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Effect Of Oat Bran On Physicochemical Properties Of Alaska Pollock (Theragra Chalcograma) Surimi Seafood

Fatimah Q. Alakhrash
North Carolina Agricultural and Technical State University

Effect of Oat Bran on Physicochemical Properties of Alaska Pollock (*Theragra chalcograma*) Surimi Seafood

Fatimah Q. Alakhrash

North Carolina A&T State University

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Fatimah Q. Alakhrash

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Approved by:

Dr. Reza Tahergorabi
Major Professor

Dr. Salam A. Ibrahim
Committee member

Dr. Anthony K. Yeboah
Committee member

Dr. Valerie L. Giddings
Department Chair

Dr. Sanjiv Sarin
Dean, The Graduate School

Biographical Sketch

Fatimah Qabbas Alakhrash is from Saudi Arabia. In 2010, she received the Bachelor of Education degree for Home Economics and Art Education in Food Science and Nutrition from King Abdulaziz University, Jeddah, Saudi Arabia. After graduation in 2010, she worked as a dietitian at a Global Small Buds kindergarten in Jeddah, Saudi Arabia. She came to the United States to earn her Master of Science degree in Food and Nutritional Sciences at North Carolina A&T State University.

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Table of Contents

List of Figures

List of Tables

List of Symbols and Abbreviations

ºC	degrees Celsius
CIE	Commission Internationale d'Eclairage
EW	Expressible Water
FDA	Food and Drug Administration
HDL	High Density Lipoprotein
LDL	Low Density Lipoprotein
LSD	Least Significant Difference
N	Newton
SD	Standard Deviation
SiO_2	Silicon Dioxide
TPA	Texture Profile Analysis
WHC	Water Holding Capacity

Abstract

Oat bran is a gluten-free dietary fiber that may reduce the risk of heart disease and diabetes. Most Americans consume less than half the recommended daily amount of fiber. Surimi seafood, which is also called “imitation crabmeat”, is not currently produced with fiber, nor has the effect of fiber on the physicochemical properties of surimi gels been thoroughly studied. The addition of fiber to surimi seafood would allow manufacturers to market added nutritional benefits. The purpose of this study was to determine the physicochemical properties (proximate composition, pH, texture, color properties, water holding capacity, and cooking loss) of Alaska pollock surimi gels formulated with variable levels of oat bran while maintaining constant levels of protein and water. Alaska pollock surimi gels were prepared with final moisture content of 78%. Oat bran and silicon dioxide (w/w) (inert filler) were added in inverse concentrations to develop treatments of 0% (control), 2%, 4%, 6%, or 8% oat bran. Texture was measured using texture profile analysis and the Kramer shear test. Color was tested by measuring L*, a*, and b* tristimulus color values. Results showed that for the proximate analyses (ash, moisture, and protein content), there were significant differences ($P<0.05$) in ash and protein content between the surimi gels containing oat bran and the control. The pH values of the treated samples with oat bran showed no significant ($P>0.05$) difference compared to the control. These results showed that pH values were not affected by the addition of oat bran to the surimi gels. For texture properties, hardness and Kramer shear force increased significantly with increased additional oat bran ($P < 0.05$). Surimi gels with oat bran showed slight but significant reductions ($P < 0.05$) in whiteness, due to significant decreases ($P < 0.05$) in L* and increases in b* values. The water holding capacity increased significantly ($P<0.05$) with all the treatments compared to the control. Cooking loss was reduced significantly ($P<0.05$) at 2%, 6%, and 8% oat

bran; the lowest cooking loss occurred with 8% oat bran. These results indicated that oat bran can be incorporated into surimi products without compromising quality, which may be useful to manufacturers for marketing surimi products with added health benefits.

CHAPTER 1

Introduction

Surimi is a term used for any fish flesh that has been deboned, minced, and washed for use in the manufacture of imitation seafood products such as imitation crab legs. Surimi's properties are viewed as wholesome and nutritious (Guenneugues, Morrissey, & Park, 2005), and surimi's price is affordable, so consumption of surimi-based products has been increasing world-wide. Alaska pollock (*Theragra chalcogramma*) is the most valuable species for making surimi because it freezes well, its odor and white color are desirable, and it tolerates cooking well. Consequently, it is a good choice for higher quality surimi (Park, Graves, Draves, & Yongsawatdigul, 2013a).

The greatest demand for surimi is in wealthier countries: United States, Japan, and European countries. Most surimi is produced in the United States and Japan, but Asian countries besides Japan are increasingly building their own processing capabilities. Park & Lin (2005) indicated that consumption in the United States has steadily increased over the years. The popularity remains high and continues to grow, possibly due to the low cholesterol, low fat, and high nutrient content of surimi seafood (Campo & Tovar, 2008). Due to its low fat content, nutritional quality, and highly functional proteins, surimi is a logical candidate for functional additives.

Dietary fiber is found only in plant foods. It is the remnant of the edible part of plants that is resistant to human digestion (American Association of Cereal Chemists, 2001). It consists of both soluble and insoluble fiber. The soluble fiber from oatmeal and oat bran is very effective in lowering blood cholesterol, normalizing blood sugar levels, and lowering the risk of cardiovascular disease, obesity, and type 2 diabetes (Brand-Miller et al., 2012). Adequate intake

for fiber is 14 g per 1,000 calories, or 25 g per day for women and 38 g per day for men. Generally, Americans do not consume the recommended amounts of dietary fiber; the average intake is only 15 g per day (Dietary Guidelines Advisory Committee, 2010).

In addition to health benefits, dietary fiber possesses hydrocolloidal properties that can be useful in food manufacturing and when fiber is added as an ingredient in final food products. Oat products such as oat bran have been used in meat systems to improve functional properties (e.g., water absorption). These properties make oat bran a functional ingredient for potential incorporation into surimi seafood products.

Since oats are not suitable for bread-making due to a lack of gluten, oats are often served as porridge, flakes, or breakfast cereals made from crushed or rolled oats. Oat flour or oatmeal is utilized in a variety of baked items like composite bread made from a mixture of oatmeal and wheat flour. Oat fiber has also been added to light bologna and frankfurters to reduce fat while retaining textural properties (Steenblock, Sebranek, Olson, & Love, 2001). In these applications, oat fiber has been shown to impart desirable functional properties.

Although dietary fiber has been well researched in baked goods, published reports relevant to surimi seafood are scarce. Fiber is not traditionally added to surimi seafood. Previous studies on fiber in surimi have utilized soluble fibers such as carrageenan, chicory root inulin, garrofin, guar, and xanthan (Cardoso, Mendes, Pedro, & Nunes, 2008; Sánchez-Alonso, Haji-Maleki, & Borderias, 2007). These soluble fibers had detrimental effects on the gelation of surimi proteins, resulting in a loss of gel elasticity and strength coupled with gel hardening and increased brittleness (Cardoso et al., 2008). Different seafood species and the type of fiber probably caused these varied results. Importantly, in the design of previous studies, the protein

concentration of surimi gels decreased proportionally with the increased concentration of added fiber, making both protein content and fiber content experimental variables.

Surimi with a lower protein concentration shows poorer thermal gelation characteristics, yielding gels with poorer textural properties (Kristinsson, Lanier, Halldorsdottir, Geirsdottir, & Park, 2013). Thus, the lower protein concentration probably confounded the experiment results that were attributed only to the added fiber. In this project, our hypothesis was that there would be a significant difference in the physicochemical properties of Alaska pollock surimi gels made with different quantities of oat bran; thus, our null hypothesis was that there would not be a significant difference in the physicochemical properties of Alaska pollock surimi gels made with different quantities of oat bran. The purpose of this study was to determine the effect of oat bran on physicochemical properties of Alaska pollock surimi gels.

CHAPTER 2

Literature Review

2.1 Surimi

Surimi is minced and deboned fish meat that has been washed of all lipids, water-soluble or sarcoplasmic proteins, and other impurities (Bodner & Sieg, 2009). After the fish are headed, filleted, and deboned, the fish mince is washed two or three times with water, and the wash water is strained through large rotary screens. The operators subjectively judge the amount of washing required at each stage. The washed mince is then passed through a refiner to remove blade skin fragments. The refiner commonly used is a rotating drum of the Beehive design, also used in the production of mechanically recovered red meat and poultry. Surimi seafood is also called "imitation crabmeat" and is widely enjoyed in the United States (Park et al., 2013a).

Surimi seafood introduced in North America during the late 1970s was in the form of a crabmeat leg (crabstick). A small modification from crabmeat stick to a ready-to-use flake created a huge market with more than 100% growth between 1983 and 1984. Consequently, flake-type products cover more than 90% of the U.S. market. There are four typical types of surimi seafood: crabmeat sticks, flakes, chunks, and combo (Pietrowski, Tahergorabi, & Jaczynski, 2012).

Currently, the United States is one of the major producers of surimi, followed closely by Japan and Thailand (Hall, 2011). With consumption and popularity becoming more widespread, surimi exports are becoming more globalized to areas such as Southeast Asia, Western Europe, and North America (Mansfield, 2003).

The primary nutritive substance of surimi seafood is protein, which contains sufficient amounts of essential amino acids. The composition of the essential amino acids of raw material

surimi is the same regardless of fish species. The digestibility of surimi seafood is higher than fresh fish meat. The lipid content in surimi seafood is low because the raw material fish of surimi is white meat fish, which contains a low lipid content (Park et al., 2013a). The content of ω-3 fatty acids, such as EPA and DHA, in surimi seafood, is almost the same content as raw fish meat. The mineral content of sodium in Japanese surimi seafood is 2.2–24% as sodium chloride and its potassium content is lower than fresh fish. Calcium is generally 25 mg/100 g and calcium-enhanced products contain 120 mg/100 g. Water-soluble and fat-soluble vitamins are removed to some extent by washing during the surimi manufacturing process. The vitamin content of surimi is, therefore, lower than raw fish meat (Park, Nozaki, Suzuki, & Beliveau, 2013b).

Bioactive effects were studied by feeding surimi seafood from Alaska pollock, or surimi seafood digested by enzymes, to rats or mice. The following bioactive effects were found: (1) the protein of surimi seafood was effective in preventing dementia, (2) dietary surimi seafood prevented colon cancer, (3) surimi seafood inhibited the absorption of oil and sugar, (4) the increase of blood pressure was significantly suppressed, and (5) a decrease of fat cells was observed in the dietary obese rat group (Chajes & Bougnoux, 2003).

An intervention study was performed, wherein chewing surimi seafood with strong elastic texture elevated the insulin level in blood. Antioxidative properties of several digested commercial surimi seafood products were estimated by the oxygen radical absorbance capacity (ORAC) assay and the autoxidation of linoleic acid. All surimi seafood products indicated excellent antioxidative capacity (Nagai, Suzuki, & Nagashima, 2006).

2.2 Oat Bran as a Dietary Fiber

Oat (*Avena sativa* L.), although consumed in considerably lower quantities worldwide than wheat (*Triticum aestivum* L., *T. durum* L.) and rice (*Oryza sativa* L.), has the advantage that it is normally consumed as a whole-grain cereal. Oat is an important food grain in temperate regions of the world. Modern oat probably originated from the Asian wild red oat, found growing naturally among other grain crops (Butt, Tahir-Nadeem, Khan, Shabir, & Butt, 2008). It is an annual crop used both for human and animal nutrition. Before being used as a food, it was used for medicinal purposes. Oat was recognized as a healthy food in the mid-1980s when developments in the field of nutrition found that a substance in it helped prevent heart disease, so it became more popular for human nutrition (Whole Grains Bureau, 2007).

Bran is the edible, outermost layer of the oat kernel and is produced by grinding clean groats or rolled oats to separate the resulting flour by sieving, bolting, and other suitable means into fractions such that the oat bran is not more than 50% of the starting material. Oat bran contains B-complex vitamins, protein, fat, minerals, and a heart-healthy soluble fiber called ß-glucan. It has at least 5.5% total ß-glucan and at least 16.0% dietary fiber, and at least one-third of total dietary fiber is soluble fiber (Feng et al., 2013). Oat bran contains 17.1% protein, 66% carbohydrates, 7% fat, 11% dietary fiber, 10.4% ß-glucan, 1.3 mg niacin, 171 mg magnesium, 6.4 mg iron, 0.17 mg copper, 441 mg potassium, and less than 0.5 mg α-tocopherol (Feng et al., 2013). By including the bran in oat food products, the antioxidant-rich portion of the grain is retained.

Coronary artery disease is the major cause of death in the United States and most Western countries, and blood cholesterol is a major risk factor. Dietary and pharmacologic reductions in total and low-density lipoprotein (LDL) cholesterol decrease the risk of the malady

(Kerckhoffs, Hornstra, & Mensink, 2003), and dietary intervention is the first-line approach. Increasing dietary fiber has been recommended as a safe and practical approach for cholesterol reduction. On the basis of numerous clinical studies, the US Food and Drug Administration (FDA) permitted the use of a claim that oat soluble fiber has the ability to reduce the risk of heart disease. The required dose of ß-glucan for a single food is 0.75 g/serving. In literature, the highly viscous ß-glucan fraction of oat has been reported to lower blood cholesterol and the intestinal absorption of glucose (Daou & Zhang, 2012).

Oat bran exerts a small but potentially useful effect on plasma lipoprotein risk factors for cardiovascular disease. In subjects with mild hypercholesterolemia and normal blood pressure receiving different diets with dietary fiber from wheat bran, oat bran, or rice bran, oat bran was the only fiber source that significantly lowered total and LDL cholesterol level (Daou & Zhang, 2012).

Due to oat bran's high content of soluble fiber, it is recommended as a potentially beneficial adjunct to lipid-lowering diets. This recommendation is supported by the results of studies that demonstrate significant, although variable, reductions in serum cholesterol after ingestion of various oat-bran-containing products (Butt et al., 2008; Kerckhoffs et al., 2003; Kumar, Kaur, Singh, & Rastogi, 2010). A mechanism for cholesterol reduction with oat bran diets can include an increased excretion of bile acid, which in turn stimulates the liver to utilize available cholesterol to produce more bile acid. Intake of oat bran results in increased lipid excretion and higher percent digestibility (Butt et al., 2008).

Researchers have also investigated the effects of high ß-glucan oat bran flour on patients with Type 2 diabetes (Tapola, Karvonen, Niskanen, Mikola, & Sarkkinen, 2005). Canadian researchers evaluated the long-term effects of oat bran concentrate on free-living subjects with

Type II diabetes: eight subjects were fed bread containing oat bran concentrate (soluble fiber ß-glucan content = 22.8%), followed by a white bread control in the second phase of the trial. Test subjects' mean total plasma cholesterol and LDL cholesterol levels were lower in the oat-bran-concentrate period than in the white-bread period of the study, and the mean ratio of LDL cholesterol to high-density lipoprotein (HDL) cholesterol was reduced by 24% in the oat bran concentrate phase of the trial. The oat-bran-concentrate bread products improved lipidemic as well as glycemic and insulinemic responses through their ability to lower total and LDL cholesterol. Incorporation of very modest amounts of soluble oat extract (50–75 g/day) into foods affects risk factors for disease without altering the acceptability or palatability of the diet (Smith & Tucker, 2011).

Celiac disease is an autoimmune hereditary disorder of the small intestine that occurs in people of all ages from middle infancy because of sensitivity to gluten in food. The safety of oats in individuals with celiac disease has been extensively investigated. Karmally, Montez, Palmas, & Martinez (2005) have found that consuming pure, uncontaminated oats is safe up to 50–70 g/day for adults and 20 to 25 g/day for children. Studies looking at the consumption of oats over 5 years have confirmed their safety. Such studies have increased the possibility of adding oats to a gluten-free diet, allowing more food choices for individuals with celiac disease and providing an additional source of carbohydrates, proteins, and fiber (Katongole, 2012; Martensson et al., 2005; Maki, Shinnick, Seeley, Veith, 2003).

Although fiber has been proven to be physiologically beneficial, it was not until the 1980s that consumers became aware of dietary fiber (Bodner & Sieg, 2009). Generally, whole foods are promoted and recommended as sources of fiber; however, the low intake of dietary fiber seen in the current U.S. diet is evidence that Americans are not meeting their needs with

whole food sources, and supplementation or fortification with isolated food components may be necessary (Smith & Tucker, 2011). In addition, observations from the Women's Health Initiative and observations by the FDA indicate that consumers are not as effective in modifying dietary habits as they intend to be (Anderson et al., 2009).

Fiber-containing ingredients such as whole grains, flours, and breadcrumbs are currently used in a variety of products (Bodner & Sieg, 2009). Processed meat may also be a vehicle for fiber supplementation (Bodner & Sieg, 2009). Germany has already come out with meat products marketed as "enriched with fibers" and "rich in fibers" (Bodner & Sieg, 2009).

Oat bran and oat fiber appears to be a suitable fat replacements in ground beef and pork sausage products due to their ability to retain water and emulate particle definition in ground meat in terms of both color and texture (Özvural & Vural, 2008). Advantages of oat bran include its savory taste, which imitates fat, the lack of cereal flavor, and the way it retains the natural flavorings of meat (Modi, Mahendrakar, Sachindra, & Rao, 2004). It also reduces fat absorption, slows carbohydrate absorption, and aids satiety (Sloan, 2003). Oat bran was used as a fat substitute in meatballs, and it has been reported that meatballs containing oat bran had lower concentrations of total fat and trans fatty acids than control samples (Yılmaz & Dağlıoğlu, 2003). Meatballs made with 20% oat bran had the highest protein, ash content, lightness, and yellowness, and the lowest moisture and redness (Yılmaz & Dağlıoğlu, 2003). There was no significant difference among the meatballs in their sensory properties, and all samples had high acceptability.

2.3 Textural Properties

Texture and savory remain the ultimate criteria of product acceptability by the consumer. Food industry efforts are to develop the proper texture for food products (Gunasekaran & AK,

2003). According to the International Organization for Standardization, the texture of a food is defined as the rheological and structural attributes of a food product that are perceived by human senses (ISO, 1992). There are two methods that can be used to measure texture, each of which provides slightly different information: Texture Profile Analysis (TPA) and Kramer shear force. TPA and Kramer shear force are considered empirical tests that characterize results so that they can be directly related to overall acceptance or hedonic ratings (Kim, Park & Yoon, 2005). Therefore, when both methods are employed, a more complete picture is obtained.

2.3.1 Texture profile analysis (TPA)

Mallikarjunan (2006) pioneered the development of the texture profile analysis. This test involved compressing a bite-size piece of food, a cube with side approximately 1 cm, to 25% of its original height (75% compression) two times in a reciprocating motion, which imitates the action of the human jaw. From the resulting force-time curve, a number of textural parameters such as cohesiveness, springiness, chewiness, resilience, gumminess, and hardness that correlate well with the sensory evaluations of those parameters were extracted. The definitions of these parameters are important, because each factor deals with different aspects of a material's texture. Hardness is defined as the force required to compress a food between molars and is measured as the maximum force (N) detected during first compression. Cohesiveness is how well the product withstands a second deformation relative to its resistance under the first deformation; cohesiveness is measured as the ratio of the positive force during the second compression to the positive force during the first compression and determines the amount of deformation for a material before it breaks. Gumminess is the energy required to disintegrate a semi-solid food product to a state ready for swallowing and is determined as the product of hardness × cohesiveness. Springiness is the ability of a material to recover its original shape after the

removal of the force; it is measured as the ratio of the distance from the second area to the second probe reversal over the distance. Chewiness is defined as the energy required to chew a solid food to the point required for swallowing; it is calculated as gumminess × springiness. Resilience measures how well a sample recovers from deformation in relation to the speed and force applied. Thus, food texture measurement is important for the following reasons:

1. Texture properties affect the consumer's sensory perception and acceptance of a food product. Once the range of sensory acceptability is determined, a texture analysis test can be constructed to distinguish between an acceptable and an unacceptable product.

2. Physical properties of food affect the design of processing equipment. Quantifying these physical properties is helpful in selecting and adjusting the equipment used to mix, transport and package products (Alvarez, Canet, & López, 2002).

2.3.2 Kramer shear force

A comprehensive description of the Kramer cell can be found in Bourne (2002). A typical system contains 10 shear blades that are 3.2 mm thick and separated by a distance equal to thickness. The sample holder is filled with the food. Shear blades are forced through the material until they pass through the bars in the bottom of the sample container. Force on the ram holding the blades is measured over time and correlated to the firmness of the product. Parameters usually measured include maximum force at a given sample weight, slope, and energy of the force-deformation curve. The relationship between the weight of material in the cell and the maximum force during the compression stroke was studied by Bourne (2002). For two products (white bread and sponge cake) a linear relationship was found between sample weight and maximum force over a limited range of sample weight. He also found a linear relationship between maximum force and sample weight for cooked poultry meat. The

relationship for the other foods was nonlinear, tending toward constant force–weight relationship at high fill weights. Some products (e.g. raw apples and cooked dry beans) never reach a linear relationship. Many products attain a constant force independent of sample weight before the cell is filled (e.g. canned beets, peas, carrots, lima beans; frozen peas and lima beans; and raw snap beans and bananas). Thus, for most foodstuffs the force per sample weight is not constant but decreases as the sample weight increases. On these grounds it is advisable to use a constant weight of sample in the test cell unless tests show that there is a linear relationship between sample weight and maximum force for that food.

A highly linear relationship has been shown for surimi weighing 5–14 g when samples are cut in parallelepipeds of 1 cm height, and with lengths and widths varying from 4 to 7 cm and 1 to 2 cm respectively. Therefore, for surimi products it is recommended to use the samples in this range of weight and size to obtain reliable results (Betti & Fletcher, 2005).

2.4 Color Properties

Color is an important quality of surimi-based products with lighter, whiter surimi desired. Color may vary depending on the type of fish used (dark-flesh or white-flesh) or surimi formulations with food-grade color modifiers (e.g., oil). Color changes may be measured instrumentally with a calorimeter, which measures color based on tristimulus values (L*a*b*). The CIE (Commission International de Elcairage) L*a*b* color scale, based on the values of redness (a*), yellowness (b*), and lightness (L*), is a well-known method for measuring the color of a sample. In surimi gels, various additives influence color properties. Park & Lin (2005) found that gels with added moisture tended to be lighter with less yellowness, causing them to look whiter than gels with lower moisture. In addition to moisture, various components can be added to surimi pastes to improve the whiteness of the gels, including titanium dioxide, calcium

carbonate, and oil (Benjakul, Visessanguan, & Kwalumtharn, 2004; Gehring, Gigliotti, Moritz, Tou, & Jaczynski, 2011). Pérez-Mateos, Boyd, & Lanier (2004) observed that oil increased lightness (L*) through the light scattering effect of emulsified oil droplets. Yilmaz & Daglioglu (2003) added 5%, 10%, 15%, or 20% of oat bran to meatballs. They found that meatballs made with 20% oat bran had the highest L* value (lightness) and b* value (yellowness), and the lowest a* value (redness).

2.5 Water Holding Capacity

Water holding capacity (WHC), also known as hydration of meat, is closely related to taste, tenderness/juiciness, color, and other features of meat quality. WHC is the ability of meat muscle to retain moisture in meat (Abdullah, Mason, Cullen, & Al-Shamma'a, 2013). It refers to the ability of the protein to absorb water and retain it against gravitational force within a protein matrix, such as protein gels or beef and fish muscle (Park et al., 2013b). This water refers to the sum of the bound water, hydrodynamic water, and the physically entrapped water.

A number of factors affect WHC of meat such as pH, animal species, and age. The most important factor is the pH of the meat. In order to study the effect of pH on the WHC of meat, a study was performed on beef (Huff-Lonergan, & Lonergan, 2005). Beef samples were immersed in buffer solutions with different pH values and their weight gains were measured afterwards. The results indicated the lowest weight gain for the samples that were immersed in the buffer solution with a pH value of 5.2. The reason could be explained by the fact that a pH of 5.2 is the isoelectric point for meat proteins. At this pH, the net charge of the proteins is equal to zero, hence they are attracted to each other, and as a result they cannot hold water inside them. Thus, their WHC was at its minimum level (Huff-Lonergan, & Lonergan, 2005). The reason for WHC to be such an important factor for the meat is that it is associated with the appearance of the meat

when exposed to heat treatment (i.e., cooking), and contributes to the juiciness of the meat. When it comes to comminuted meat products (e.g., sausages), WHC is a particularly important quality attribute. During the production of comminuted meat products, due to the mincing process of the meat, the structure of the meat proteins that hold water is destroyed, and therefore, the ability of the meat to hold water is decreased (Schmidt, Scheier, & Hopkins, 2013). Therefore, WHC greatly affects the quality of comminuted meat products.

2.6 Cooking Loss

One of the important factors that determine the quality of the meat product is cooking loss. Cooking loss indicates the amount of water which is lost during cooking, and therefore, it is associated with water holding capacity of the meat. When meat is heated, if the meat has lower cooking loss, it will be understood that the meat has a higher ability to hold water, and therefore, it has greater WHC. If the water holding capacity of a meat product is low, the meat will lose a larger amount of water during cooking, leading to production of a drier product that may be unacceptable to consumers (Park et al., 2013b). Cooking loss occurs with the denaturation of meat proteins. During cooking, the structure of meat proteins change by shrinkage of muscle fibers and connective tissues, and aggregation of proteins occurs leading to water release from the cells (i.e., decrease of WHC). The temperature at which the meat proteins denature is in the range of 37 °C to 75 °C, and the recommended internal temperature for cooking is 75 °C (Huff-Lonergan, & Lonergan, 2005).

In this project, our hypothesis was that there would be a significant difference in the physicochemical properties of Alaska pollock surimi gels made with different quantities of oat bran; thus, our null hypothesis was that there would not be a significant difference in the physicochemical properties of Alaska pollock surimi gels made with different quantities of

oat bran. The purpose of this study was to determine the effect of oat bran on physicochemical properties of Alaska pollock surimi gels.

CHAPTER 3

Methodology

The overall objective of this study was to determine the effect of oat bran on the physicochemical properties of surimi gels. In this project, we tested the changes in the physicochemical properties of surimi gels when different quantities of oat bran were added. We analyzed the proximate composition, change in pH values, texture properties, change in color, ability of gels to hold water, and the amount of water that was lost during cooking. The explanation of different treatments is presented in Table 1.

Table 1

Final Surimi Batter Formulations

Oat Bran (g/1000 g)	Inert Filler - SiO_2 (g/1000 g)	Surimi (g/1000 g)	Water (g/1000 g)	Salt (g/1000 g)	Batch weight (g)
0.0 (control)	80.0	480.0	420.0	20.0	1000.0
20.0	60.0	480.0	420.0	20.0	1000.0
40.0	40.0	480.0	420.0	20.0	1000.0
60.0	20.0	480.0	420.0	20.0	1000.0
80.0	0.0	480.0	420.0	20.0	1000.0

Batters with different levels of oat bran were formulated to contain 78% moisture and constant amounts of protein, water, and salt by using inert filler (silicon dioxide - SiO_2). Batch size was 1000g.

3.1 Surimi

Frozen Alaska pollock surimi grade A was purchased from Trident Seafoods Corp. (Seattle, WA). The surimi contained cryoprotectants (4 g/100 g of sorbitol and 4 g/100 g of sucrose, 0.15 g/100 g of sodium tripolyphosphate, and 0.15 g/100 g of tetrasodium pyrophosphate) that were delivered in tight boxes surrounded with ice. The frozen surimi was cut

in 600 g blocks and placed in vacuum bags. The air was removed from the package, which was then stored at -80°C until needed.

Figure 1. A block of frozen surimi.

3.1.1 Preparation of surimi paste

The surimi paste was made according to the process described by Jaczynski & Park (2003a; 2003b; 2004). The first step was to thaw the frozen surimi at 4°C overnight. The surimi was then chopped at low speed for 1 min in a universal food processor (Model UMC5, Stephan Machinery Corp., Columbus, OH). The temperature was controlled between 1-4°C during chopping by using a chopping bowl equipped with a cooling jacket and adding ice to the paste (Poowakanjana & Park, 2013). The surimi paste was obtained by extracting surimi myofibrillar protein with 2g/100 g of NaCl (non-iodized Morton salt, Morton International Inc., Chicago, IL) and chopping at low speed for 0.5 min. Final moisture of the surimi gels was adjusted to 78 g/100 g by adding ice to the paste according to the batter formulation in Table 1.

In order to calculate the amount of all ingredients in this project, including surimi, a batch calculator was used. In order to maintain the same protein concentration and moisture content for all treatment groups but variable concentration of soluble fiber, silicon dioxide (SiO_2) was added

to surimi gels as inert filler (Table 1). Soluble fiber (Old Fashioned Quaker Oat Bran, Chicago, IL) and SiO_2 (silicon dioxide crystalline 325 mesh, Spectrum Chemical, Gardena, CA) were added to the surimi paste in four combinations to a total final concentration of 8% (Table 1). One treatment without added fiber (with 8 g/100 g silicon dioxide) was a control. All ingredients remained constant except for fiber and silicon dioxide. Treatments included 0% fiber (0% oat bran, 8% silicon dioxide - control), 2% fiber (2% oat bran, 6% silicon dioxide), 4% fiber (4% oat bran, 4% silicon dioxide), 6% fiber (6% oat bran, 2% silicon dioxide), and 8% fiber (8% oat bran, 0% silicon dioxide). All ingredients in each treatment were chopped at low speed for 1 min. Additional chopping was performed at high speed under vacuum (0.5 bar) for 3 min. The paste temperature was controlled between 1°C and 4°C during chopping. Surimi pastes were prepared in 1 kg batches. Final formulations are listed in Table 1. Pastes prepared in this manner were used to develop heat-set surimi gels.

3.1.2 Preparation of surimi gels

A surimi paste was stuffed through plastic hotdog casings (Lem Products Direct; West Chester, OH) (diameter: 2.6 cm, length: 17.5 cm), and the casings were tightened from both sides. Surimi pastes were cooked in a water bath at 90°C for 30 min, cooled in an ice bath for approximately 20 min, and the hotdog casings were peeled. Heat-set surimi gels prepared in this manner were used for evaluation of proximate composition (ash, moisture, and protein content), pH, color (tristimulus color values), texture (texture profile analysis and Kramer shear force), water holding capacity, and cooking loss.

3.2 Analyzing the Effect of Oat Bran on the Proximate Composition of Surimi Gels

3.2.1 Moisture content

The aluminum weigh dishes were labeled and weighed (W1). A weight of 2.5g of surimi gels was added to the dish. The total weight of each dish and sample was recorded (W2). The dishes containing the surimi gels were placed into a vacuum oven (Fisher Scientific Co., Fairlawn, NJ) to dry at 80° C for 24 hours. The samples were then taken out of the oven and placed in desiccators to cool to room temperature, and then the dishes containing the dry samples were weighed (W3). The moisture content was calculated using the following equation:

$$\% \text{ of moisture (wt/wt)} = (W2 - W3) / (W2 - W1) \times 100$$

3.2.2 Protein content

Total protein content of surimi gels was determined by a combustion method using Leco TrueSpec Element Analyzer (Leco Corporation, St. Joseph, Michigan). Approximately 0.100g of surimi gel samples were weighed into a foil cup. The samples were then wrapped and placed in the auto sampler. Each sample's name and actual amount of mass were input to the analyzer according to the manual provided by the manufacturer. The total % nitrogen and % protein were recorded (a conversion factor of N= 6.25 was used to convert nitrogen content to protein content).

$$\text{Total protein (\%)} = \text{Total nitrogen} \times \text{N Factor}$$

3.2.3 Ash content

The weights of ashing crucibles were taken and recorded (W1). In each crucible, 2.00g of surimi gels were added and the total weight was recorded (W2). The ashing crucibles were placed in a Barnstead Thermolyne 30400 Muffle Furnace (Thermo Fisher Scienctific, Dubuque,

Iowa) and heated at 550°C for 5 hours. The crucibles were removed from the oven, cooled to room temperature, and the weight of the crucible containing the ash was recorded (W3). The percentage of ash was calculated as follows:

$$\% \text{ of ash} = (W3 - W1) / (W2 - W1) \times 100$$

3.3 Analyzing the Effect of Oat Bran on the pH Changes of Surimi Gels

According to Park et al. (2013a), myofibrillar proteins of various fish species are most stable at neutral pH, and the denaturation rate increased rapidly when pH was lower than 6.5. Lanier, Yongsawatdigul, & Carvajal-Rondanelli (2013) reported that pH of surimi relates to the water-holding and gel-forming properties of cooked gels. Lanier et al. (2013) stated that pH has a significant effect on the texture properties of various protein gels. To determine the pH of surimi gels, a pH meter (Oakton, Vernon Hills, IL) was standardized using pH 4, 7, and 10 buffers. The samples were mixed gently and the electrode was dipped into the samples. When the value displayed was stable, the pH values were recorded. Between samples, the electrode was rinsed with distilled water and wiped with tissue (Xu, Xia, Yang, & Nie, 2010).

3.4 Analyzing the Effect of Oat Bran on the Texture Properties of Surimi Gels

Two different methods were applied to determine the surimi texture properties: the Kramer shear test and texture profile analysis (TPA). Cylindrical surimi gels (height = 8.0 cm, diameter = 2 cm) were used for the Kramer shear test (Model TA-HDi, Texture Technologies Corp., Scarsdale, NY) with a Kramer cell attachment (Tahergorabi, Beamer, Matak, & Jaczynski, 2011). The Kramer shear cell contained five 3.0-mm thick and 70-mm wide shear blades passing through a cell with a corresponding number of slots. Individual samples were weighed and placed under the blades in the Kramer cell. Shear force was measured at 127-

mm/min crosshead speeds and expressed as maximum peak force (N) per g of sample.

The TPA method was performed according to Tahergorabi et al. (2011). Cylindrical gels (height = 2.5 cm, diameter = 2 cm) were used for the TPA measurement. Surimi samples were exposed to two cycles at 50% compression using the texture analyzer 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.

3.5 Analyzing the Effect of Oat Bran on the Color Properties of Surimi Gels

The surimi gels were equilibrated to room temperature before color measurements. The color properties of surimi gels were determined by using a Minolta Chroma Meter CR-400/410 colorimeter (Minolta Camera Co. Ltd., Osaka, Japan). Cylindrical gels (height = 2.5 cm, diameter = 2 cm) were used for color measurements. The values of the CIE (Commission Internationale d'Eclairage of France) color method using L*a*b* tristimulus color values were determined. The whiteness of surimi gels was calculated based on the following equation (Park & Lin, 2005).

$$\text{Whiteness} = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]1/2$$

3.6 Analyzing the Effect of Oat Bran on the Expressible Water and Water Holding Capacity of Surimi Gels

The expressible water (EW) refers to the amount of liquid squeezed from a protein by the application of force (Nielsen, 2010). EW of surimi gels was calculated according to Park et al. (2013b): a slice of surimi gel (2 cm diameter, 0.3 cm thick, and about 1 g in weight) was placed between two filter papers and pressed by oil pressure equipment under a fixed pressure (10

kg/cm^2) for 20 sec. Expressible water was calculated as a percentage with the following formula. Three samples were tested, and the average value was used.

$$\text{Expressible water} = \frac{pre{-}pressed\ weight\ (g){-}\ post{-}\ pressed\ weight\ (g)}{pre{-}pressed\ weight\ (g)} \times 100$$

The water holding capacity (WHC) of surimi gels was calculated as a percentage as the ratio of the water remaining to the initial water content of the sample:

$$\text{Water-Holding Capacity} = \frac{Total\ Moisture\ Content\ (g) -\ Expressible\ Water\ Content(g)}{Total\ Moisture\ Content\ (g)} \times 100$$

3.7 Analyzing the Effect of Oat Bran on the Cooking Loss of Surimi Gels

Cooking loss was determined by weighing 5g of surimi from each treatment group before cooking (initial weight) and after cooking (final weight). Cooking loss was calculated as a percentage:

$$\text{Cooking loss} = \frac{Initial\ Weight{-}Final\ Weight}{Initial\ Weight} \times 100$$

3.8 Statistical Analysis

The data obtained from this study were subjected to one-way analysis of variance (ANOVA). A significant difference was determined at the 0.05 probability level and differences between treatments were tested using the Least Significant Difference (LSD) test (Ott & Longnecker, 2008). All statistical analyses of data were performed using SAS (2002). The data are reported as mean values ± standard deviation (SD). The experiments were independently triplicated (n = 3).

CHAPTER 4

Results

The overall objective of this study was to determine the effect of oat bran on the physicochemical properties of surimi gels. In this project, we tested the changes in the physicochemical properties of surimi gels when different quantities of oat bran were added. We analyzed the proximate composition, change in pH values, texture properties, change in color, ability of gels to hold water, and the amount of water that was lost during cooking. The explanation of different treatments is presented in Table 1.

4.1 Analyzing the Effect of Oat Bran on the Proximate Composition of Surimi Gels

Table 2

Effect of Oat Bran on Proximate Composition and pH* of Surimi Gels*

	Oat Bran Concentrations (w/w) %				
	0 (Control)	2	4	6	8
Moisture (%)	76.95±0.3 ^{b}	77.56±0.1 ^{ab}	78.49±0.2 ^{a}	77.45±0.93 ^{ab}	78.3±0.2 ^{a}
Protein (%)	9.03±0 ^{c}	9.22±0.2 ^{bc}	9.07±0.1 ^{bc}	10.94±0.8 ^{ab}	12.38±0.6 ^{a}
Ash (%)	10.45±0.3 ^{a}	8.38±0.2 ^{b}	6.24±0.1 ^{c}	4.62±0.1 ^{d}	1.99±0 ^{e}
pH	6.85±0.64 ^{a}	6.88±0.02 ^{a}	6.87±0 ^{a}	6.88±0.02 ^{a}	6.71±0.04^{a}

*Data are given as mean values ± standard deviation (SD, n = 3). Different letters within the same row indicate significant differences (Fisher's Least Significant Difference, $P<0.05$) between mean values.

4.1.1 Moisture content

The moisture content of surimi gels (Table 2) developed with different concentrations of oat bran was approximately similar in all the treatments except for the control. Although the

moisture content of the control sample was significantly different ($P<0.05$) from the other treatments, numerically it was only slightly lower.

4.1.2 Protein content

The protein values shown in Table 2 show a significant ($P<0.05$) increase compared to the control for all treatments containing oat bran, from 2% to 8%. The addition of 8% oat bran showed the greatest ($P<0.05$) protein content compared to the control.

4.1.3 Ash content

With the addition of oat bran, the ash content of all the treated samples decreased significantly ($P<0.05$) compared to the control. With the treatment containing 8% oat bran, the lowest value ($P<0.05$) of ash was obtained.

4.2 Analyzing the Effect of Oat Bran on the pH Changes of Surimi Gels

The pH values of the treated samples showed no significant ($P>0.05$) difference compared to the control. These results showed that pH value was not affected by the addition of oat bran to the surimi gel.

4.3 Analyzing the Effect of Oat Bran on the Texture Properties of Surimi Gels

4.3.1 Kramer shear force

The Kramer shear test is a measure of gel strength; the results are shown in Figure 2. The Kramer shear force increased with the addition of oat bran compared to the control. In all of the treatments, the addition of oat bran showed significantly ($P<0.05$) greater Kramer shear force than the control. The highest Kramer force value (1.51 N/g) was obtained for the sample with 8% oat bran added.

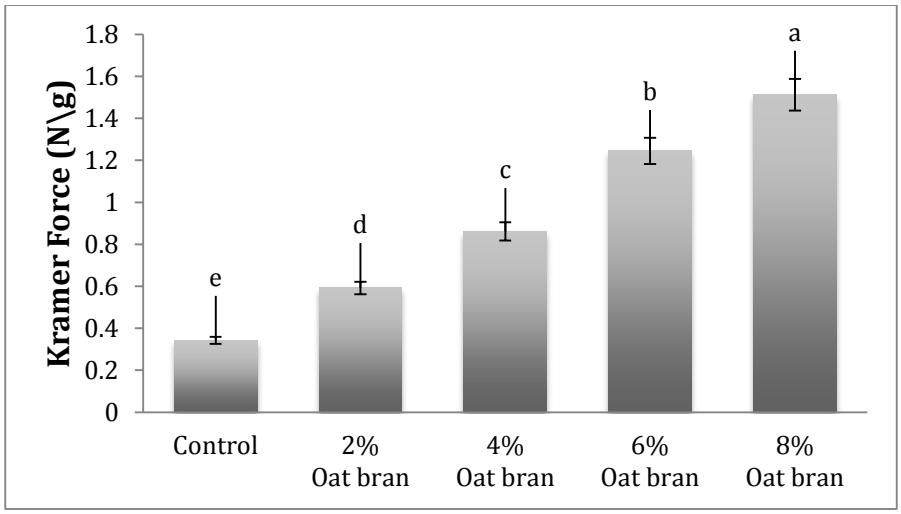

Figure 2. Effect of oat bran on Kramer shear force* of surimi gels.

*Data are given as mean values ± standard deviation (SD, n = 3). Small bars on the top of data bars indicate SD. Different letters on the top of SD bars indicate significant differences (Fisher's Least Significant Difference, $P < 0.05$) between mean values.

4.3.2 Texture profile analysis

Texture Profile Analysis (TPA) measures various textural parameters including hardness, cohesiveness, gumminess, springiness, chewiness, and resilience. Hardness is the peak height on the first compression that measures a food's resistance during a bite. Springiness is the ratio of product height on the second compression to the original compression distance that measures the ability of the product to retain its shape and size after one bite. Cohesiveness is the ratio of the second compression area to the first compression area that measures the resistance of the product during chewing. Gumminess is the product of hardness and chewiness that measures strength required in chewing. Chewiness is the product of gumminess and springiness that measures the energy used in chewing. Resilience is a measure of how well a product regains its original position (Cardoso et al., 2008).

Table 3 and Figure 3 show the results for TPA and hardness, respectively. These data

show that the addition of 2% oat bran had no significant increase ($P>0.05$) in the springiness and cohesiveness of the surimi gels. The gumminess, chewiness, and resilience of the surimi gels, however, showed a significant increase ($P<0.05$) with the addition of 2% oat bran. Treatments with 4%, 6%, and 8% oat bran caused a significant increase ($P<0.05$) in springiness, cohesiveness, gumminess, chewiness, and resilience of the surimi gels compared to the control. The highest values for all properties were shown by the sample with 8% oat bran treatment.

Table 3

Effect of Oat Bran on Texture Profile Analysis of Surimi Gels*

	Oat Bran Concentrations (w/w) %				
	0 (Control)	2	4	6	8
Springiness	0.9±0.5 [b]	0.9±0.5 [b]	1.1± 0.4 [a]	1.1± 0.4 [a]	1.1± 0.4 [a]
Cohesiveness	0.6±0 [c]	0.6±0 [c]	0.7±0 [b]	0.7±0 [b]	0.8±0 [a]
Gumminess	3.0±0.5 [e]	4.6±0.2 [d]	6.5±0.3 [c]	9.7±0.6 [b]	12.3±0.5 [a]
Chewiness	2.7±0.6 [e]	4.4±0.2 [d]	7.7±0.4 [c]	9.4±0.7 [b]	11.3±0.6 [a]
Resilience	0.2±0 [c]	0.3±0 [b]	0.3±0 [b]	0.4±0 [a]	0.4±0 [a]

*Data are given as mean values ± standard deviation (SD, n = 3). Different letters within the same row indicate significant differences (Fisher's Least Significant Difference, $P<0.05$) between mean values.

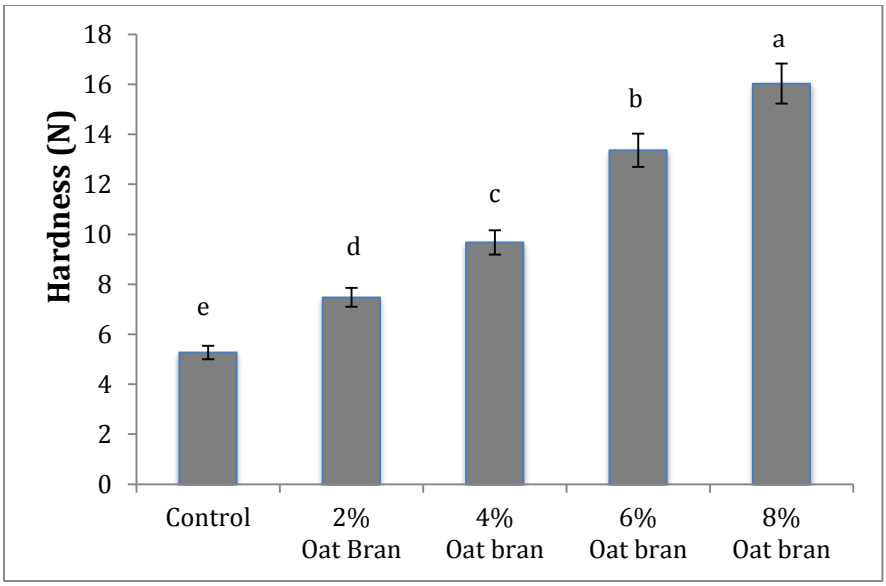

Figure 3. Effect of oat bran on hardness (TPA)* of surimi gels.

*Data are given as mean values ± standard deviation (SD, n = 3). Small bars on the top of data bars indicate SD. Different letters on the top of SD bars indicate significant differences (Fisher's Least Significant Difference, $P < 0.05$) between mean values.

Hardness values (shown in Figure 3) showed a significant ($P<0.05$) increase with the increased percentage of oat bran in the treatments, compared to the control. The hardness values followed a trend similar to the Kramer shear force. The greatest ($P<0.05$) hardness value, compared to the control, was seen with the addition of 8% oat bran.

4.4 Analyzing the Effect of Oat Bran on the Color Properties of Surimi Gels

Table 4 shows the tristimulus color values (L*, a*, and b*), and Figure 4 shows the graphical depiction of whiteness values. L* is on a scale from 0 to 100 of blackness and whiteness, with 0 being more black and 100 being more white. The value a* correlates with redness (positive values) and greenness (negative values), and b* is a measure of yellowness (positive values) and blueness (negative values). Whiteness was calculated using L*, a*, and b*.

With the addition of oat bran to the samples, the lightness (L*) decreased ($P<0.05$). For

all treatments with the addition of 2%, 4%, 6% or 8% oat bran, the lightness was significantly lower than that of the control ($P<0.05$). The samples containing 6% and 8% oat bran showed the lowest lightness values, though there was no significant difference in lightness value between these two treatments. The decrease in lightness (L*) with the addition of oat bran was accompanied by an increase in yellowness (+b*) of the treated samples.

The addition of oat bran to surimi, in all treatments, resulted in more negative a* values, indicating a slightly greater green hue in these treatments. Though the a* values for those of 2% and 4% and those of 6% and 8% oat bran were not significantly different from each other, their a* values were significantly different from the control ($P<0.05$), i.e., they were less green than the control. The samples with 6% and 8% oat bran displayed the lowest (greenest) a* values.

The addition of oat bran in all of the treatments increased the b* (yellowness) value significantly ($P<0.05$) compared to the control. The samples with 6% and 8% oat bran showed the highest b* values and a significant increase in yellowness ($P<0.05$) even when compared to the 4% and 2% oat bran treatments.

With the increase in the amount of oat bran added from 2% to 8%, the lightness (L*) and greenness (a*) decreased, and yellowness (b*) increased. Overall whiteness of the samples decreased significantly ($P<0.05$) with the oat bran treatments compared to the control. The 6% and 8% oat bran treatments showed the lowest ($P<0.05$) whiteness.

Table 4

Effect of Oat Bran on Color Properties of Surimi Gels*

	Oat Bran Concentrations (w/w) %				
	0 (Control)	2	4	6	8
L*	88.6±0.4 [a]	87.50±0.4 [b]	85.7±0.3 [c]	83.4±0.7 [d]	83.4±0.7 [d]
a*	-0.9± 0.1 [a]	-1.2±0 [b]	-1.3±0.1 [b]	-1.6±0.1 [c]	-1.6±0.1 [c]
b*	5.5±0.5 [d]	6.7±0.4 [c]	7.4±0.3 [b]	8.8±0.5 [a]	8.8±0.5 [a]

*Data are given as mean values ± standard deviation (SD, n = 3). Different letters within the same row indicate significant differences (Fisher's Least Significant Difference, P<0.05) between mean values.

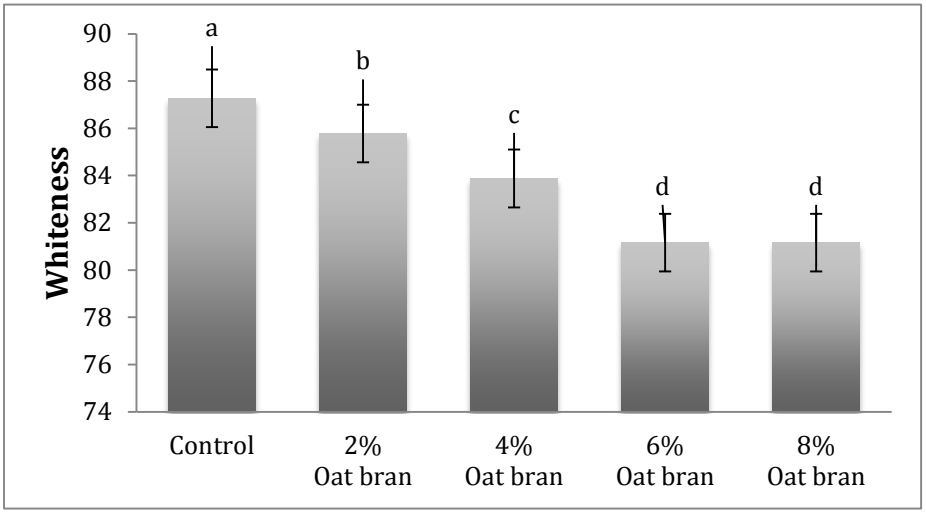

Figure 4. Effect of oat bran on whiteness* of surimi gels.

*Data are given as mean values ± standard deviation (SD, n = 3). Small bars on the top of data bars indicate SD. Different letters on the top of SD bars indicate significant differences (Fisher's Least Significant Difference, P < 0.05) between mean values.

4.5 Analyzing the Effect of Oat Bran on the Expressible Water and Water Holding Capacity of Surimi Gels

The data for expressible water (EW) and water holding capacity (WHC) of the surimi gels are shown in Table 5. The WHC increased significantly ($P<0.05$) with all the treatments compared to the control. The highest value ($P<0.05$) was seen with the 8% oat bran treatment.

The EW decreased significantly ($P<0.05$) with all the treatments compared to the control. The lowest value ($P<0.05$) was seen with the sample that contained the 8% oat bran treatment.

Table 5

Effect of Oat Bran on Water Holding Capacity (WHC) and Expressible Water (EW) of Surimi Gels

Oat Bran Concentrations (w/w)%	WHC (%)	EW (g)
0 (control)	92.00±0.0 ^{e}	6.1±0.0 ^{a}
2	94.79±0.0 ^{c}	4±0.0 ^{c}
4	92.43±0.0 ^{de}	5.9±0.0 ^{b}
6	95.87± 0.2 ^{b}	3.1±0.0 ^{d}
8	96.61±0.0 ^{a}	2.5±0.0 ^{e}

*Data are given as mean values ± standard deviation (SD, n = 3). Different letters within the same row indicate significant differences (Fisher's Least Significant Difference, $P<0.05$) between mean values.

4.6 Analyzing the Effect of Oat Bran on the Cooking Loss of Surimi Gels

Cooking loss is shown in Figure 5. Compared to the control, the 2% oat bran treatment showed significant ($P<0.05$) decrease in cooking loss, but the 4% oat bran treatment did not show significant ($P>0.05$) decrease in cooking loss. The 6% and 8% treatment samples both showed significant ($P<0.05$) decreases in cooking loss compared to the control. The 8% oat bran treatment had the lowest value of cooking loss, showing that the addition of oat bran fiber to surimi gels helped to reduce cooking losses.

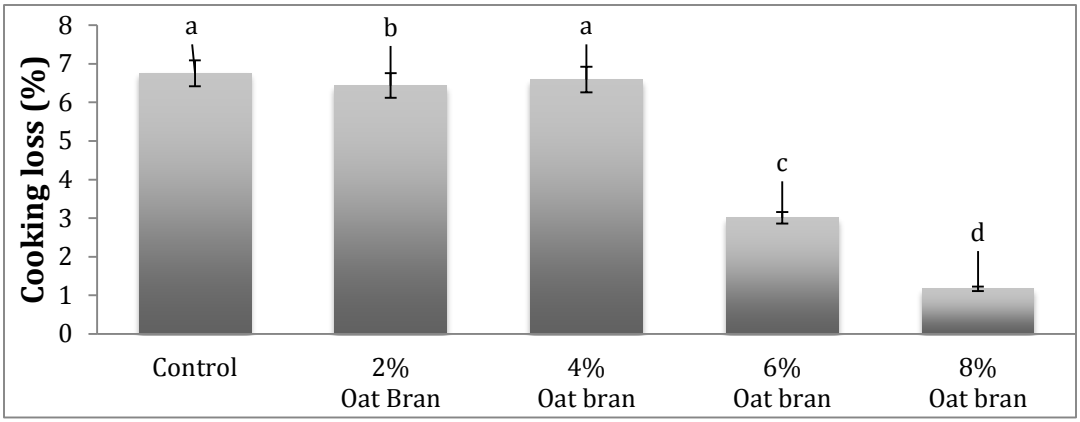

Figure 5. Effect of oat bran on cooking loss* of surimi gels.

*Data are given as mean values ± standard deviation (SD, n = 3). Small bars on the top of data bars indicate SD. Different letters on the top of SD bars indicate significant differences (Fisher's Least Significant Difference, $P < 0.05$) between mean values.

CHAPTER 5

Discussion and Future Research

The purpose of this study was to determine the physicochemical properties (proximate composition, pH, texture, color properties, water holding capacity, and cooking loss) of Alaska pollock surimi gels formulated with variable levels of oat bran while maintaining constant levels of protein and water.

Moisture content of surimi gels developed with different concentrations of oat bran was approximately similar in all the treatments except for the control. Although the moisture content of the control sample was significantly different ($P<0.05$) from the other treatments, numerically it was only slightly lower. This is due to the fact that moisture or water added to different treatments in this study was constant. However, in contrast to this study, Yilmaz & Daglioglu (2003) found that the moisture content of meatballs decreased with the addition of oat bran. They found that the addition of 20% oat bran had the lowest ($P < 0.05$) moisture values. The moisture contents of the samples decreased as more oat bran was added. The control meatballs had the highest ($P < 0.05$) moisture content. This might be due to the different levels of fat and water they used in their study. The protein content in the treated samples shows a significant ($P<0.05$) increase compared to the control for all oat bran treatments from 2% to 8%. The 8% oat bran treatment showed the greatest ($P<0.05$) protein value compared to the control. This is because the oat bran used in this study contained 3.7% protein. Yilmaz & Daglioglu (2003) found similar results when they added oat bran to meatball samples. They found significant differences between the protein content of the control and the treated meatball samples. They obtained the highest protein content with the highest (20%) level of oat bran treatment. Kumar et al. (2010) also showed that the protein content of Chevon (goat) meat was enhanced with the addition of

20% oat bran; that could be considered an added effect. Ash content of the samples was found to be significantly ($P < 0.05$) affected by the addition of oat bran. Yilmaz & Daglioglu (2003) reported that ash content increased with more oat bran added; the highest value was obtained in the 20% added oat bran samples, while the lowest was in the control meatballs. However, in our study, with the addition of oat bran, the ash content of the treated samples decreased significantly ($P<0.05$) compared to the control. In the treatment containing 8% oat bran, the lowest value ($P<0.05$) of ash was obtained. This might be due to the fact that the addition of filler (SiO_2) was the highest in the control sample, and it contributed to increasing the ash content.

In this study, the pH values of the treated samples showed no significant ($P >0.05$) difference compared to the control. These results showed that pH value was not affected by the addition of oat bran to the surimi gels. Similar to these results, Serdaroglu (2006) found that the addition of oat bran had no significant effect ($P >0.05$) on pH in beef patties. Steenblock et al. (2001) also found that pH values of both light bologna and frankfurters were not different ($P > 0.05$) for all levels of oat fiber, so oat fiber did not alter products' pH. The optimum pH for gelation is reported to be within the range of 6.5-7.5 (Park et al., 2013a) and the pH for this study was found to lie between these ranges.

Texture is a major component in measuring the functional characteristics of surimi seafood. (Park, Yoon, & Kim, 2013c). The measurement of texture is the sum of the properties of individual protein fibers and the matrix between these fibers that causes them to adhere (Lanier et al., 2013). It is very important to keep a consistent surimi texture to maintain the seafood quality. Its texture can be affected by various factors, including protein concentration, heating temperature, heating period, and additives (Park et al., 2013a). In this study, all the treatments (the addition of 2%, 4%, 6%, or 8% oat bran) showed significantly ($P<0.05$) greater

shear force than the control. The highest Kramer force value (1.51 N/g) was obtained for the 8% added oat bran sample. This means that the addition of oat bran fiber to the surimi gels improves the gel strength of the treated samples. In the case of Chevon (goat) meat patties, however, the addition of oat bran resulted in a decrease in shear force with increased fiber (Kumar et al., 2010). The product containing 50% oat bran had much lower shear force values compared to the control and the product with 15% oat bran ($P<0.05$). This might be due to the increasing amount of water added to different treatments; in our study, the added water and protein content were maintained at constant levels. In addition, texture profile analysis (TPA) is considered to be an empirical measure that involves compressing a sample twice between two parallel surfaces to imitate the action of the human jaw (Kim, et al., 2005; Park et al., 2013a). TPA measures various textural parameters such as hardness, which measures a food's resistance during a bite. Springiness measures the ability of the product to retain its shape and size after one bite. Cohesiveness measures the resistance of the product during chewing. Gumminess measures the strength required in chewing. Chewiness is a measure of the energy used in chewing; and resilience is a measure of how well a product regains its original position. Though the addition of 2% oat bran had no significant increase ($P>0.05$) in the springiness and cohesiveness of the surimi gels, the gumminess, chewiness, and resilience of the surimi gels increased with the addition of 2% oat bran. All treatments with greater oat bran content (4%, 6%, or 8% oat bran) caused a significant increase ($P<0.05$) in springiness, cohesiveness, gumminess, chewiness, and resilience of the surimi gels. The highest values for all properties were shown by the highest oat bran treatment. This is in accordance with Steenblock et al. (2001), who indicated that the highest springiness values were found in the highest level of oat bran used (3%), and chewiness was generally increased by oat bran. Comparing the control with our other treatment groups, it

can be observed that all chewiness values are higher for the treatments than for the control. Similarly, hardness values also increased with the increased percentage of oat bran in the treatments. The greatest hardness value compared to the control was seen with the addition of 8% oat bran. The hardness values followed a trend similar to the Kramer shear force. Yilmaz & Daglioglu (2003) used oat bran in the production of meatballs and indicated that hardness of meatballs increased with the addition of more oat bran. The control meatballs had the lowest ($P < 0.05$) hardness value. On the other hand, the meatballs produced with the addition of 20% oat bran had the highest ($P < 0.05$) hardness value. Previous studies of fiber incorporation in surimi showed mixed results, with some reporting a decrease in gel strength and hardness, and others reporting an increase in these measures (Cardoso, Mendes, & Nunes, 2007; Cardoso et al., 2008; Cardoso, Mendes, Vaz-Pires & Nunes, 2009). Steenblock et al. (2001) also showed that for frankfurters, the 1% and 2% oat fiber additions had greater hardness values than other treatments, but hardness was not increased for frankfurters to the same extent that it was for bologna. This may reflect the greater added water content in the frankfurters, since moisture content is well-recognized as an important factor in product hardness/softness of processed meats.

Several physicochemical characteristics are of primary concern in studies that assess surimi gel's characteristics. The color properties of surimi gels can be influenced by the use of additives. Studies by Behall & Hallfrisch (2011) found that gels with added moisture tended to be lighter with less yellowness, causing them to look whiter than gels with lower moisture. Because of the significance of whiteness in surimi gels, studies have been performed to increase the intensity of whiteness by the addition of external agents to it. Moisture content is the component generally used to increase whiteness. In addition to moisture, components such as

titanium dioxide, calcium carbonate, or oils can be added to surimi pastes to improve the whiteness of the gels (Gehring et al., 2011). Hsu & chiang (2002) also have found that the addition of oil can increase lightness through the light-scattering effect, and some oils also contain pigments that increase either a* or b*. Algae oil, for example, contains carotenoids that are yellow-orange in color, and these colors are reflected in surimi gels. In all treatments, the addition of oat bran to surimi resulted in a decrease in lightness (L*) values. The decrease in lightness (L*) with the addition of oat bran was accompanied by an increase in yellowness (+b*) of the treated samples. Also, the addition of oat bran resulted in more negative a* values, indicating a slightly greater green hue in the treatments compared to the control. Increasing the percent of oat bran increased the hue of green. Therefore, it was found that with the increase in the percent of oat bran added from 2% to 8%, the lightness decreased, greenness and yellowness increased, and the overall whiteness of the samples decreased. The increase in yellow color of the samples is due to the carotenoid pigments present in oat bran (Yilmaz & Daglioglu, 2003). Overall whiteness of the samples decreased significantly ($P<0.05$) with the oat bran treatments compared to the control. The highest levels of oat bran treatment (6% and 8%) resulted in the lowest whiteness. These results are in accordance with those of Yilmaz & Daglioglu (2003), who added 5%, 10%, 15%, or 20% of oat bran to meatballs. They found that meatballs made with 20% oat bran had the highest b* value (yellowness), and the lowest a* (redness). However, Hughes, Cofrades, & Troy (1997) found that the addition of oat fiber to frankfurters had no effect on the color, regardless of the fat level.

Expressible Water (EW) decreased significantly ($P<0.05$) with all the treatments compared to the control. The lowest EW value was seen with the sample that received 8% oat bran. Water Holding Capacity (WHC) of the surimi gels increased significantly ($P<0.05$) with all

the treatments compared to the control. The highest WHC was seen with the 8% oat bran treatment. These results are not in accordance with Talukder & Sharma (2010), who found that adding oat bran to chicken meat affected EW ($P < 0.05$). Higher EW values were found with increased added oat bran. This might be due to increasing levels of water which were added to their treatments. In our study, the water content was maintained at a constant level for all treatments, allowing us to compare the effect of different levels of oat bran on surimi gels.

In our study, cooking loss is shown in Figure 5. Compared to the control, the 2% oat bran treatment shows a significant ($P<0.05$) decrease in cooking loss, but the 4% oat bran treatment did not show a significant ($P>0.05$) decrease in cooking loss. The 6% and 8% treatment samples both showed significant ($P<0.05$) decreases in cooking loss compared to the control. The 8% oat bran treatment had the lowest value of cooking loss, showing that the addition of oat bran fiber to surimi gels helped to reduce cooking loss. Similar to our results, Kerr, Wang, & Choi (2005) also found that the addition of oat fiber significantly reduced cooking loss. This result is in line with Talukder and Sharma (2010), who found that increasing the amount of added oat bran decreased cooking loss, due to the absorbent nature of oat bran. This could be due to the presence of ß-glucan, a component of oat bran that is hydrophilic and consequently binds free water.

This study demonstrated that dietary fiber can be used to fortify surimi seafood. Most populations have insufficient intake of this health-beneficial nutrient. Fortification of surimi with dietary fiber up to 6 g/100 g improved textural properties; although it resulted in slightly lower color values, these values are still acceptable in premium grade surimi. Textural properties correlated well with water holding capacity, which indicated the ability of surimi to retain more water by oat bran addition. Cooking loss was also reduced significantly. These results are promising for the future implications of manufacturing and marketing a surimi product with

potential health benefits from added oat bran. Although these results are promising, sensory evaluation is recommended to assess consumer acceptance of the product.

Despite the fact that color properties were affected with the addition of oat bran, mainly by increased yellowness (+b*) and decreased lightness (L*), this may be overcome by the addition of whitening agents or possibly by the incorporation of vegetable oils with water or another substance to disperse the color pigments. The addition of oil can increase lightness through the light-scattering effect. Hence, future research would be to study the effects of adding oil in addition to oat bran, to increase the whiteness of the surimi gels.

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