail egg yolks by altering levels of flaxseed in the feed. Although results showed a reduction in total saturated FA content, in addition to an increase in PUFA in some treatments groups, no difference was found in cholesterol levels between all groups. Thus, even though nutritionally-enhanced eggs via alteration of hens' diets may contain less saturated fat, their cholesterol content remains unchanged.

There are, however, many liquid egg products and egg substitute products on the market, such as Egg Beaters™ that do not contain saturated fat or cholesterol. Although, these types of products, while relatively high in protein and low in calories, often do not gain consumer acceptability due to sensory quality when compared to that of regular eggs (Leutzinger, Baldwin, & Cotterill, 1977). In addition, these products do not contain ω-3 PUFA; and therefore, lack the potential health/nutraceutical and marketing benefits.

The broad objective of this study was to develop cooked egg products that are not only rich in ω-3 PUFA, but also have reduced cholesterol and saturated fat. We hypothesize that such egg products can be developed via processing of eggs, rather than by enhancing chicken feed. The investigation reported in this article was aimed specifically at determination of texture and color properties as well as nutrient composition of nutritionally-enhanced cooked egg products developed by the removal of the cholesterol-containing yolk and addition of ω-3 PUFA from alternative sources, including flaxseed, menhaden, krill, and algae oils. The nutrient composition as well as texture and color properties of the resulting nutritionally-enhanced cooked egg products were also compared to those of mixed whole egg and Egg Beaters™.

2. Materials and methods

2.1. Development of experimental egg products

Fresh, store brand quality 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 and the storage time did not exceed three days. The experimental egg products consisted of fresh egg whites, alternative oil, freeze-dried egg whites, non-iodized salt (NaCl), and annatto. The egg whites were manually separated from whole eggs. The yolks were not used in the experiments. 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 alternative oils were used in the formulation of experimental eggs:

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 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 objective of the formulation of experimental egg products was to achieve moisture, crude protein, and total fat that would be similar ($P > 0.05$) to the proximate composition of mixed whole egg. An optimization spreadsheet was set up and preliminary experiments (data not shown) were conducted to meet this objective. The optimized composition of the experimental eggs 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 formulation that included the DHASCO algae oil contained 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 (data not shown) that 20 g of soybean lecithin prevented phase separation and after cooking, the resultant gels were uniform. The DHA S oil contained lecithin. The same fresh egg whites were used for freeze-drying (VirTis Genesis 35SQ Super XL freeze-dryer, Virtis, Gardiner, NY) as the fresh egg whites used in the development of experimental egg products. The freeze-dried egg whites were added in order to increase crude protein content in the experimental eggs so that it would be similar ($P > 0.05$) to that of mixed 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 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 (data not shown) that this procedure allowed hydration of freeze-dried egg whites and after cooking the resultant gels were uniform. Following 18 h of hydration, all other ingredients were added and the experimental egg products were mixed for 2 h at room temperature, while mixed whole egg and Egg Beaters™ for 1 h also at room temperature. The beaker was placed on a mixing plate (Thermix Strirring Hot Plate Model 310T, Fisher Scientific, Fairlawn, NJ) with a standard 3-inch magnetic stir bar. The mixing plate was set at

speed 5 for experimental egg products, while speed 3 was used for mixed whole egg and Egg Beaters™. It was determined in the preliminary experiments (data not shown) that these mixing procedures prevented phase separation and after cooking, the resultant gels were uniform. Following mixing, the experimental egg products, mixed whole egg, or Egg Beaters™ was stuffed into tubes and cooked.

For texture profile analysis (TPA), Kramer shear test, and color properties (see below) the experimental egg products, mixed whole egg, or Egg Beaters™ was stuffed into polycarbonate tubes (length = 18 cm, internal diameter = 1.90 cm, wall thickness = 0.635 cm). The tubes had polycarbonate screw caps at both ends that were sealed with standard o-rings. The tubes were placed in a standard 1100 Watt household microwave oven (Model JES1139WL, GE Appliances, Louisville, KY) set at 50% power and the experimental egg products, mixed whole egg, or Egg Beaters™ was cooked for 60 s. Preliminary experiments (data not shown) showed that these settings were optimal for cooking of the experimental egg products, mixed whole egg, and Egg Beaters™, resulting in uniformly set egg gels.

For torsion test (see below) the experimental egg products, mixed whole egg, or Egg Beaters™ was stuffed into teflon-coated stainless steel pre-molded torsion tubes (Chen & Jaczynski, 2007a, 2007; Taskaya, Chen, & Jaczynski, 2009; Taskaya, Chen, & Jaczynski, 2010;). These pro-molded tubes allow simultaneous cooking of six torsion samples. Following cooking each torsion sample has an hourglass cylindrical shape (length = 2.54 cm, end diameter = 1.90 cm, and midsection diameter = 1.0 cm). These dimensions and shape are required for torsion test (Kim, Park, & Yoon, 2005). The tubes had stainless steel screw caps at both ends. The tubes were placed in a standard circulating water bath (Model 260 Circulating Bath, Precision, Winchester, VA) set at 90 °C and the experimental egg products, mixed whole egg, or Egg Beaters™ was cooked for 10 min. Preliminary experiments (data not shown) showed that these setting were optimal for gelation of the experimental egg products, mixed whole egg, and Egg Beaters™, resulting in uniformly cooked gels without over- or under-cooking.

2.3. Texture properties of cooked gels

Three different methods were employed to determine texture: torsion test, Kramer shear test, and texture profile analysis (TPA). Although these three texture measurements are commonly employed for determination of textural properties, each method provides slightly different information. Torsion test is considered a fundamental test for texture, while Kramer shear test and TPA are empirical tests (Kim et al., 2005). Likely, the most comprehensive understanding of textural properties is provided by a combination of the fundamental and empirical tests. Therefore, these three different tests were employed in the present study.

Shear stress and shear strain of cooked gels (i.e., experimental egg products, mixed whole egg, or Egg Beaters™) was determined using torsion test (Chen & Jaczynski, 2007a, 2007b; Jaczynski & Park, 2004; Taskaya et al., 2010, Taskaya, Chen & Jaczynski, 2009). The gels were equilibrated to room temperature for 2 h prior to the measurement. At least five hourglass cylindrical gels (length = 2.54 cm, end diameter = 1.90 cm, and midsection diameter = 1.0 cm) per treatment were glued to plastic discs and subjected to torsional shear using a Hamman Gelometer (Gel Consultant, Raleigh, NC) set at 2.5 rpm. Shear stress and shear strain at mechanical fracture were measured to determine gel strength and gel cohesiveness, respectively.

At least five cooked gels (i.e., experimental egg products, mixed whole egg, or Egg Beaters™) (length = 8.0 cm, diameter = 1.9 cm) were subjected to Kramer shear test using a texture analyzer (Model TA-HDi, Texture Technologies Corp., Scarsdale, NY) equipped with a Kramer cell attachment. Kramer shear cell consisted of five 3.0-mm thick and 70-mm wide shear blades passing through a cell having a corresponding number of slots. Individual gel samples were weighed and placed under the blades in the Kramer cell. Shear force was measured at a 127 mm/min crosshead speed and expressed as maximum peak force (g peak force/g of gel sample) (Chen & Jaczynski, 2007a, 2007b; Taskaya, Chen, Beamer, & Jaczynski, 2009; Taskaya et al., 2009; Taskaya et al., 2010).

Texture profile analysis (TPA) of cooked gels (i.e., experimental egg products, mixed whole egg, or Egg Beaters™) was performed according to Cheret, Chapleau, Delbarre-Ladrat, Verrez-Bagnis, and Lamballerie (2005). The gel samples at room temperature were subjected to two-cycle compression at 50% using the texture analyzer (Model TA-HDi, Texture Technologies Corp., Scarsdale, NY) equipped with a 70-mm TPA compression plate attachment moving at a speed of 127 mm/min. From the resulting force-time curves, hardness, springiness, cohesiveness, gumminess, chewiness, and resilience were determined (Chen & Jaczynski, 2007a, 2007b; Taskaya, Chen, Beamer, et al., 2009; Taskaya et al., 2009; Taskaya et al., 2010). The definitions of the TPA parameters are as following: (1) hardness indicates the maximum force required to compress a sample; (2) springiness indicates ability of sample to recover its original form after the deforming force is removed; (3) cohesiveness corresponds to the extent to which the sample can be deformed before rupture; (4) gumminess is the force required to disintegrate a semisolid sample to a steady state of swallowing (hardness × cohesiveness); (5) chewiness is related to the work needed to chew a solid sample to a steady state of swallowing (springiness × gumminess); (6) resilience shows how well a sample resists to regain its original position. At least five cylindrical gels (length = 2.54 cm, diameter = 1.90 cm) per treatment were used for the TPA.

2.4. Color properties of cooked gels

The cooked gel samples (i.e., experimental egg products, mixed whole egg, or Egg Beaters™) were equilibrated to room temperature for 2 h prior to the color measurements. Color properties of cooked gels were determined using a Minolta Chroma Meter CR-400 colorimeter (Minolta Camera Co. Ltd., Osaka, Japan). At least seven cylindrical gels (length = 2.54 cm, diameter = 1.90 cm) per treatment were used for color measurement. A CIE color system using $L^*a^*b^*$ tristimulus color values were determined (Chen & Jaczynski, 2007a, 2007b; Taskaya, Chen, Beamer, et al., 2009; Taskaya et al., 2009; Taskaya et al., 2010).

2.5. Proximate composition analysis of cooked gels

The moisture content, total fat, crude protein, and ash content were determined for cooked gel samples (i.e., experimental egg products, mixed whole egg, or Egg Beaters™). For moisture determination, sample (2 g) was placed on an aluminum dish (Fisher Scientific Co., Fairlawn, NJ), spread evenly across the dish and oven-dried (105 °C for 24 h) (AOAC, 1995). Total fat content was determined according to the Soxhlet extraction method (AOAC, 1995) and expressed as g/100 g (dry and wet weight basis). Crude protein was determined by Kjeldahl assay (AOAC, 1995) and expressed as g/100 g (dry and wet weight basis). Ash content was performed by incinerating samples in a muffle furnace at 550 °C for 24 h (AOAC, 1995) and expressed as g/100 g (dry and wet weight basis). All proximate analyses are reported as mean values of at least three replicates.

Table 1
Proximate analysis[a] of cooked gels (g/100 g). Proximate composition of cooked mixed whole egg and Egg Beaters™ was compared to cooked experimental egg products developed with addition of flaxseed, menhaden, algae (DHAS and DHASCO), and krill oils.

	Whole egg	Egg Beaters™	Flax	Menhaden	Algae (DHAS)	Algae (DHASCO)	Krill
Moisture (g/100 g)	73.3 ± 1.0 b	87.5 ± 0.7 a	73.2 ± 2.1 b	74.1 ± 1.2 b	73.2 ± 1.1 b	73.9 ± 1.2 b	73.4 ± 1.9 b
Crude protein (g/100 g)							
Dry basis	51.5 ± 0.8 b	78.8 ± 0.7 a	51.9 ± 1.9 b	52.1 ± 1.3 b	52.2 ± 0.8 b	51.8 ± 0.3 b	51.8 ± 0.3 b
Wet basis	13.8 ± 0.2 a	9.9 ± 0.2 b	13.9 ± 0.5 a	13.5 ± 0.3 a	14.0 ± 0.2 a	13.5 ± 0.1 a	13.8 ± 0.1 a
Total fat (g/100 g)							
Dry basis	42.3 ± 2.6 a	2.6 ± 0.9 b	41.7 ± 2.5 a	40.7 ± 2.8 a	40.7 ± 2.7 a	41.5 ± 2.0 a	40.3 ± 8.7 a
Wet basis	11.3 ± 0.6 a	0.3 ± 0.2 b	11.2 ± 0.6 a	10.5 ± 0.7 a	10.9 ± 0.7 a	10.8 ± 0.5 a	10.7 ± 2.2 a
Ash (g/100 g)							
Dry basis	3.7 ± 0.0 b	6.8 ± 0.3 a	6.6 ± 0.3 a	6.9 ± 0.3 a	6.8 ± 0.2 a	6.7 ± 0.3 a	6.8 ± 0.2 a
Wet basis	1.0 ± 0.0 b	0.9 ± 0.1 b	1.8 ± 0.1 a	1.8 ± 0.1 a	1.8 ± 0.1 a	1.7 ± 0.1 a	1.8 ± 0.1 a

Different letters within the same row indicate significant differences (Fisher's least significant difference, $P < 0.05$) between mean values.
[a] Data are given as mean values ± standard deviation ($n = 3$).

2.6. Statistics

The experiments were triplicated ($n = 3$). In each triplicate, at least three measurements were performed for proximate analysis (i.e., moisture content, total fat, crude protein, and ash content), at least five measurements were performed for determination of texture properties (i.e., torsion test, Kramer shear test, and TPA), and at least seven measurements were performed for determination of color properties (i.e., $L^*a^*b^*$). Data were subjected to one-way analysis of variance (ANOVA). A significant difference was used at 0.05 probability level and differences between treatments were tested using the Fisher's Least Significant Difference (LSD) test (Freud & Wilson, 1997). The statistical analysis was performed using R version 2.0.9 software (Ihaka & Gentleman, 1996). The data are reported as mean values ± standard deviation (SD).

3. Results and discussion

3.1. Proximate analysis

The proximate composition following cooking of the experimental egg products was compared to that of cooked mixed whole egg and cooked Egg Beaters™ (Table 1). The moisture content, crude protein, and total fat of the experimental egg products were similar ($P > 0.05$) to those of mixed whole egg. This result was expected since the experimental egg products were formulated to match the proximate composition of mixed whole egg. Fat influences texture of food products (mouth-feel, hardness, chewiness, etc.) and is also typically considered as a carrier of lipophilic flavors and aromatic compounds. At the same time, food proteins undergo gelation when subjected to heat, resulting in texture development. Following cooking, protein gel matrix also traps fat molecules along with the lipophilic flavors and aromatic compounds. Therefore, protein content directly affects several textural parameters in addition to indirect effect on food flavor and aroma. Consequently, fat and protein in a food product collectively contribute to sensory quality of that product and as a result, fat and protein content influence consumers' perception. The moisture content is also important since water in food products provides reaction medium. Water is also considered a pre-requisite for protein gelation; and therefore, proper texture development. This is why one of the objectives of the present study was to match ($P > 0.05$) total fat, crude protein, and moisture content of the experimental egg products to those of mixed whole egg. As confirmed by statistical analysis of the proximate composition, this objective was met.

The USDA reports proximate composition (dry weight basis) of whole egg as 75.8, 47.4, 41.0, and 3.7 g/100g for moisture, crude protein, total lipid, and ash, respectively (USDA, 2009b). The proximate composition of the experimental egg products developed in this study and the mixed whole egg used as a control are similar to the composition data reported by the USDA (USDA, 2009b). However, it is important to note that Egg Beaters™ had different ($P < 0.05$) proximate composition than the experimental egg products and mixed whole egg. Egg Beaters™ had higher ($P < 0.05$) moisture content and crude protein (on dry weight basis) as well as lower ($P < 0.05$) total fat (on dry and wet weight basis) than experimental egg products and mixed whole egg. However, the crude protein and total fat content on wet basis (often referred to as "as-is" basis) for Egg Beaters™ were 9.9 and 0.3 g/100 g, respectively; while the corresponding average values for the experimental egg products and mixed whole egg were 13.8 and 10.9 g/100 g, respectively. Therefore, these differences in proximate composition of Egg Beaters™ may translate into differences in the texture and flavor. This data is consistent with the fact that the base ingredient for Egg Beaters™ are egg whites that are void of fat and have higher moisture content when compared to mixed whole egg. Therefore, in order to match the crude protein and moisture content of mixed whole egg, freeze-dried egg whites were added during formulation of experimental egg products in the present study.

The ash content on dry basis of the experimental egg products was similar ($P > 0.05$) to that of Egg Beaters™ and higher ($P < 0.05$) than that of mixed whole egg. A possible explanation is that the addition of the non-iodized salt, annatto, and freeze-dried egg

Table 2
Tristimulus color values[a] ($L^*a^*b^*$) of cooked gels. Color values of cooked mixed whole egg and Egg Beaters™ were compared to cooked experimental egg products developed with addition of flaxseed, menhaden, algae (DHAS and DHASCO), and krill oils.

	Whole egg	Egg beaters™	Flax	Menhaden	Algae (DHAS)	Algae (DHASCO)	Krill
L^*	87.2 ± 0.9 cd	92.7 ± 0.8 a	88.4 ± 0.4 b	88.0 ± 0.3 bc	87.7 ± 0.2 bcd	86.6 ± 0.8 d	73.1 ± 0.6 e
a^*	−4.3 ± 0.2 f	−3.1 ± 0.1 e	0.9 ± 0.1 d	1.1 ± 0.1 d	1.9 ± 0.1 c	3.7 ± 0.4 b	37.5 ± 1.1 a
b^*	27.9 ± 0.6 d	23.8 ± 2.1 e	43.1 ± 0.2 c	44.9 ± 0.4 c	49.0 ± 1.2 b	52.0 ± 2.0 a	51.0 ± 2.2 ab

Different letters within the same row indicate significant differences (Fisher's least significant difference, $P < 0.05$) between mean values.
[a] Data are given as mean values ± standard deviation ($n = 3$).

Table 3
Texture profile analysis[a] (TPA) of cooked gels. Texture profile of cooked mixed whole egg and Egg Beaters™ was compared to cooked experimental egg products developed with addition of flaxseed, menhaden, algae (DHAS and DHASCO), and krill oils.

	Whole egg	Egg Beaters™	Flax	Menhaden	Algae (DHAS)	Algae (DHASCO)	Krill
Springiness	2.04 ± 0.01 a	0.83 ± 0.29 b	1.92 ± 0.24 a	1.75 ± 0.13 a	1.83 ± 0.22 a	1.84 ± 0.23 a	1.83 ± 0.22 a
Cohesiveness	0.61 ± 0.03 a	0.27 ± 0.04 b	0.65 ± 0.04 a	0.63 ± 0.03 a	0.65 ± 0.02 a	0.63 ± 0.03 a	0.65 ± 0.04 a
Gumminess	981 ± 349 a	78 ± 19 b	992 ± 64 a	810 ± 29 a	919 ± 183 a	747 ± 89 a	846 ± 85 a
Chewiness	1596 ± 456 a	120 ± 20 b	1519 ± 171 a	1325 ± 50 a	1640 ± 133 a	1307 ± 315 a	1487 ± 299 a
Resilience	0.32 ± 0.03 a	0.18 ± 0.04 b	0.33 ± 0.03 a	0.33 ± 0.02 a	0.33 ± 0.02 a	0.30 ± 0.03 a	0.32 ± 0.03 a

Different letters within the same row indicate significant differences (Fisher's least significant difference, $P < 0.05$) between mean values.
[a] Data are given as mean values ± standard deviation ($n = 3$).

whites may have contributed to higher ash content in the experimental egg products than in mixed whole egg. Furthermore, Egg Beaters™ also contain added salt and colorings, in addition to other additives such as thickening agents and preservatives. This is likely why the ash content on dry basis of the experimental egg products was similar to Egg Beaters™.

3.2. Color properties

Table 2 displays the tristimulus color values ($L^*a^*b^*$) of the cooked egg gels. L^* is a relative measurement between the light reflected and absorbed by the samples where each color can be considered equivalent to a member of the gray scale ranging from 0 to 100 corresponding to a gradual scale from black to white, respectively. When menhaden, DHAS, and DHASCO oils were used in the experimental egg products, the L^* values were 88.0 ± 0.3, 87.7 ± 0.2, and 86.6 ± 0.8, respectively. These L^* values were similar ($P > 0.05$) to that of mixed whole egg (87.2 ± 0.9). Egg Beaters™ were the lightest in color (because they lack yolk); and thus, had the highest ($P < 0.05$) L^* value (92.7 ± 0.8). In contrast, the experimental egg products that contained krill oil were visibly darker in color compared to all other samples and had the lowest ($P < 0.05$) L^* value (73.1 ± 0.6).

The other two tristimulus color values, a^* and b^* are coordinates in which a^* has positive or negative values for reddish or greenish hues, respectively; whereas, b^* has positive or negative values for yellowish or bluish hues, respectively. In terms of consumer acceptability of whole egg products, typically the yellow coordinate (i.e., positive b^*) is considered the most important hue from the color spectrum. Therefore, positive b^* is likely the most important color value for egg products. The experimental egg products had more ($P < 0.05$) positive b^* values than mixed whole egg or Egg Beaters™ indicating more yellow hues in their color. Experimental egg products containing algae (DHAS and DHASCO) and krill oils had the most ($P < 0.05$) positive b^* values (49.0 ± 1.2, 52.0 ± 2.0, and 51.0 ± 2.2, respectively), which again are the direct contribution of antioxidant pigmentation. These antioxidants were present in the oils added during formulation of the experimental egg products. Although the same concentration of annatto pigment was used during formulation of the experimental egg products, the original color of the added oils likely contributed to the differences in b^* values. Flaxseed and menhaden oils had less intense yellow color; and therefore, the b^* values for experimental egg products containing these oils were lower ($P < 0.05$) than for egg products containing algae and krill oils, yet higher ($P < 0.05$) than b^* for mixed whole egg and Egg Beaters™. Herber-McNeill and Van Elswyk (1998) investigated addition of marine algae to chicken feed. They reported similar a^* (2.7 ± 0.4) and b^* (47.2 ± 0.4) and found that these values enhanced consumer acceptability of eggs. Therefore, more yellow hue in the experimental egg products reported in the present study would likely be acceptable to consumers. However, sensory studies including consumer acceptability are needed to determine this factor. Our laboratory has started such studies and a report is forthcoming.

Mixed whole egg and Egg Beaters™ had negative a^* values of −4.3 ± 0.2 and −3.1 ± 0.1, respectively; while experimental egg products had positive a^* (0.9–3.7 except krill), with the experimental egg products that contained krill oil having the highest ($P < 0.05$) a^* value (37.5 ± 1.1). The experimental egg products containing krill oil had the most prominent red hue. However, it needs to be emphasized that although mixed whole egg and Egg Beaters™ had significantly different a^* from experimental egg products, the numerical differences were relatively small except for experimental egg products containing krill oil. The reddish color of the krill oil is the result of the bright red antioxidant, astaxanthin (Bustos, Romo, Yanez, Diaz, & Romo, 2003; Tou, Jaczynski, & Chen, 2007).

3.3. Texture analysis

Texture profile analysis (TPA) revealed no differences ($P > 0.05$) in the six texture parameters (hardness, springiness, cohesiveness, gumminess, chewiness, and resilience) of the experimental egg products compared to mixed whole egg (Fig. 3, Table 3). Similar TPA values for whole egg texture have been reported (Franchini et al., 2002). Thus, the substitution of yolk with ω-3 PUFA-rich oils does not alter texture of cooked egg as determined with TPA. In 2004, Hoz, D'Arrigo, Cambero, and Ordóñez investigated the enhancement of sausages with ω-3 PUFA-rich oils and found no differences ($P > 0.05$) in the TPA parameters when compared to control values. The TPA data shown in the present study confirms similar trend. The varying phospholipid concentrations of the ω-3 PUFA-rich oils facilitated stabilization of the meat emulsion system in sausages

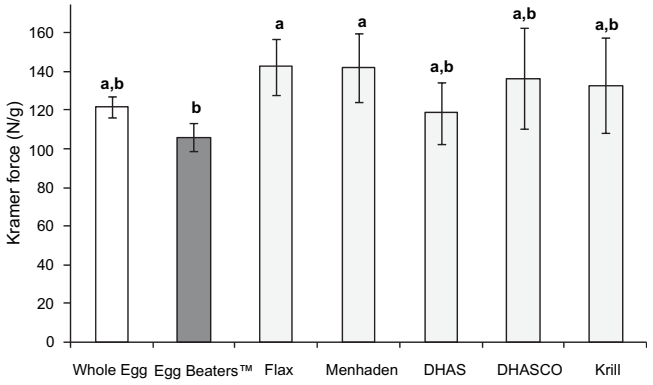

Fig. 1. Kramer shear force* of cooked gels. Kramer force of cooked mixed whole egg and Egg Beaters™ was compared to cooked experimental egg products developed with addition of flaxseed, menhaden, algae (DHAS and DHASCO), and krill oils. *Data are given as mean values ± standard deviation ($n = 3$). Different letters on the top of data bars indicate significant differences (Fisher's Least Significant Difference, $P < 0.05$) between mean values.

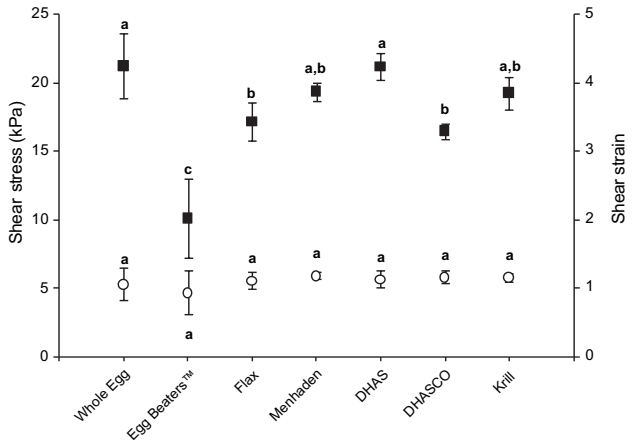

Fig. 2. Shear stress* and shear strain* of cooked gels. Shear Stress and strain of cooked mixed whole egg and Egg Beaters™ were compared to cooked experimental egg products developed with addition of flaxseed, menhaden, algae (DHAS and DHASCO), and krill oils. ■ – shear stress; ○ – shear strain. *Data are given as mean values ± standard deviation ($n = 3$). Different letters on the top of data points indicate significant differences (Fisher's Least Significant Difference, $P < 0.05$) between mean values within shear stress or shear strain.

(Hoz, D'Arrigo, Cambero, & Ordóñez, 2004). Similar stabilization likely occurred due to yolk phospholipids and phospholipids (including soybean lecithin) of the alternative oils (krill, flaxseed, algae, and menhaden oils) that emulsified fat in mixed whole egg and experimental egg products, respectively; thus, resulting in similar textural properties in the present study. A similar trend was also suggested for meat products fortified with ω-3 PUFA (Lee, Faustman, Djordjevic, Faraji, & Decker, 2005). The TPA values of Egg Beaters™ showed consistently much poorer ($P < 0.05$) textural properties for all of the six TPA parameters when compared to mixed whole egg and experimental egg products. The poorer texture of Egg Beaters™ can be attributed to high moisture content (87.5 g/100) in addition to the low protein (9.9 g/100 g, wet basis) and lipid (0.3 g/100 g, wet basis) content (Table 1). Similar values for springiness (0.88) and cohesiveness (0.23) have been reported for cooked egg whites (Min et al., 2005).

Mixed whole egg, Egg Beaters™, and experimental egg products containing algae and krill oil had similar ($P > 0.05$) Kramer shear force (Fig. 1). However, experimental egg products containing flaxseed and menhaden oil had slightly greater ($P < 0.05$) shear force compared to all other samples. It needs to be notes that although insignificant ($P > 0.05$), Egg Beaters™ had a tendency to have lowest shear force. Fat emulsification results in stabilization of food products (Hoz et al., 2004), which in turn requires more shear force to fracture a sample. This is also confirmed by the torsion shear stress and TPA hardness presented in Figs. 2 and 3, respectively; where the values of both mixed whole egg and experimental egg products were higher ($P < 0.05$) than those of Egg Beaters™. Moreover, there was no ($P > 0.05$) difference in shear strain among the samples tested (Fig. 2). Shear strain is a measure of gel cohesiveness; and thus, the shear strain for all samples, ranging from 0.93 to 1.19, confirmed the TPA cohesiveness values, ranging from 0.61 to 0.65 (with the exception of the Egg Beaters™ at 0.27) (Table 3). The numerical difference between shear strain of Egg Beaters™ measured with torsion test and TPA can be explained by the different test (TPA – empirical test, torsion – fundamental test) and cooking methods (TPA – microwave, torsion test – water bath).

Although the results of this study point towards the potential for a novel, marketable nutraceutical/functional food product, sensory tests are recommended.

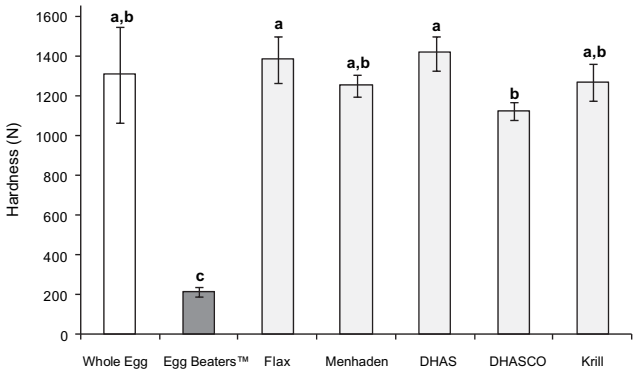

Fig. 3. Hardness* (texture profile analysis) of cooked gels. Hardness of cooked mixed whole egg and Egg Beaters™ was compared to cooked experimental egg products developed with addition of flaxseed, menhaden, algae (DHAS and DHASCO), and krill oils. *Data are given as mean values ± standard deviation ($n = 3$). Different letters on the top of data bars indicate significant differences (Fisher's least significant difference, $P < 0.05$) between mean values.

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