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Sensory Characteristics and Storage Quality Indicators of Surimi Franks Nutritionally Enhanced with Omega-3 Rich Flaxseed Oil and Salmon Oil

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**Sensory Characteristics and Storage Quality Indicators of Surimi Franks
Nutritionally Enhanced with Omega-3 Rich Flaxseed Oil and Salmon Oil**

Christin Rose Sell

**Thesis submitted to the
Davis College of Agriculture, Natural Resources and Design
at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
Nutritional and Food Science**

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Division of Animal and Nutritional Sciences

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**Key Words: surimi; omega-3 polyunsaturated fatty acids; sensory evaluation;
flaxseed oil; salmon oil**

ABSTRACT

Sensory Characteristics and Storage Quality Indicators of Surimi Franks Nutritionally Enhanced with Omega-3 Rich Flaxseed Oil and Salmon Oil

Christin Sell

Surimi, a lean source of fish protein, is consumed worldwide in various forms. Considerable increase in U.S. consumption of surimi products was observed in the 1980s but tapered off in recent decades. Consumer demand for foods enriched with ω -3 fatty acids including DHA and EPA has increased due to potential health benefits. Therefore, the purpose of this study was to (1) create a surimi frank enhanced with ω -3 PUFA rich salmon oil or flaxseed oil, (2) evaluate product composition and quality indicators (pH, color {L*, a*, b*}, syneresis, thiobarbituric acid reactive substances test, and texture) over 21d, and (3) establish product acceptability by sensory evaluation. Frank composition included Alaska pollock surimi, functional additives, and flavoring. Flaxseed or salmon oil was added at 2% based on current recommendations for ω -3 fatty acids. Franks without added oil served as a control. Franks were cooked in sausage casings, vacuum-packed, and stored at 4°C. Proximate analyses (ash, moisture, protein, total fat, and carbohydrate) showed differences ($P < 0.05$) in moisture and fat between the oil-enriched franks and control. Color values did not differ over 21d ($P < 0.05$). There were interactions between sausage types and day in their effect on lipid oxidation ($P < 0.05$); however, there was no change in pH or MDA concentrations over time ($P > 0.05$). Syneresis of samples did not differ over time or between sample treatments ($P > 0.05$). Differences in textural properties of fortified franks were observed during storage ($P < 0.05$). Control samples became increasingly chewy, gummy, cohesive, and harder after two weeks ($P < 0.05$). Participants ($N=79$; age 18-35yrs) evaluated product attributes (visual appeal, color, aroma, texture, flavor, and acceptability) via a scale where 1 = Dislike Extremely and 9 = Like Extremely. There were no differences in sensory attributes ($P > 0.05$) between franks. Although 24% of participants claimed to have never consumed surimi, 69% reported consuming sausage on a weekly to monthly basis. Most panelists (63%) indicated interest in purchasing this type product. Results indicate that the surimi franks were generally accepted by young adult consumers, which may indicate market potential of these types of products.

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CHAPTER I

Introduction

Omega-3 polyunsaturated fatty acid (ω -3 PUFA) alpha linolenic acid (ALA, 18:3 ω -3) cannot be synthesized by the body and is obtained in the diet largely from plant sources including seeds, nuts, and vegetable oils (Kris-Etherton et al., 2002). ALA is the precursor for longer chain fatty acids eicosapentaenoic acid (EPA, 20:5 ω -3) and docosahexaenoic acid (DHA, 22:6 ω -3); however, conversion in humans is limited so a diet including fatty fish species as direct source promotes accumulation of these fatty acids in the body (Goyens et al., 2005). Research suggests that consumption of ω -3 PUFAs is associated with beneficial physiological outcomes involving blood pressure, thrombosis, endothelial function, and other cardiovascular risk factors (Mozaffarian & Wu, 2011; Gebauer et al., 2006).

It is recommended by the American Heart Association that healthy adults consume at least two servings of fatty fish (e.g. salmon, tuna) a week to increase dietary ω -3 PUFA intake (2006). Factors including personal preference and expense make delivery of specific nutrients through functional foods an alternative method of incorporating ω -3 PUFAs into the diet as well as increasing variety of nutrition options. To a degree, all foods may be considered “functional”; however, the American Dietetic Association states that functional foods may be fortified or enhanced to provide nutrients that promote health (2009).

Development of meat products fortified with ω -3 oils is gaining popularity (Kouba & Mourot, 2009). Surimi products, manufactured and flavored lean minced fish muscle, were documented as early as the 8th century in Japan, but in the 1960's processing and preservation advancements revolutionized surimi seafood distribution on a global level offering an opportunity to utilize fish species with lesser commercial value as a source of protein (Park, 2005; Martín-Sánchez et al., 2009). Surimi seafood, which may be prepared and flavored in a variety of ways e.g. fried, steamed crabstick, fish balls, has shown potential for fortification (Park, 2005; Pérez-Mateos et al., 2004; Pietrowski et al., 2011; Tolasa, Cakli, & Lee, 2010). There are currently no studies examining the quality parameters and sensory characteristics of Alaska pollock surimi prepared as a frankfurter and fortified with ω -3 oils. Therefore, the aim of the present study was to develop a surimi frank enhanced with ω -3 oils including DHA and EPA rich salmon oil or plant-based ALA rich flaxseed oil. Product composition, quality characteristics (pH, color, syneresis, lipid oxidation, and texture) during a three week refrigerated storage period, and sensory evaluation was examined.

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CHAPTER II

Review of Literature

Omega-3 polyunsaturated fatty acids

Omega-3 polyunsaturated fatty acids (ω -3 PUFAs) are comprised of long carbon chains linked to hydrogen with three or more double bonds. These dietary fats may be derived and obtained in a human diet from both animal and plant sources. Humans are deficient in the desaturase enzyme necessary for adding double bonds to the C-12 and C-15 position of a fatty acid carbon chain; therefore plant derived alpha linolenic acid (ALA, 18:3 ω -3) is an essential fatty acid that may only be obtained by humans from dietary sources including seeds, nuts, and their oils (Surette, 2008; Gebauer, Harris, & Kris-Etherton, 2006). ALA is an ω -3 PUFA as well as a precursor for synthesis of other ω -3 PUFAs including eicosapentaenoic acid (EPA, 20:5 ω -3), docosapentaenoic acid (DPA, 22:5 ω -3), and subsequently docosahexaenoic acid (DHA, 22:6 ω -3) (Wang et al., 2005).

ALA competes with ω -6 PUFA, linoleic acid (LA, 18:2 ω -6), for the delta-6 desaturase enzyme which is often considered the rate-limiting step in the conversion of ALA to DHA (Nakamura, Cho, & Clarke, 2000). However, conversion is limited in adults from approximately 7%, to as low as 0.2% of ALA to EPA and < 0.1% of ALA to DHA (Goyens et al., 2005; Pawlosky et al., 2001; Burdge & Wootton, 2002a;b). In addition, the conversion of DPA, which is the intermediary product between EPA and DHA, to DHA is limited in hepatic tissues and has the tendency of retro-conversion to EPA in other tissues (Goyens et al., 2005; Gotoh et al., 2009). Secondary to this low conversion

rate, direct sources of EPA and DHA are typically supplied in the diet via fatty fish such as salmon, trout, and tuna (Kris-Etherton et al., 2002). Fish can accumulate these fats into their cell membranes and tissues via a diet comprised of primary producers of EPA and DHA, mainly from environmental algae (Arterburn, Hall, & Oken, 2006).

Differing sources of oil contain various types as well as amounts of ω -3 PUFAs. Research suggests that marine derived ω -3 PUFAs containing greater concentrations of EPA and DHA have a cardio protective effect (Gebauer et al., 2006). The proposed mechanism associated with health benefits from EPA and DHA consumption involves incorporation of these fatty acids into tissues. One study found that rats fed a variety of vegetable and marine oils had the greatest ω -3 fatty acid tissue accumulation, digestibility, and the least lipid oxidation with salmon oil and tuna oil supplemented diets (Tou et al., 2011). Fish oil contains higher concentrations of health promoting EPA and DHA; however, fortification may be associated with decreased palatability (Pérez-Mateos, Boyd, & Lanier, 2004; Jiang et al., 2011). As an alternative, flaxseed oil, which is plant-derived and economically accessible, contains approximately 50-60% ALA making it a common resource for ω -3 fatty acid enrichment in foods (Przybylski, 2005). Simmons and others reported that farmed brook trout fed flaxseed oil enhanced diets resulted in overall greater percentage of ω -3 PUFA in fish fillets yielding a favorable quality product (Simmons et al., 2011). Bermúdez-Aguirre & Barbosa-Cánovas (2011) fortified cheeses with either flaxseed oil or microencapsulated fish oil and found that while there were some physiochemical and textural differences in the fortified cheeses, sensory evaluation (n=240) showed greater consumer acceptability in flaxseed oil enhanced cheeses.

Consumption of foods containing ω -3 PUFAs, including foods fortified with ω -3 PUFAs, has gained popularity because of reported health benefits including reducing the risk for cardiovascular disease (CVD) in adults (Kris-Etherton et al., 2002). In 2004, the Food and Drug Administration recognized the health claim that ω -3 PUFAs may reduce the risk of CVD (FDA, 2004). Studies have also examined the potential benefits of omega-3 fatty acid consumption in infant development and cancer (Riediger et al., 2009). The National Institutes of Health recommend healthy adults receive 650mg daily combined intake of EPA and DHA (Simopoulos, 2008). However, the Institute of Medicine suggests that adult men consume 1.6g/d ALA 10% of which is EPA + DHA and adult women consume 1.1g/d ALA 10% of which is EPA + DHA (Kris-Etherton et al., 2002).

EPA, an ω -3 PUFA, and ω -6 PUFA arachidonic acid (AA 20:4 ω -6) utilize the same enzymes that ultimately catalyze eicosanoid production, which plays a regulatory role in various physiological processes such as blood clotting, blood pressure, and immune function (James, Gibson, & Cleland, 2000). Production of pro-inflammatory 2-series eicosanoids are derived from ω -6 PUFAs; however ω -3 PUFAs competitively inhibit AA metabolism which shifts to 3-series eicosanoid production with lesser inflammatory effects (James, Gibson, & Cleland, 2000). Therefore, an important consideration is the ratio of omega-6 polyunsaturated fatty acids (ω -6 PUFA) to ω -3 PUFA (ω -6/ ω -3) consumed. On average, the typical Western diet contains a 15-20:1 ratio of ω -6/ ω -3 PUFAs; while varying among disease states, the preferred ratio ranges from 1:1- 4:1, (Simopoulos, 2008). Consumers may incorporate ALA, EPA, and DHA

into the diet to achieve a more desirable ratio. A method of incorporating these fatty acids into the diet would be consumption of ω -3 fortified foods.

Surimi: A vehicle for omega-3 enhancement and product development

Surimi is derived from the Japanese term for deboned, minced, washed fish flesh (Park & Lin, 2005). Technology for processing fish in such a way was developed in Japan to maximize utilization of harvested fish (Martín-Sánchez et al., 2009). Alaska pollock is often used for surimi development because this white-flesh fish provides a high quality product in terms of texture, gel strength, and desired color; however, surimi products have also been formulated from poultry meat such as minced spent laying hen, and spent duck meat (Park, 2004; Jin et al., 2011; Nurkhoeriyati, Huda, & Ahmad, 2011).

Surimi seafood is produced and consumed globally with greatest demand in Japan, United States, and European nations (Martín-Sánchez et al., 2009). Japan uses approximately 60% of the world's surimi; however, consumption has slowly declined suggesting Japan's younger generations may be adopting more Western dietary patterns (Park, 2005). In America, the Food and Drug Administration (FDA) regulates terminology for labeling surimi-based products previously known as "imitation" crab legs, lobster meat, etc.; however, in 2006 legislation approved "...-flavored seafood, made with surimi, a fully cooked fish protein" (Billingslea, 2006). Changes in labeling may better represent content of surimi seafood to consumers.

During the processing of surimi seafood, myofibrillar proteins are isolated and then blended with cryoprotectants including low molecular weight carbohydrates such as sorbitol and sucrose, acting to stabilize the actomyosin protein complex during

freezing in turn preventing protein denaturation (Park et al., 2004). Product development varies; however, functional additives and flavoring may be incorporated to create seafood analogs. Therefore, opportunity exists to fortify surimi products with omega-3 rich oils because surimi is comprised largely of protein, some carbohydrate, and small amounts of lipid. Several studies have examined the incorporation and stabilization of omega-3 fatty acids in surimi gels (Tolasa, Lee, & Cakli, 2010; Pérez-Mateos, Boyd, & Lanier, 2004; Park et al., 2004). With the increasing popularity of ω -3 PUFA fortified products (Whelan & Rust, 2006), marketability for an innovative surimi-based product may increase surimi consumption while meeting consumer demands for alternative vehicles of dietary essential ω -3 PUFAs.

Lipid oxidation

Long chain polyunsaturated fatty acids are susceptible to oxidation resulting in undesirable characteristics such as decreased shelf-life and altered nutritional value secondary to rancidity (Faustman et al., 2010). Primary products of lipid peroxidation are highly reactive compounds known as lipid hydroperoxides that remove hydrogen atoms from the fatty acid skeleton ultimately forming acids, aldehydes, alcohols, and ketones (Pratt, Tallman, & Porter, 2011). Lipid oxidation in surimi seafood nutritionally enhanced with omega-3 oils may be assessed using the thiobarbituric reactive substances (TBARS) assay. Light spectrophotometry measures malondialdehyde (MDA) content, a secondary product of lipid oxidation, as it reacts with thiobarbituric acid (TBA) to produce red pigmentation (Wang et al., 2002). Although this assay is sensitive and commonly used to detect lipid peroxidation, TBA may react with other functional ingredients, which could produce interfering colors that are not a result of lipid

oxidation (Fernández, Pérez-Álvarez, & Fernández-López, 1997; Shlafer & Shepard, 1984). In 1984, Ke and others evaluated the rancidity of fish flesh with the application of TBARS values and proposed that values less than 0.58 mg/kg were specified as not rancid, while values ranging from 0.58-1.51 mg/kg were indicative of being slightly rancid but acceptable. Values greater than 1.51 mg/kg should be considered rancid and unacceptable.

Pérez-Mateos and others (2004) concluded that, during a two month chilled storage period, surimi-based crab analogues may be fortified with fish oil (containing antioxidants) up to 2.5% without exhibiting unfavorable effects on stability and quality characteristics. Another study performed in 2004 by Park and others examined stabilization of ω -3 fatty acids from algal oil added to surimi in bulk oil or oil-in-water emulsion. Results indicated that surimi prepared with emulsified oil were more susceptible to lipid oxidation compared with bulk oil preparation possibly because increased lipid surface area. They also evaluated the function of exogenous and endogenous antioxidants on oxidative stability and found that the cryoprotectant, sodium tripolyphosphate effectively inhibited lipid oxidation in surimi. More recently, in 2010, Tolasa, Lee, and Cakli studied the effects of oil dispersion and surimi gel quality in the oxidative stability of ω -PUFAs added to surimi seafood. They recognized that although the surimi seafood industry has begun to add ω -3 oils to products; research regarding lipid oxidation in fortified surimi products is lacking. The findings of this study suggest that formulation of a stable fortified surimi analog is achievable without use of additional antioxidants through a highly cohesive gel matrix with uniform oil dispersion.

Texture

Heating surimi pastes initiates protein denaturation and gelation resulting from formation of hydrogen bonds, ionic linkages, hydrophobic interactions, and covalent bonds (Lanier, Carvajal, & Yongsawatigul, 2005). Surimi gel formation as well as strength is contingent on multiple variables including myofibrillar protein content and functional additives. For example, enzyme and functional additive transglutaminase (TGase) successfully improved the texture of chicken sausage in a study performed by Muguruma and others (2003). In surimi gels, TGase increases protein covalent cross-linkages between amino acids glutamine and lysine therefore creating a stronger gel (Lanier, Carvajal, & Yongsawatigul, 2005; DeJong & Koppelman, 2002).

Textural properties of a gel may be determined via Texture Profile Analysis (TPA), an empirical test used in conjunction with sensory evaluation to provide insight on product acceptance (Kim & Park, 2000). Cheret and others (2005) defined the following TPA parameters: (1) hardness represents maximal force required for sample compression; (2) springiness is the ability of a sample to regain its original form after the deforming force is removed; (3) cohesiveness is the level of deformity a sample may withstand prior to rupturing; (4) gumminess expresses the force required to disintegrate a semisolid sample to a steady state of swallowing (hardness x cohesiveness); (5) chewiness describes the work needed to chew a solid sample to a steady state of swallowing (springiness x gumminess); and (6) resilience displays how well a sample resists to return to its original position (Cheret et al., 2005).

Sensory Evaluation

According to Hein and others, sensory properties of food products testing individual acceptance and preference are essential for determination of food selection; however, methods of evaluation should consider study methodology, practicality, and other relevant factors (2008). Consumer acceptance testing does not directly compare product formulations; however, it does allow for assessment based on a continuum or scale for quantification of acceptability (Hein et al., 2008). Lawless and others compared three commonly used acceptance tests including the labeled magnitude (LAM) scale, 11-point category scale, and the traditional 9-point hedonic scale and found each scale effective in differentiating product acceptability (Lawless, Popper, & Kroll, 2010). On the other hand, preference testing elicits comparison and partiality of products including the best-worst test, which consumers reported as being the easiest scale to use as well as having more confidence in providing accurate information when compared with the 9-point hedonic scale and LAM scale (Hein et al., 2008).

In addition to methods of evaluation, examination of sensory characteristics may provide information concerning quality assurance. Several studies involving shelf life and sensory evaluation of aquatic food products address characteristics such as overall preference, color, appearance, odor, flavor, taste, and texture (Rahman et al., 2007; Cardoso et al., 2009). Attributes may be analyzed by trained and untrained panelists alike in accordance to administered tests. Rahman and others evaluated fish sausages via a trained panel (n=9) to obtain detailed sensory data on textural attributes to compare results with instrumental textural data (Rahman et al., 2007). On the other hand, another study conducted sensory testing using a 9-point hedonic scale with a

larger number of consumer panelists (n=85), who although untrained, provided information concerning acceptance of omega-3 fortified ice-cream sandwiches (Borneo et al., 2007).

Existence for product marketability in the food industry depends on multiple variables including consumer acceptance, preference, attitudes and beliefs, as well as quality characteristic perceptions.

Summary

According to the United States Department of Agriculture (USDA) Economic Research Service, there were approximately 19,000 new food and beverage products introduced to retail outlets in 2009, up by almost 10,000 since the early 1990s (USDA, 2010). Fortification of surimi seafood with ω -3 PUFAs is a recent development in the surimi industry. Research exists on the incorporation of potentially healthful ω -3 oils into surimi gels resembling commercial crab analogue products and its influence on product characteristics such as color, texture, and oxidative stability (Pérez-Mateos, Boyd, & Lanier 2004; Park et al., 2004; Tolasa, Lee, & Cakli, 2010). However, there are no current studies testing quality parameters including sensory analysis of a seafood surimi frank fortified with ω -3 fatty acids. Therefore, the purpose of the present study was to create a surimi frank enhanced with ω -3 oils including DHA and EPA rich salmon oil or plant-based ALA rich flaxseed oil and evaluate product composition, assess quality indicators in vacuum packaging over three week refrigerated storage, and determine sensory characteristics. Proximate composition, fatty acid profile, pH, color, syneresis, lipid oxidation, texture, and consumer perceptions were investigated.

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CHAPTER III

Sensory Characteristics and Storage Quality Indicators of Surimi Franks

Nutritionally Enhanced with Omega-3 Rich Flaxseed Oil and Salmon Oil

Abstract

Surimi, a lean source of fish protein, is consumed worldwide in various forms. Considerable increase in U.S. consumption of surimi products was observed in the 1980s but tapered off in recent decades. Consumer demand for foods enriched with ω -3 fatty acids including DHA and EPA has increased related to potential health benefits. Therefore, the purpose of this study was to (1) create a surimi frank enhanced with ω -3 rich salmon oil or flaxseed oil, (2) evaluate product composition and quality indicators (pH, color $\{L^*, a^*, b^*\}$, syneresis, thiobarbituric acid reactive substances test, and texture) over 21d, and (3) establish product acceptability by sensory evaluation. Frank composition included Alaska pollock surimi, functional additives, and flavoring. Flaxseed or salmon oil was added at 2% based on current recommendations for ω -3 fatty acids. Franks without added oil served as a control. Franks were cooked in sausage casings, vacuum-packed, and stored at 4°C. Proximate analyses (ash, moisture, protein, total fat, and carbohydrate) showed differences ($P < 0.05$) in moisture and fat between the oil-enriched franks and control. Color values did not differ over 21d ($P < 0.05$). There were interactions between sausage types and day in their effect on lipid oxidation ($P < 0.05$); however, there were no changes in pH or MDA concentrations over time ($P > 0.05$). Syneresis of samples did not differ over time or between sample treatments ($P > 0.05$). Differences in textural properties of fortified franks were observed during storage ($P < 0.05$). Control samples became increasingly chewy, gummy, cohesive, and harder after two weeks ($P < 0.05$). Participants ($N = 79$; age 18-35yrs) evaluated product attributes (visual appeal, color, aroma, texture, flavor, and acceptability) via a scale where 1 = Dislike Extremely and 9 = Like Extremely. There were no differences in

sensory attributes ($P>0.05$) between franks. Although 24% of participants claimed to have never consumed surimi, 69% reported consuming sausage on a weekly to monthly basis. Most panelists (63%) indicated interest in purchasing this type product. Results indicate that the surimi franks were generally accepted by young adult consumers, which may indicate market potential of these types of products.

Introduction

Consumer demand of foods containing omega-3 polyunsaturated fatty acids (ω -3 PUFAs), including alpha linolenic acid (ALA, 18:3 ω -3), eicosapentaenoic acid (EPA, 20:5 ω -3), docosahexaenoic acid (DHA, 22:6 ω -3), has increased because of reported health benefits associated with reduced incidence of cardiovascular disease (CVD) (Kris-Etherton et al., 2002). The United States Department of Agriculture (USDA) 2010 Dietary Guidelines for Americans suggest that there is an association with consuming 225g/wk or two servings of a variety of fatty fish and reduced cardiac deaths among individuals with and without pre-existing CVD (USDA & HHS, 2010).

Although a considerable amount of research has examined the link between dietary ω -3 PUFAs and cardiovascular health, recent studies are investigating its affect on other conditions including infant development and cancer (Riediger et al., 2009). EPA competes with omega-6 polyunsaturated fatty acid (ω -6 PUFA) arachidonic acid (AA 20:4 ω -6) for enzymes involved in production of eicosanoids which play a part in regulating physiological processes such as of blood pressure, immune function, and blood clotting (James, Gibson, & Cleland, 2000). One proposed mechanism of action is that pro-inflammatory 2-series eicosanoids are derived mainly from AA (ω -6 PUFA), while ω -3 PUFAs produce 3-series eicosanoids with lesser inflammatory effects (James, Gibson, & Cleland, 2000).

Different sources range in the type and amount of ω -3 PUFAs. While marine oils are concentrated sources of health promoting EPA and DHA, fortification has been associated with decreased palatability (Pérez-Mateos, Boyd, & Lanier, 2004; Jiang et al., 2011). However, salmon oil and tuna oil have shown greater digestibility and

incorporation into tissues compared to flaxseed oil, krill oil, menhaden oil (Tou et al., 2011). In contrast, plant-derived ALA rich flaxseed oil has shown greater consumer acceptability (Simmons et al., 2011; Bermúdez-Aguirre & Barbosa-Cánovas, 2011).

Guidelines of required dosage for health benefits vary and are dependent on factors such as disease state; therefore, a practical consideration for consumers would be to balance the ratio of ω -6 PUFAs to ω -3 PUFAs (ω -6/ ω -3) in the diet (Kris-Etherton et. al, 2002). The typical Western diet contains a 15-20:1 ratio of ω -6/ ω -3 PUFAs, while the preferred ratio ranges from 1:1- 4:1, (Simopoulos, 2008). A more desirable ratio may be achieved by incorporating ω -3 PUFAs (ALA, EPA, and DHA) in the diet. A method of integrating these fatty acids into the diet would be to consume ω -3 PUFA fortified foods.

Processing and development of surimi, an economical method of utilizing marine harvest, involves a series of washing, deboning, and mincing fish muscle (Park & Lin, 2005). Surimi production incorporates underutilized species with lesser commercial value as a protein source offering a more sustainable use of resources (Martín-Sánchez et al., 2009). Recovered proteins, often from white fish species such as Alaska pollock, are combined with low molecular weight carbohydrates including cryoprotectants and sorbitol to prevent protein denaturation during frozen storage (Park & Lin, 2005). Surimi macronutrient composition is largely protein and carbohydrate with little lipid, thus lending opportunity for fortification with healthful ω -3 PUFAs. While ω -3 PUFA enriched surimi seafood products exist on the market in many parts of the world, research examining product quality parameters including lipid oxidation is relatively recent (Pérez-Mateos et al., 2004; Park et al., 2004; Tolasa, Cakli, & Lee, 2010; Pietrowski et

al., 2011). Surimi seafood is flavored and prepared in various forms with a crab-flavored analogue (crabstick) being one of the most recognized in America; however, a more traditional baked, steamed, or fried fish sausage is also available (Park, 2005a). Development of sausages from alternative meat sources including minced fish has shown increasing interest with favorable acceptance (Cardoso et al., 2008; Jin et al., 2007; Rahman et al., 2007)

With increasing popularity of ω -3 PUFA fortified products, marketability for an innovative surimi-based product may meet consumer demands for an alternative vehicle of fortification. The aim of the present study was to create a surimi frank enhanced with ω -3 oils including DHA and EPA rich salmon oil or plant-derived ALA rich flaxseed oil. Product composition, quality characteristics (pH, color, syneresis, lipid oxidation, and texture) during a three week refrigerated storage period, and sensory evaluation were examined.

Materials and Methods

Surimi Frank Development

Frozen surimi blocks comprised of Alaska pollock (*Theragra chalcogramma*), 4% sorbitol, 4% sucrose, 0.15% sodium tripolyphosphate, and 0.15% tetrasodium pyrophosphate were obtained from Trident Seafoods Corporation (Seattle, WA). The product was shipped overnight in thick cardboard boxes surrounded by dry ice and kept at -80°C. Upon arrival, the surimi was cut while frozen into smaller 1kg blocks and then immediately vacuum-packaged in oxygen-impermeable bags. Packaged and labeled surimi was stored in a -80°C freezer.

Formulation of surimi paste was derived and modified from Jaczynski and Park (2004). Twenty-four hr prior to use, surimi was taken from the -80°C freezer and thawed in a 4°C refrigerator. Thawed surimi was cubed and then chopped at low speed for 1 min by a Cuisinart Pro Classic DLC10 Food Processor (East Windsor, NJ 08520). Functional additives (see next paragraph), all in dry form except for the crab paste, were blended along with surimi at low speed for 0.5 min. Final moisture content was adjusted to 78% (390g/500g) by adding ice and 2% (10g/500g) of either flaxseed or salmon omega-3 rich oils to the paste. Flaxseed oil and a salmon oil blend containing 18% eicosapentaenoic acid (EPA) plus 12% docosahexaenoic acid (DHA) were obtained from Jedwards International, Inc. (Quincy, MA). The control surimi product contained no oil treatment. Flaxseed oil was chosen because this plant-based oil contains high concentrations of alpha-linolenic acid (ALA) and is generally less expensive than fish oil. Salmon oil was chosen because it provides a direct source of EPA and DHA. Oil replaced a fraction of the added water in a 1:1 (w/w) ratio. With the addition of oil and

water, surimi paste was blended at low speed for 1 min. After manually scraping the sides of the processor, the paste was blended for an additional 3 min on high speed. Surimi pastes were prepared in 500g batches. Paste was refrigerated at 4°C for up to 12 h to allow transglutaminase (TGase) enzyme action.

The following functional additives and their concentrations were included in the surimi paste formulation:

- 1) 4.9% Circle S Binder (Con Yeager Spice Co., Zelienople, PA) (24.5g/500g) [75% modified potato starch, 12.5% non-fat dry milk, 12.5% sweet dairy whey]
- 2) 2% Powdered Cellulose Fiber (International Fiber Corp. Urbana, OH) (10g/500g)
- 3) 2% Crab Paste (MY-A & Company, Cheverly, MD) [crabmeat, soybean oil, garlic, water, salt, soy sauce powder, pepper, monosodium glutamate] (10g/500g)
- 4) 1.5% Non-Iodized Salt (Morton Salt Inc., Chicago IL) NaCl (7.5g/500g)
- 5) 0.8% Old Bay seasoning (McCormick & Co., Inc. Hunt Valley, MD) (4g/500g) [salt, celery seed, red pepper, black pepper, and paprika]
- 6) 0.5% Transglutaminase (TGase) (Ajinomoto U.S.A. Inc., Teaneck, NJ) (2.5g/500g) [sodium caseinate, maltodextrin, transglutaminase]
- 7) 0.3% Polyphosphate (Con Yeager Spice Co., Zelienople, PA) (1.5g/500g)

Surimi gels resembling commercial crab products were created in various studies using the listed concentrations of NaCl and polyphosphates/starches (Chen & Jaczynski 2007a, 2007b, Pérez-Mateos, Lanier, & Boyd 2006). Cellulose fiber was added to establish desired structure and texture to the surimi product. Flavor and seasoning enhancers were added in various concentrations during preliminary studies. A small panel of faculty/students at West Virginia University taste-tested proto-types and ranked

the most appealing product in terms of taste, texture, color, and overall acceptability. Crab paste and seasoning were added in concentrations according to proto-type acceptability. Binder, often used in sausage production, and the protein-binding enzyme TGase were added to aid in supporting the product's textural integrity.

Uniform sized surimi franks were made with the surimi pastes by stuffing the surimi pastes into stainless steel tubes (length = 17.5 cm, internal diameter = 1.9 cm) with screw end caps. Surimi franks were cooked in a 90°C water bath for 15 min and then immediately chilled in an ice bath for approximately 5 min or until room temperature. These uniformly sized franks were used to characterize proximate composition, fat composition (fatty acid profile [FAP]), pH, color (tristimulus color values [L*a*b*]), syneresis, fat oxidation (thiobarbituric reactive substances [TBARS]), and texture (texture profile analysis [TPA]). Uniform franks were vacuum-packed and stored at 4° C until analyses were performed.

Surimi Frank Analysis

Proximate Composition: Crude protein, total fat, ash, moisture, and carbohydrate (by difference) of the surimi franks were determined (AOAC, 1995). The Kjeldahl assay was performed for crude protein determination and the Soxhlet extraction method was used to determine total fat content of samples. Ground samples were incinerated in a muffle furnace at 550 °C for 24 hr to determine ash content. Moisture content was determined by spreading a 2 g sample on an aluminum dish (Fisher Scientific Co., Fairlawn, NJ) and drying the sample at 105 °C for 24 hr. Carbohydrate content was calculated by difference (FAO, 1998). Measurements were taken in duplicate and reported as g/100 g (wet weight basis).

Fatty Acid Profile (FAP): Fatty acid profile was determined according to the AOAC official methods 996.06 and 965.49 (2002). Fatty acid methyl esters (FAMES) were generated from lipids extracted via acid hydrolysis into petroleum ether. A capillary gas-liquid chromatograph (GLC) Model 7890A (Agilent Technologies, Santa Clara, CA) measured the isolated FAMES against an internal standard (C19:1). The carrier gas, helium, was used at a flow rate of 0.75ml/min and a 200:1 split ratio. A 4 min holding temperature of 100°C was increased by 3°C/min to a final temperature of 240°C. This final temperature was held for 15 min. The injector temperature was 225°C and the detector temperature was 285°C. Identification of fatty acids was determined by using known standards and references to compare fatty acid retention times (Ackman, 1980). Duplicate measurements taken for each treatment and expressed as mean mg/g ($\pm$ standard deviation).

pH: Surface pH was tested using the pH/ion analyzer (Model 350, Corning Inc.; Corning NY, USA). The analyzer probe was placed on the external cylindrical surface of the room temperature frank and readings were taken in triplicate on days 0, 7, 14, and 21.

Color: A Minolta Chroma Meter CR-300 colorimeter was calibrated with a standard white-plate No.21333180 (CIE L 93.1; a* 0.3135; b* 0.3198) and used on room temperature surimi frank samples to determine color changes during storage (Minolta Camera Co. Ltd., Osaka, Japan). Color was quantified as tri-stimulus L* a* b* values. Readings were taken on three cylindrical samples per treatment (height = 2.54 cm, diameter = 1.90 cm) on days 0, 7, 14, and 21.

Syneresis: Water expulsion from the surimi frank, or syneresis, was assessed in triplicate over the 21-day storage period (days 7, 14, and 21) by using the following calculation (Cardoso et al. 2008):

$$\% \text{ weight loss} = [(\text{initial weight} - \text{final weight}) / \text{initial weight}] \times 100\%$$

Surimi franks were weighed prior to packaging (initial weight). The final weight was determined after franks were removed from packaging and dried on filter paper for 5min.

Thiobarbituric Acid Reactive Substances (TBARS): Lipid oxidation of the surimi franks were measured in duplicate over a 21-day storage period by a 2-thiobarbituric acid reactive substances (TBARS) assay as previously described (Chen et al., 2008; Jaczynski & Park, 2003). The absorbance of malondialdehyde (MDA), a byproduct of oxidative rancidity, was measured at 535 nm with a UV/Vis spectrophotometer (model DU530, Beckman Instruments, Fullerton, CA). TBARS values were calculated using molar absorptivity of MDA ($156,000 \text{ M}^{-1} \text{ cm}^{-1}$) at 535 nm and reported as mg of MDA per kg of cooked frank sample.

Texture Profile Analysis (TPA): Changes in TPA of surimi franks over a 21-day storage period were determined. Measurements were taken in triplicate on days 0, 7, 14 and 21. A model TA-HDi texture analyzer (Texture Technologies Corp., Scarsdale, NY) with a 70-mm compression plate attachment was programmed to move at a rate of 127 mm/min for two-cycle compression of room temperature samples (length = 2.54 cm, diameter = 1.90 cm) at 50% compression (Cheret et al., 2005). Force vs. displacement over time was recorded to determine sample textural properties including hardness, cohesiveness, chewiness, gumminess, springiness, and resilience (Chen and

Jaczynski, 2007a; 2007b; Taskaya et al., 2009a; 2009b; 2009c). According to Cheret et al. (2005): hardness is represented by the maximum force of initial compression; springiness is the sample's capacity to return to its original shape post sample compression; cohesiveness is sample deformability prior to rupture; gumminess (cohesiveness x hardness) refers to the force needed to pulverize a sample so it may be swallowed at a steady state; chewiness (springiness x gumminess) is the amount of exertion required to chew a sample to achieve a steady swallow state; and resilience is the level of opposition the sample provides to restore original formation.

Sensory Evaluation: Using a Kitchen Aid Professional 600TM mixer and sausage stuffer (KP26MIX, St. Joseph, MI), the surimi paste was stuffed into 2.54 cm diameter collagen casings (Nitta Casings Inc., Somerville, NJ) and 15 cm links were tied off with twine. Surimi franks were cooked in a 90° C water bath for 15 min and then chilled in an ice bath for approximately 5 min. Cooked franks were tested for microbial growth by aerobic plate count after cooking. Ten g of cooked surimi franks were minced until uniformly mixed in a filtered stomacher bag with 90 mL of deionized, distilled water. A micropipette was used to isolate 0.1 mL of sample mixture for spread plating on a Trypticase Soy Agar (TSA; Difco, Becton Dickinson, Sparks, MD) plate. Plates were incubated (Fisher Scientific low temperature incubator) at 35° C for 24 hours and then the colonies were counted. Aerobic bacterial contamination was not detected.

Collagen casings were removed and franks were cut into 1 cm thick discs, placed in lidded soufflé cups encoded with a random 3-digit numerical code and held in a warming oven at 70° C until sensory evaluation was conducted. Samples were not held longer than 1 h. The sensory evaluation of the surimi franks was carried out in the

Kitchen and Foods Lab at West Virginia University (WVU). Participants (> 18yrs) were recruited from the faculty, staff, and students of the Davis College of Agriculture, Natural Resources and Design at WVU. Prior to testing, participants were assigned to a private evaluation station and instructed to read an informational hand-out approved by the Institutional Review Board at WVU. A pre-testing questionnaire was given to screen for food allergies and assess the panelist demographics, dietary habits and fish consumption. Panelists were then presented with one set of three coded samples in a balanced randomized order and instructed to taste samples one at a time from left to right. Room temperature water and unsalted crackers were provided to cleanse the palate between tastings. Panelists evaluated visual appeal, color, aroma, flavor, and overall acceptability using a 9-point scale where 1 = dislike extremely and 9 = like extremely. Room was provided on the scorecard for comments on each sample.

A second set of three samples coded with different 3-digit codes was presented in a balanced randomized order. Panelists were asked to taste the samples as described above and “rank” them from most liked = 1 to least liked = 3.

Statistical Analysis: The storage portion of this study was replicated at least three times. Measurements were performed in triplicate for the determination of pH, color, weight loss, and TPA. Two measurements were completed for proximate composition (moisture, protein, total fat, and ash), FAP, and TBARS. A 3 x 4 factorial experiment in a completely randomized design with sub-sampling was used. Data were analyzed using one-way analysis of variance (ANOVA) where the two factors were frank type with levels no added oil control, flaxseed oil, and salmon oil and time with levels 0, 7, 14, and 21 d. All data are reported as mean $\pm$ standard deviation, including sensory

data, and were analyzed using SAS Software (SAS Institute, 2002). A significance level of 0.05 was set and separation of means was determined using Tukey's Honestly Significant Differences Test.

Results and Discussion

Proximate Composition

Reported proximate composition of surimi (wet weight basis) are 76.3, 15.2, 0.9, 0.6, 6.85 g/100g for moisture, crude protein, total fat, ash, and carbohydrate (by difference) respectively (USDA, 2011). In comparison, the composition of control surimi franks without added oil was 73.7, 10.5, 1.7, 2.0, and 11.8 g/100g for moisture, crude protein, total fat, ash, and carbohydrate respectively (Table 1). Although functional additives contributed some variation in USDA surimi compared with the control surimi frank composition, total ash and protein content of control samples were similar to crab flavored surimi gels reported in Pietrowski and others (2011). Crab paste, used for flavoring, contained soybean oil, which explains the higher total fat content in control franks. Expectedly, the total lipid and moisture content of 2% oil-enriched surimi franks were significantly different ($P<0.05$) from control franks. Protein, ash, and carbohydrate (wet weight basis) were generally the same between samples.

Fatty Acid Profile (FAP)

The major ω -3 PUFAs and ω -6 PUFAs in cooked surimi franks with and without the addition of flaxseed or salmon oils are shown in Figure 1. In all samples AA was not detected; however, concentrations of LA (18:2 ω 6) ranged from 1.8-2.8mg/g for all frank variations, with the no added oil control having the highest concentration. Surimi franks were flavored with crab paste that contained soybean oil, which likely contributed to the LA and ALA content in all the franks. In addition, the crabmeat in the crab paste flavoring likely contributed to the presence of EPA and DHA in the franks; which were not seen in the no-oil added surimi-seafood developed by Pietrowski et al. (2011) who

used water-soluble crab flavoring in lieu of the crab paste used in this current study. Surimi franks with added flaxseed oil, a rich source of ALA (Przybylski, 2005), had expectedly greater amounts of ALA (3.4 mg/g) than the salmon oil (0.35 mg/g) and control (0.62 mg/g) franks with soybean oil in the crab paste supplying some ALA. Samples fortified with ω -3 PUFA rich oils did contain significantly more total ω -3 PUFAs and less total ω -6 PUFAs ($P<0.05$) (Figure 2). Concentrations of EPA and DHA, similar in control and flaxseed franks at approximately 2%, were significantly greater in the salmon franks at 0.97 mg/g EPA and 0.52 mg/g DHA ($P<0.05$). Total UFAs were similar between groups; however, the UFAs/SFAs ratio (Table 2) for cooked surimi franks was lower ($P<0.05$) in salmon oil added samples. The ω -6/ ω -3 ratio approximated 1:1 in oil added franks while control franks approached 3:1 (Table 2). EPA utilizes the same enzymes as AA to catalyze eicosanoid production, with ω -3 PUFAs yielding lesser inflammatory effects (James, Gibson, & Cleland, 2000). Therefore a balance of ω -6/ ω -3 intake is suggested to promote health with a desirable range of 1:1-4:1; however the current Western diet ranges from 15-20:1 (Simopoulos, 2008).

Surface pH

There were no significant differences in pH between no added oil franks and experimental franks on each day of storage ($P>0.05$). The average pH of cooked surimi franks were acidic ranging from 6.41-6.73. A pH of surimi between 7-7.2 has been shown to support gel formation while extremely acidic or alkaline pH increases muscle protein solubility leading to denaturation of protein gels (Lanier & Carvajal, 2005; Park, 2005b; Park & Lin, 2005). Liu and others (2010) found that at a pH 5.5-7.5 fish myosin formed a gel but structural integrity declined as pH shifted from neutral. There were no

changes in pH over time in any of the treatments ($P>0.05$). Vacuum packing in gas impermeable bags and storage temperature most likely contributed to the maintenance of pH over time.

Color

Results from the tristimulus ($L^* a^* b^*$) color test reported in Table 3 indicate no change in color of surimi franks over storage time ($P>0.05$). However, the lightness, or L^* value, of experimental samples were statistically different from control samples. Representative of a scale from black = 0 to white = 100, L^* values quantify light absorbed and reflected off the surface of an object. Franks with added flaxseed oil and salmon oil measured lighter in color than the control (71.6 ± 1.6) at 74.5 ± 1.5 and 74.2 ± 1.3 respectively ($P<0.05$). This trend is consistent with current literature (Pietrowski et al., 2011, Pérez-Mateos, Lanier, & Boyd, 2006, Chen & Jaczynski, 2007b). Pérez-Mateos and others (2006) suggest that lipid droplet suspension in the surimi gel scatters light thus increasing light reflection and subsequently L^* values. In terms of favorability in color of surimi franks, the sensory analysis (Table 6) results did not indicate differences in preference of color between fortified and control samples ($P>0.05$).

Negative a^* values represent a greenish color. Surimi franks displayed more of a reddish hue, characterized by positive a^* measurements, that is commonly seen in animal protein sausages on the market. Since surimi is generally white, it is apparent that ingredients used for seasoning and flavor (likely red pepper and paprika) were direct sources of coloration. Measurements of a^* over time and between control (9.6 ± 1.4), flaxseed oil (9.2 ± 0.8), and salmon oil (9.3 ± 0.8) franks did not differ ($P>0.05$). Positive b^* values indicate yellowish coloration while negative b^* values represent bluish

coloration. Positive b^* values of 36.3 ± 2.1 , 35.9 ± 1.6 , and 35.6 ± 1.1 in control, flaxseed, and salmon samples showed no significant difference between samples or over time ($P > 0.05$). Variation in measurements may be explained by random distribution of spice flecks in samples and its potential interference in color readings.

Syneresis

Syneresis or exudation of water, from surimi franks ranged from 6.3% to 7.5% and did not significantly differ between experimental and control franks ($P > 0.05$). This observed percent loss was similar to low-fat chicken sausages at 4%-10% (Andrés et al., 2006) and low-fat fat beef frankfurters at approximately 2%-8% loss (Candogan & Kolsarici, 2003). Percent weight loss exhibited no significant relationship over the 21-day storage time ($P > 0.05$). Water holding capacity of a protein gel may be increased by bipolymeric ingredients including starch, milk proteins, and cellulose (used in present study) (Lee, 2002). Lee suggests thermal activation of modified starch, a water-binding agent in surimi gels, may occur through granule gelatinization and swelling (2002). The starches in surimi franks most likely improved its water retention. Minimizing retrogradation of water in gel-based composite foods is important for desirable texture as well as freeze-thaw stability during storage (Park, Lee, & Yoon, 2008; Lee, 2002).

Thiobarbituric Reactive Substances (TBARS)

The thiobarbituric reactive substances (TBARS) assay uses light spectrophotometry to measure red pigmentation produced when malondialdehyde (MDA), a secondary product of lipid oxidation, reacts with thiobarbituric acid (TBA) (Wang et al., 2002). The concentration of MDA has been used to predict oxidative stability of surimi seafood products (Pietrowski et al., 2011; Pérez-Mateos, Boyd, &

Lanier, 2004). In the present study, results from TBARS analysis indicate there were significant differences in MDA concentrations between experimental treatments ($P < 0.05$); however, this was independent of storage time ($P > 0.05$). Day 0 concentrations of MDA in salmon oil franks were significantly greater than both the no-oil added control franks and the flaxseed oil franks ($P < 0.05$). It is likely that the salmon oil had undergone some degree of lipid oxidation due to the greater amounts of long chain ω -3 PUFAs, EPA and DHA. There was no significant change over time in MDA concentrations of control, flaxseed oil, or salmon oil franks ($P > 0.05$); likely due to vacuum packaging.

Ke and others (1984) proposed that MDA concentrations of fish flesh less than 0.58 mg/kg were specified as not rancid, values 0.58-1.51 mg/kg were indicative of being slightly rancid but acceptable, and values greater than 1.51 mg/kg should be considered rancid and unacceptable. According to this scale, control and flaxseed franks would be considered slightly rancid but acceptable while salmon franks would be rancid and unacceptable. Concentrations of MDA in salmon franks ranging from 1.25mg/kg-2.00 mg/kg over the 21-day storage period were similar to fish sausages developed from African walking catfish with the addition of 2% marine oil (~1.00mg/kg-~3.00mg/kg) over three weeks refrigerated storage (Panpipat & Yongsawatdigul, 2008). Surimi franks were not solely comprised of white fish flesh and its reddish coloration may have interfered with spectrophotometer readings used to calculate MDA concentrations. Although the TBARS assay is commonly performed to measure lipid oxidation in meat, it is proposed that interfering agents including pigments, nitrites, and sucrose may influence spectrophotometric readings and yield altered results

(Fernández, Pérez-Álvarez, & Fernández-López, 1997; Shlafer & Shepard, 1984).

Therefore, examining changes in TBARS values between samples and over time may be more indicative of oxidative stability of surimi franks than the actual TBARS value.

Texture Profile Analysis (TPA)

The texture profile of cooked surimi franks with and without added oil is shown in Tables 5-10. On day 14, control surimi franks were significantly harder, more cohesive, gummier, and chewier than flaxseed oil surimi franks ($P < 0.05$). The resilience of flaxseed oil surimi franks decreased after the first week ($P < 0.05$), but remained consistent from days 7 to 21 ($P > 0.05$). Salmon oil surimi franks were more cohesive on day 14; however, there was no significant difference by the end of the storage period ($P < 0.05$). Similarly, control samples containing no added oil became harder, more cohesive, gummier, and chewier on day 14 ($P < 0.05$), though by day 21 there were no significant differences in these parameters ($P > 0.05$) (Figure 3). Cardoso and others (2009) reported similar results with increased hardness, gumminess, and chewiness during refrigerated storage of low-fat fish sausages containing dietary fiber. They acknowledged the theory that increase in hardness over time may be attributed to water loss during storage; however, similar to Cardoso and others (2009), in the present study there were no significant differences in syneresis between treatments or over storage time ($P > 0.05$).

Transglutaminase and other starches including cellulose powder, a beta-1,4-glycan polymer, may work synergistically to improve water-binding capacity and gel formation in minced fish muscle (Borderías, Sánchez-Alonso, & Pérez-Mateos, 2005; Benjakul & Visessanguan, 2003). Transglutaminase is a water-soluble enzyme that

catalyzes formation of covalent bonds between glutamine and lysine amino acids, therefore increasing the strength, or more specifically hardness of surimi gels (Lanier & Carvajal, 2005; Park, 2005b). This enzyme functions to set surimi gels; however, its activity is temporary and diminished with thermal processing (Takeda & Seki, 1996). Control franks contained greater moisture content and lower lipid levels than oil-enriched samples. Lesser fat, an emulsifying agent that imparts tenderness to sausages, in the control franks may have influenced textural properties (Sun & Holley, 2011). It is also possible that in the control franks more moisture was available for absorption from porous cellulose powder; therefore increasing gel hardness, cohesiveness, chewiness, and gumminess as these are factors of each other.

Sensory Evaluation

Demographics of panelists. Participants (N=79) recruited from the Davis College of Agriculture, Natural Resources and Design at West Virginia University were between the ages of 18-35yrs. Almost a quarter (23%) of participants claimed to have never consumed surimi products. Of this group, one third stated preference to “real crabmeat” as the reason for not trying surimi-based seafood. Surprisingly, 69% of participants claimed to consume sausage on a weekly to monthly basis. While 95% of panelists felt that it was important to consume ω -3 fatty acids, 85% of these individuals claimed to be unfamiliar with ALA, DHA, and EPA. A majority (63%) of participants stated that they were likely to buy a product similar to the surimi franks.

Attribute testing and ranking. Results from the attribute test and are shown in Table 11. There were no statistically significant differences ($P>0.05$) in panelist attribute scoring. Panelists favorably approved all surimi frank formulations with mean scores for

overall acceptability at 5.6, 5.8, and 5.4 (for control, flaxseed, and salmon treatments) on a 9-point scale. Lower visual appeal scores may be improved by presentation and method of preparation. There was no significant difference between control (2.03 ± 0.8), flaxseed (1.83 ± 0.8), and salmon (2.13 ± 0.8) in panelist ranking preference of surimi franks.

Conclusions

Alaska pollock surimi was used as a vehicle for development of nutritionally enhanced surimi franks with either flaxseed oil or salmon oil, which increased ω -3 PUFA concentrations of ALA as well as EPA and DHA, respectively. Evaluation of quality parameters show that although textural properties varied, pH, color, syneresis, and TBARS values of fortified franks were generally unchanged during the 21-day refrigerated storage period. Sensory evaluation results indicate that the surimi franks were accepted by young adult consumers, which may indicate market potential of this type product. However, future studies should assess various packaging methods and the addition of antioxidants to reduce lipid oxidation as well as maintain sensory attributes over storage.

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Table 1: Proximate composition of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oil. Proximate composition expressed in g/100g on a wet weight basis.

	Moisture	Crude Protein	Total Lipid	Ash	Carbohydrate
Control	73.7±0.0 A	10.5±0.4 A	1.7±0.7 B	2.0±0.3 A	11.8±1.0 A
Flaxseed	71.3±0.0 B	10.3±0.2 A	3.9±0.7 A	2.3± 0.1 A	12.2±0.7 A
Salmon	71.8±0.0 B	9.7±0.2 A	3.7±0.6 A	2.3±0.2 A	12.2±1.1 A

Different uppercase letters within the same column indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation (n=4).

Table 2. The omega-6/omega-3 fatty acids (ω -6/ ω -3) ratio and unsaturated/saturated (UFAs/SFAs) ratio for cooked surimi franks with and without the addition of flaxseed and salmon oils.

	Control	Flaxseed	Salmon
ω-6/ω-3	2.7 $\pm$ 0.02 a	0.6 $\pm$ 0.04 c	1.0 $\pm$ 0.03 b
UFAs/SFAs	6.4 $\pm$ 0.50 a	6.2 $\pm$ 0.47 a	3.0 $\pm$ 0.39 b

Different lowercase letters within the same row indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation (n=3).

Table 3: Color analysis of control surimi frank with no added oil and experimental franks with addition of either flaxseed oil or salmon oil over a 21-day storage period. There were no changes ($P>0.05$) over a 21-day storage period, data were combined.

	Control	Flaxseed	Salmon
L*	71.6 ± 1.6 b	74.5 ± 1.5 a	74.2 ± 1.3 a
a*	9.6 ± 1.4 a	9.2 ± 0.8 a	9.3 ± 0.8 a
b*	36.3 ± 2.1 a	35.9 ± 1.6 a	35.6 ± 1.1 a

Different lowercase letters within the same row indicate significant differences (Tukey HSD mean pair comparison, $P<0.05$). Data expressed as mean value ± standard deviation (n=4).

Table 4: mg MDA/kg sample in control surimi frank with no added oil and experimental surimi franks with addition of flaxseed oil or salmon oil over a 21-day storage period with no significant differences in each treatment over time ($P>0.05$).

Treatment	Day 0	Day 7	Day 14	Day 21
Control	0.84±0.3 B	0.85±0.2 A	0.71±0.4 B	0.58±0.4 B
Flaxseed	0.92±0.2 B	1.10±0.4 A	1.41±0.7 A	0.94±0.4 AB
Salmon	1.99±0.4 A	2.00±1.3 A	1.25±0.3 AB	1.86±0.6 A

Different uppercase letters within the same column indicate significant differences (Tukey HSD mean pair comparison, $P<0.05$). Data expressed as mean value $\pm$ standard deviation ($n=3$).

Table 5. Hardness of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils over a 21-day storage period.

Treatment	Day 0	Day 7	Day 14	Day 21
Control	1133.0±674.0 b	1771.1±401.8 ab	1990.0±475.6 A, a	1735.0±603.9 ab
Flaxseed	935.3±383.7	1451.7±489.5	1193.1±487.8 B	1274.1±523.8
Salmon	1074.6±546.4	1590.6±520.0	1413.0±503.4 AB	1515.4±524.9

Different uppercase letters within the same column indicate significant differences. Different lowercase letters within the same row indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation (n=4).

Table 6. Springiness of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils over a 21-day storage period with no significant differences in each treatment over time or between treatments on each day ($P>0.05$).

Treatment	Day 0	Day 7	Day 14	Day 21
Control	2.1±0.2	2.0±0.0	2.0±0.0	2.0±0.1
Flaxseed	2.0±0.4	1.9±0.4	2.0± 0.1	1.9±0.4
Salmon	1.9±0.5	1.9±0.1	2.0± 0.1	2.0± 0.0

Data expressed as mean value ± standard deviation (n=4).

Table 7. Cohesiveness of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils over a 21-day storage period.

Treatment	Day 0	Day 7	Day 14	Day 21
Control	0.61±0.2 b	0.72±0.0 a	0.73±0.0 A, a	0.67±0.1 ab
Flaxseed	0.48±0.1	0.61±0.1	0.59±0.1 B	0.58±0.1
Salmon	0.52±0.1 b	0.66±0.1 ab	0.68±0.1 AB, a	0.63±0.1 ab

Different uppercase letters within the same column indicate significant differences. Different lowercase letters within the same row indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation ($n=4$).

Table 8. Gumminess of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils over a 21-day storage period.

Treatment	Day 0	Day 7	Day 14	Day 21
Control	730.1±504.7 b	1282.7±323.7 ab	1463.9±397.5 A, a	1205.3±324.6 ab
Flaxseed	499.6±324.1	941.7±460.6	759.1±442.6 B	791.2±468.5
Salmon	621.9±432.2	1093.2±465.7	954.9±383.1 AB	1013.3±413.2

Different uppercase letters within the same column indicate significant differences. Different lowercase letters within the same row indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation (n=4).

Table 9. Chewiness of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils over a 21-day storage period.

Treatment	Day 0	Day 7	Day 14	Day 21
Control	1472.2±972.1 b	2509.5±624.1 ab	2864.0±748.7 A, a	2391.7±629.0 ab
Flaxseed	1016.9±641.1	1812.3±970.8	1509.8±850.8 B	1494.8±929.8
Salmon	1238.1±800.6	2095.3±899.2	1876.7±747.9 AB	2022.9±821.6

Different uppercase letters within the same column indicate significant differences. Different lowercase letters within the same row indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation (n=4).

Table 10. Resilience of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils over a 21- day storage period.

Treatment	Day 0	Day 7	Day 14	Day 21
Control	0.4±0.2	0.4±0.0	0.4±0.0	0.4±0.0
Flaxseed	0.6±0.3 a	0.4±0.1 b	0.4±0.1 b	0.3± 0.1 b
Salmon	0.4±0.2	0.4±0.1	0.4±0.0	0.4±0.0

Different lowercase letters within the same row indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation (n=4).

Table 11: Sensory attribute evaluation of control surimi frank with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils. There were no significant differences between treatments ($P>0.05$).

Treatment	Visual Appeal	Color	Aroma	Texture	Flavor	Overall Acceptability
Control	4.9±1.7	5.3±1.8	5.8±2.1	5.0±2.0	5.9±2.3	5.6±2.1
Flaxseed	4.8±1.6	5.2±1.6	5.7±2.0	5.3±1.9	6.0±2.2	5.8±2.1
Salmon	4.7±1.6	5.1±1.7	5.4±2.0	5.0±1.8	5.7±2.0	5.4±1.9

Data expressed as mean value $\pm$ standard deviation (N=79). Attributes were scored using a 9-point hedonic scale 1=Dislike Extremely, 2=Dislike Very Much, 3=Dislike Moderately, 4=Dislike Slightly, 5=Neither Like or Dislike, 6=Like Slightly, 7=Like Moderately, 8=Like Very Much, 9=Like Extremely.

Figure 1. Major fatty acids* (FAs) of control surimi franks with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils. Data are expressed as mean values $\pm$ standard deviation (n=3). Different lowercase letters on bars indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$) between mean values within the same FA.

*ALA – linolenic (18:3 ω 3), EPA – eicosapentaenoic (20:5 ω 3), DHA – docosahexaenoic (22:6 ω 3), LA – linoleic (18:2 ω 6), and AA – arachidonic (AA, 20:4 ω 6).

Figure 2. The omega-6 (ω -6), omega-3 (ω -3), unsaturated (UFAs), and saturated (SFAs) fatty acids* for control surimi franks with no added oil and experimental surimi franks with the addition of flaxseed or salmon oils. Data are expressed as mean values $\pm$ standard deviation (n=3). Different lowercase letters on bars indicate significant differences (Tukey HSD mean pair comparison, $P < 0.05$) between mean values within the same FA.

* ω -3 – total ω -3 FAs, ω -6 – total ω -6 FAs, SFA – total saturated FAs, and UFA – total unsaturated FAs.

Figure 3. Hardness, Gumminess, and Chewiness of cooked surimi franks without added oil over 21-day storage period.

Different lowercase letters indicate significant differences. (Tukey HSD mean pair comparison, $P < 0.05$). Data expressed as mean value $\pm$ standard deviation.

APPENDICES

Appendix I: Additional Tables

pH of no added oil control surimi franks and experimental surimi franks with the addition of either flaxseed oil or salmon oil over a 21-day storage period with no significant differences in each treatment over time or between treatments on each day ($P>0.05$).

Treatment	Day 0	Day 7	Day 14	Day 21
Control	6.68±0.3	6.73±0.2	6.56±0.3	6.50±0.0
Flaxseed	6.71±0.2	6.73±0.1	6.59±0.0	6.55±0.2
Salmon	6.72±0.2	6.71±0.1	6.58±0.2	6.41±0.3

Data expressed as mean value ± standard deviation (n=4).

L* or lightness color values of no added oil control surimi franks and experimental surimi franks with the addition of either flaxseed oil or salmon oil over a 21-day storage period with no significant differences in each treatment over time ($P>0.05$).

Treatment	Day 0	Day 7	Day 14	Day 21
Control	71.9± 2.1 B	72.3±1.6 A	70.5±2.4 B	71.5±2.1 A
Flaxseed	74.3± 2.2 A	74.4±1.5 A	74.8±1.9 A	74.4±2.2 A
Salmon	75.2± 1.7 A	74.2±1.3 A	74.7±1.2 A	73.9±1.6 A

Different uppercase letters within the same column indicate significant differences (Tukey HSD mean pair comparison, $P<0.05$). Data expressed as mean value ± standard deviation (n=4).

a* color values (positive value = reddish hue, negative value = greenish hue) of control surimi frank and experimental surimi franks with addition of either flaxseed oil or salmon oil over 21-day storage period with no significant differences in each treatment over time or between treatments on each day ($P>0.05$)

Treatment	Day 0	Day 7	Day 14	Day 21
Control	9.6±2.1	9.7±1.8	9.4±1.1	9.6±1.3
Flaxseed	8.7±1.1	9.4±0.9	9.1±0.9	9.5±1.1
Salmon	8.8±1.2	9.3±0.5	9.5±1.1	9.7±0.4

Data expressed as mean value ± standard deviation (n=4).

b* color values (positive value = yellowish, negative value = bluish hue) of control surimi frank and experimental surimi franks with addition of either flaxseed oil or salmon oil over a 21-day storage period with no significant differences in each treatment over time or between treatments on each day ($P>0.05$).

Treatment	Day 0	Day 7	Day 14	Day 21
Control	37.1±2.7	36.8±3.1	36.1±2.0	35.0±2.6
Flaxseed	36.2±2.4	36.5±1.8	35.1±1.8	35.7±2.7
Salmon	35.6±1.3	35.4±1.3	35.9±1.9	35.4±1.5

Data expressed as mean value ± standard deviation (n=4).

Syneresis expressed as percent weight loss of control surimi franks and experimental surimi franks with the addition of flaxseed or salmon oil over a 21-day storage period with no significant differences in each treatment over time or between treatments on each day ($P>0.05$).

Treatment	Day 7	Day 14	Day 21
Control	6.8±0.02	6.8±0.02	6.8±0.01
Flaxseed	6.3±0.01	6.5±0.01	7.0±0.01
Salmon	7.5±0.01	6.8±0.02	6.3±0.01

Data expressed as mean value ± standard deviation (n=4).

Appendix II: Consent Form

Project Title: Sensory evaluation of surimi franks nutritionally enhanced with omega-3 oils

Investigators: Kristen Matak, Assistant Professor
Division of Animal and Nutritional Sciences

Christin Sell, Graduate Student
Nutritional and Food Science

I. Purpose of this Research/Project

The purpose of this Masters level research project is to determine the interest of consuming a sausage made from omega-3 enhanced surimi and its sensory attributes.

II. Procedures

Three randomized coded samples will be provided to panelists for sensory evaluation. Product visual appeal, color, aroma, flavor, texture, and overall liking will be evaluated based on a 9-point hedonic scale. The panelist will then rank the three samples according to what they liked best. Additional descriptive remarks and observations are encouraged.

III. Benefits/Risks

Participants must be 18 years or older to be a panelist.

Your participation in the project will provide information about willingness to consume a sausage composed of omega-3 enhanced surimi. Data will also be gathered on sensory attributes of surimi franks containing different sources of omega-3 fatty acids. All participants will have access to panel results upon study completion.

No identifiable risks are associated with product sampling.

IV. Anonymity and Confidentiality

The results of your performance are strictly confidential. Individual panelists will not be referred to in any publications or reviews.

V. Compensation

Participants will not receive any form of monetary compensation, but participation will result in the experiential gain of contributing to food sensory research.

VI. Freedom to Withdraw

Subjects are free to withdraw, without penalty, from this study at any point in time. The success of the sensory evaluation is dependent on your completion of each session; however, during the panel (at any time) if you choose not to participate please notify an investigator.

VII. Approval of Research

This research has been acknowledged by the Institutional Review Board for projects involving human subjects at West Virginia University. The IRB Review is on file.

Please contact the individuals listed below if you have any pertinent questions about this research or its conduct, research subjects' rights, and/or emergency contacts in the event of research-related injury to the subject.

Kristen Matak (Investigator) Phone: (304) 293-2631 x 4401

Christin Sell (Investigator) Phone: (304) 293-2159

Matthew Wilson (Director ANS) Phone: (302) 293-2231 x 4413

WVU Institutional Review Board Phone: (304) 293-7073

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Equal Opportunity/Affirmative Action Institution

Appendix III: Prescreening Questionnaire

History:

Name: _____

Age Range: 18 – 35 years ____ 36 – 55 years ____ 56 + years ____

Sex: Male ____ Female ____

Health:

Please indicate any food allergies/intolerances:

Is there any reason (i.e. medication use, treatment, disorders) that your sense of taste, smell, or vision may be impaired?

Food Habits: (Please place a check by the option that best represents your response. Elaborate if necessary.)

1. How often do you consume surimi products (i.e. imitation crab meat)?
Never ____ Yearly ____ On Occasion ____ Monthly ____ Weekly ____ Daily ____
If never, why? _____
2. How often do you consume sausage products (made from turkey, pork, beef, tofu, etc.)?
Never ____ Yearly ____ On Occasion ____ Monthly ____ Weekly ____ Daily ____
If never, why? _____
3. How comfortable are you with trying new/different food products?
Not at all comfortable ____ Somewhat comfortable ____ Very comfortable ____
4. Are you familiar with ALA, DHA and/or EPA? Yes ____ No ____
If yes, explain _____
5. How important is it for you to consume omega-3 fatty acids?
Very important ____ Somewhat important ____ Not important ____
6. How likely are you to purchase and consume a sausage developed from lean, high protein surimi enriched with omega-3 oils? Very likely ____ Somewhat likely ____ Not likely ____

Appendix IV: Ranking Form

Ranking Form

Instructions: Please rank each sample from 1-3 (1 being the sample you like the most and 3 being the sample you least liked). Assign one number to each sample and use each number once.

Sample #:_____ Rank: _____

Sample #:_____ Rank: _____

Sample #:_____ Rank: _____

Ranking Form

Instructions: Please rank each sample from 1-3 (1 being the sample you like the most and 3 being the sample you least liked). Assign one number to each sample and use each number once.

Sample #:_____ Rank: _____

Sample #:_____ Rank: _____

Sample #:_____ Rank: _____

Ranking Form

Instructions: Please rank each sample from 1-3 (1 being the sample you like the most and 3 being the sample you least liked). Assign one number to each sample and use each number once.

Sample #:_____ Rank: _____

Sample #:_____ Rank: _____

Sample #:_____ Rank: _____

Appendix V: Hedonic Scale Form

Instructions: Each panelist will receive 3 surimi frank samples. For each sample, use the scale below to rate product characteristics i.e. visual appeal, color, aroma, flavor, texture, and overall liking. Circle or mark the number in the box that best fits your opinion. Then rate your willingness to buy this product if made available in surrounding locations. Please write notes or additional descriptive comments.

1 = Dislike Extremely, 2 = Dislike Very Much, 3 = Dislike Moderately, 4 = Dislike Somewhat, 5 = Neither Like nor Dislike, 6 = Like Somewhat, 7 = Like Moderately, 8 = Like Very Much, 9 = Like Extremely

Sample # _____

Visual appeal

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Color

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Aroma

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Texture

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Flavor

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Overall acceptability

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Attribute Comments

Visual appeal:

Color:

Aroma:

Texture:

Flavor:

Sample # _____

Visual appeal

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Color

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Aroma

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Texture

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Flavor

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Overall acceptability

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Attribute Comments

Visual appeal:

Color:

Aroma:

Texture:

Flavor:

Sample # _____

Visual appeal

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Color

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Aroma

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Texture

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Flavor

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Overall liking

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Attribute Comments

Visual appeal:

Color:

Aroma:

Flavor:

Texture: