ABSTRACT

CARMAC, ZOE. Effects of Emulsification, Binding Agents, and Rosemary Extract on the Quality of Boudin Made from Cold-Smoked Salmon Trimmings. (Under the direction of Dr. Alexander Chouljenko).

Seafood processing generates substantial amounts of byproducts that are often discarded despite their nutritional value and potential for upcycled food applications. Cold-smoked salmon production, in particular, yields trimmings rich in protein, unsaturated fats, and salt that are typically discarded. This thesis investigated the development of a boudin sausage made from cold-smoked salmon trimmings as a novel value-added product, examining the effects of emulsification, binding agents, and rosemary extract on product quality.

The first study evaluated the functionality of binding agents free of major allergens in boudin formulated from cold-smoked salmon trimmings. Carrot fiber, cornstarch, and flaxseed meal were incorporated at 1.03% and compared with a control (no binder) and an emulsion-based treatment. Sausages were analyzed for cook loss, proximate composition, color, texture, and water-holding capacity. There were no significant differences for most of these parameters except for protein content, which was lower in the control, cornstarch, and emulsion treatments compared with carrot fiber and flaxseed meal sausages. Cook loss was significantly reduced in the emulsion treatment (4.28%±0.80%) compared with the control (8.91%±0.50%), and emulsion sausages exhibited a lighter color (higher L^* value), likely due to improved emulsion formation before cooking. Given its significantly reduced cook loss relative to other treatments and the absence of practically meaningful differences in other quality measures, the emulsion-based boudin was identified as the most promising for further evaluation.

Building on these results, the second study examined the influence of rosemary extract on sensory quality and frozen storage stability of emulsion-based boudin made from cold-smoked salmon trimmings. Formulations containing 0, 40, or 60 ppm carnosic acid rosemary extract were vacuum-packaged and stored at −18 °C for up to 120 days. Thawed samples were objectively analyzed for thaw loss, texture, color, and lipid oxidation (TBARS). All treatments maintained acceptable physicochemical quality, with TBARS and thaw loss values generally remaining within acceptable ranges reported in the literature. Consumers (N = 107) evaluated sensory liking (nine-point hedonic scale), attribute intensity (JAR scale), and purchase intent (five-point scale) of thawed and reheated samples stored frozen for 7 days and thawed for 2 days. Sensory evaluation revealed minor perceptible differences in JAR or specific attribute liking scores among treatments, aside from texture being the least liked attribute. Slight but statistically significant preferences were observed for boudin containing 40 or 60 ppm rosemary extract in overall liking and purchase intent compared with the control. Penalty analysis indicated areas for improvement in flavor balance and color through formulation or processing modifications.

Together, these studies demonstrate the feasibility of producing boudin from cold-smoked salmon trimmings using standard processing methods while maintaining acceptable quality during 120-day frozen storage. This work highlights an opportunity for seafood processors to upcycle smoked salmon trimmings into value-added products with demonstrated market potential. Future research on smoked salmon boudin could address consumer sensory queries, extend frozen storage testing beyond 120 days while evaluating sensory quality, or assess refrigerated shelf life.

Effects of Emulsification, Binding Agents, and Rosemary Extract on the Quality of Boudin Made from Cold-Smoked Salmon Trimmings.

By Zoe Carmac

A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the degree of Master of Science

Food Science

Raleigh, North Carolina

2025

APPROVED BY:

_____

Dr. Alexander Chouljenko

Committee Chair

_____ _____

Dr. Fernanda Santos Dr. Dana Hanson

BIOGRAPHY

Zoë Carmac was born January 1, 2002 in Asheboro, North Carolina. She stayed in North Carolina and attended NC State University from 2020-2023 to complete a Bachelor's degree in Applied Nutrition Science. In January 2024, she decided to continue her education, and began a Master's degree in Food Science at NC State under the supervision of Dr. Alexander Chouljenko. During this time, she learned how to develop a product out of salmon byproducts, and analyze the shelf stability and consumer liking. Outside of research, she enjoys trying new coffee shops, going to the beach, and spending time with friends and family.

ACKNOWLEDGEMENTS

"Commit your work to the Lord, and your plans will be established." Proverbs 16:3. This experience would not be possible without my advisor Dr. Alexander Chouljenko and my committee members Drs. Fernanda Santos, Dana Hanson, or the NC State seafood lab, Dr. Alona Chepiha, Greg Bolton, Sanaz Mirtalebi, and Isabelle Clayton. Thank you to the Drake lab for all your help and assistance in the sensory testing process. I am also so grateful for Professor Paige Luck, who started this entire journey for me by making her intro to food science course so much fun to take, and April Hix Morrison who encouraged me to continue my food science education as a minor, as well as all of other NC State faculty, staff, and students who have answered my many, many questions throughout this experience. To all my professors who provided my education, thank you. To Acme Smoked Fish, thank you for your contribution of salmon. I would also like to thank my friends and peers, Madeline Keefe, Abigail Lin, Allison Ahrens, Bailey Willis, Kathryn Perry, Ayah Idris, Rachael Dale, and Jacob Collins for your support over the last two years. Thank you to my church and community group, who have instilled so much wisdom in me, and constantly prayed over my success. In addition, to my family, you have my eternal gratitude. Last, but certainly not least, a very special thank you is owed to my all-time supporter and #1 fan Sarah Hurley.

TABLE OF CONTENTS

LIST OF TABLES

Chapter 2

Chapter 3

LIST OF FIGURES

Chapter 2

CHAPTER 1: LITERATURE REVIEW

1.1. Salmon nutrient composition

1.1.1. Protein

Protein is an essential macromolecule and plays an important role in the maintenance of bones and muscular health. The Recommended Daily Allowance communicates that 0.8 g/kg or 0.36 g/lb of protein should be consumed per day to meet biological needs (Wu, 2016). Salmon can be characterized as a source of protein. The head of *Oncorhynchus nerka* (Sockeye) salmon has been estimated to be around 11.9% protein of the total wet weight, while the viscera has about 14.8% when proximate analysis was analyzed (Wu et al., 2011). Per 100 g of filet, Sockeye salmon has about 28 g of protein (Agricultural Research Service, 2023). The United States Department of Agriculture (USDA) has additionally calculated that 100 g of a raw, farmed Atlantic salmon filet has 20.4 g protein (Agricultural Research Service 2024a). These estimates are supported as a substantial source of protein. The filet portion of raw Atlantic salmon was found to be approximately 14.73% protein (Fomena Temgoua et al., 2022). Boiling, steaming, and oven-cooking increased the protein content to respective estimations of 16.69%, 18.90%, and 20.59% (Fomena Temgoua et al., 2022). When the belly flap of salmon was analyzed among Atlantic salmon whole body samples, the protein content was calculated to be between 14% and 16% (Ulleberg et al., 2023). When a separate study fed a commercial type diet to Atlantic salmon, it was found that approximately 18.2 g of protein were present in 100 g of the fish as a whole (Bell et al., 2016).

1.1.2. Fat

Appropriate fat intake is essential for biological function (Crowley, 2024). Salmon is a source of a variety of fats. However, different parts contain different makeup of total fat content. The head of *Oncorhynchus nerka* salmon has been estimated to be around 17.4% fat of the total wet weight, while the viscera has about 3.1% when proximate analysis was analyzed (Wu et al.,

2011). Per 100 g, Sockeye salmon has about 3.51 g of fat (Agricultural Research Service, 2023). A study that analyzed the lipid profile of Atlantic salmon filets found that farmed Atlantic salmon was composed of approximately 15.0% saturated fatty acids, 55.4% monounsaturated fatty acids, and 29.6% polyunsaturated acids. The wild Atlantic salmon's monounsaturated, and polyunsaturated fat measurements were lower in comparison at approximately 47.4%, and 26.3%, while the saturated fat was higher at 26.3% (Molversmyr et al., 2022). The filet portion of raw Atlantic salmon was found to be approximately 9.02% fat (Fomena Temgoua et al., 2022). Boiling, steaming, and oven-cooking increased the protein content to respective estimations of 9.52%, 11.19%, and 11.66% (Fomena Temgoua et al., 2022). The belly flap of Atlantic salmon trimming samples has an estimated lipid content of approximately 35% (Ulleberg et al., 2023). When a separate study fed a commercial type diet to Atlantic salmon, it was found that approximately 7.8 g of lipid were present in 100 g of the fish as a whole (Bell et al., 2016).

1.1.3. Carbohydrates

Salmon is not a significant source of carbohydrates. However, carbohydrates are encouraged to come predominantly from fruit, starch, legume, and vegetable sources (Hermann, 2021). Additionally, the MyPlate illustration outlines the recommended daily intake for each food group, and demonstrates that fruits and grains should represent almost half of a meal's make up (MyPlate, 2025). Salmon's low carb disposition provides the protein and fat macromolecules, and paired with a nutrient-dense carbohydrate source creates a foundation for healthy meals.

1.1.4. Omega-3 Fatty Acids

A unique nutritional characteristic of many marine animals, including Atlantic salmon, is the presence of omega-3 fatty acids (National Institute of Health, 2022b). Omega-3 fatty acids are unsaturated fats, and an essential nutrient for humans that must be attained via diet (National Institute of Health, 2023). Omega-3 fatty acids serve many functions throughout the body, including the creation of cell membranes and sex hormones (National Institute of Health, 2023). Additionally, they are vital for heart health, and suggested to combat cardiovascular disease (National Institute of Health, 2022b). Omega-3 deficiencies are characterized by dry skin and red, itchy rashes, suggesting an additional function in the role of skin (National Institute of Health, 2022b).

The three main omega-3s obtained from food are alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). EPA and DHA are the primary omega-3s found in fish (National Institute of Health, 2022b). In 100 g of raw Atlantic salmon filet, it has been estimated that there is approximately 602 mg EPA and 1285 mg DHA (Fomena Temgoua et al., 2022). When analyzing wild and farmed Atlantic salmon, it was found in the filets that the EPA and DHA levels were similar, and ranged around 520 mg and 523 mg/100g, suggesting that the diet of the farmed Atlantic salmon influences the EPA and DHA comparison to wild Atlantic salmon (Molversmyr et al., 2022).

A different study compared the EPA and DHA levels of wild and farmed raw Atlantic salmon, and found a wider range of results. Within a 100 g sample of each, the EPA levels of wild and farmed salmon were measured at 260 mg and 440 mg, while DHA levels were measured at 520 mg and 620 mg, respectively (Jensen et al., 2012). These are unusual results, and likely due to the quality of the food being fed to the farmed salmon (Jensen et al., 2012). A study that analyzed the fatty acid profile of five different farmed salmon species found a wide

variety of EPA and DHA, further suggesting that diet has a substantial effect on the fatty acid profile of salmon nutrient content (Cladis et al., 2014).

The recommendation for fish consumption is two servings per week, with an emphasis placed on fatty fish, as specified by the American Heart Association (AHA, 2024). Following 2015-2020 dietary recommendations of 8 oz of seafood per week would result in about 250 mg of DHA and EPA consumption weekly (Zhang et a.l, 2019; USDHHS & United States Department of Agriculture, 2015). Inverse relationships between the consumption of fish and coronary mortality have the greatest evidence in populations that can be characterized by low intake of fish (Kris-Etherton et al., 2002). Furthermore, omega-3 fatty acids are suggested to be inversely related to blood pressure, suggesting consumption may reduce the effects of coronary disease (Ueshima et al., 2007).

The inhibition of several calcium-ion channels is a potential explanation for omega-3's perceived role in protection from arrhythmia (Kennedy, 2016). Many contributors to cardiovascular disease are suggested to be altered by omega-3s. This includes decreases in blood pressure, chemoattractant production, and growth factors while increasing endothelial relaxation and stability of plaque formation in the arteries (Calder, 2014). The mortality rate in those at risk of heart disease has been significantly decreased by omega-3 consumption in multiple studies. Clot formation is lowered or weakened when eicosanoids production is stunted by omega-3s. A lower and more variant heart rate has also been observed in relation to omega-3 consumption. When heart rate is unfavorable, responses to stress can have increasingly dangerous results. The stabilization of plaque build up contributes as well in that blood can move more freely through the arteries (Calder, 2014).

Along with its heart health attributes, omega-3 has several properties that are suggested to block, inhibit, or lessen inflammatory reactions. One example is the reduction of cytokine quantity to reduce or block inflammation responses (Kennedy, 2016). Omega-3 polyunsaturated fatty acids found in marine animals tend to have a higher quantity of the endocannabinoids made up of DHA or EPA (Calder, 2013). The properties of these variations of omega-3 are suggested to bind and inhibit several receptors known to cause inflammation (Calder 2013).

1.1.5. Vitamins and Minerals

Salmon contains a variety of vitamins and mineral content. Two of the most abundant minerals found are selenium and potassium. Selenium is an antioxidant activator, and important for muscle physiology and immune system function. Eyesight and skin tend to be in less than optimal condition when selenium deficiencies occur as well. The recommended daily selenium intake for individuals between ages of 14-71+ is 55 mcg (National Institute of Health, 2024a). Wild sockeye salmon and farmed Atlantic salmon are estimated to have about 30.2µg and 24µg selenium per 100 g, respectively (Agricultural Research Service, 2024a; Agricultural Research Service, 2024b). One study found that the omega-3 and selenium composition within plasma was found to increase significantly over the course of 8 weeks when 120 g of salmon was consumed twice a week, further supporting the recommendation of consuming fish twice a week (Stonehouse et al., 2011; G. Wu, 2016).

The adequate daily intake of potassium is 3,400 mg for males and 2,600 mg for females ages 19+ (National Institute of Health, 2022a). Potassium and sodium regulate the water quantity and the movement of waste and nutrients within cells via the potassium-sodium pump. Muscle contraction, heart regulation, and nerve function all rely on potassium as well (National Institute of Health, 2022a) Increases in blood pressure and the risk of kidney stones are risks of

insufficient potassium levels (National Institute of Health, 2022a). A 100g serving of raw, farmed Atlantic salmon has approximately 363 mg of potassium, respectively (Agricultural Research Service, 2024a).

Furthermore, while there are minimal foods that naturally contain vitamin D, fatty fish such as salmon are recognized as a source (National Institute of Health, 2024b). Vitamin D's primary function is to promote the absorption of calcium into the bones (National Institute of Health, 2024b). Osteoporosis, rickets, and osteomalacia are all risks of vitamin D deficiency (National Institute of Health, 2024b). Adults are recommended to consume 600-800 IU of vitamin D per day, and 100 g raw, farmed Atlantic salmon is estimated to contain approximately 441 IU of D2+D3, respectively (Agricultural Research Service, 2024a; National Institute of Health, 2024b). The location where wild salmon is caught is suggested to have an impact on the vitamin D levels within the filet. It was found that a wild Atlantic salmon filet was measured at approximately 18.5 μg of vitamin D, while a wild caught Pacific salmon filet had approximately 9.4 μg (Jakobsen et al., 2019).

1.1.6. Pigments

The potential heart health and anti-inflammatory properties are further supported by the presence of astaxanthin (Pereira et al., 2021). A carotenoid and antioxidant, astaxanthin is responsible for the red-orange coloring of salmon flesh and is proven to have strong antioxidant properties (Donoso et al., 2021). When compared to a popularly used antioxidant, alpha tocopherol, astaxanthin has 100-500 times greater antioxidant capacity (Donoso et al., 2021). The color and strong antioxidant ability can be explained by the presence of a conjugated double bond at the center (Higuera-Ciapara et al., 2006). Research indicates that consumption of astaxanthin may lower LDL oxidation and increase HDL levels (Kishimoto et al., 2016).

Additionally, astaxanthin has been used more frequently in attempts to treat and prevent neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease (Galasso et al., 2018). Astaxanthin is suggested to inhibit LDL oxidation, and may be a way to combat atherosclerosis (Iwamoto et al., 2000). Farmed atlantic salmon is estimated to have approximately 6-8 mg astaxanthin per kg flesh (Ambati et al., 2014).

1.2. History of Boudin

The concept of 'blood sausage' has been demonstrated throughout Europe in variations among different countries and cultures. Blood sausage is a style of sausage that utilizes blood byproducts, and often other byproducts as well. The French version, 'boudin', typically contains pig byproducts, rice, and vegetables stuffed into a pork casing (Albert, 1979). The French immigration to Louisiana, USA led to local variations of this style. Inclusion of seafood such as crawfish, crab, and shrimp can be found in boudin prepared in the area.

There are a few variations of French style boudin (Albert, 1979). *Boudin blanc* is described as a method that boils and grinds the meat before adding cooked green onions and spices. The boiled water is saved and used as a thinning agent after all the filling is made as needed. Additional spices and rice are added and then the filling is stuffed into a pork casing. *Boudin rouge* is the version that utilizes the blood, and historical evidence suggests that 1-2 lbs are typically used for 100 lbs worth of sausage. Salt is added to the blood to prevent coagulation.

1.3. Boudin Research

Given the niche population of consumers, minimal research has been conducted on boudin, especially regarding blood sausage specifically. Blood sausage is prepared differently across regions, creating a wide variety of experimental research. A shelf life study was conducted regarding a blood sausage that utilized the blood, heart, and kidney of goat, in

addition to its regular meat (Silva et al., 2014). A separate Korean study measured quality characteristics of a pig blood sausage when different vinegars were applied (Choe & Kim, 2016). However, the most common meat of choice for blood sausage appears to be pork. A Portuguese version was made by mixing pork, blood, onions, rice, and spices and stuffed into a casing to be boiled in a prepared broth (Pereira et al., 2008). A popular version of blood sausage in Italy combines pig discards, lard, blood, and spices and stuffed into pork bowels. This variation is recommended to either be consumed fresh or to undergo 30 minutes of boiling (Iacumin et al. 2017).

The Korean blood sausage was prepared by soaking pig skin in various vinegars and then soaking in water until a slightly acidic pH was reached. The pork meat, blood, and boiled fat were mixed together and ground using a 3 mm plate. The rest of the ingredients were then added and stuffed into 30 mm hog casings and smoked at 80ºC. Physicochemical tests were completed on chemical composition, pH, cooking loss, swelling yield, color, texture, and TBARS. Sensory work focused on product description, including juiciness, color, vinegar flavor, tenderness, color, flavor, and tenderness (Choe & Kim, 2016).

In comparison, a Portuguese version mixed all the ingredients at once and stuffed into a beef 60-65 mm casing. The ingredients included minced pork meat, raw rice, spices, pork blood, water, and lard. The blood sausage was then cooked in a batch vessel filled with water and broth (J. Pereira et al., 2008). Another popular style in Italy does not include rice at all, and combines blood, meat, and lard before adding spices and stuffing into pork bowels and boiling (Iacumin et al. 2017). After testing for the presence of various microbial organisms, it was determined that the blood sausage could be consumed safely within approximately 30 days, and was best within the first 14 days (Iacumin et al. 2017). Ascorbic acid was the primary preserving agent (Iacumin

et al. 2017). The sensory aspects tested included external and slice appearance, odor, and taste. No significant differences were observed between days 0 and 30. Boudin and blood sausage research is traditionally concentrated on either physicochemical properties or sensory properties, however not a thorough combination. Cold smoked salmon trimming boudin currently has no published work on any physicochemical or sensory properties

Regardless of where a meat product is made, basic meat science must be considered. In a typical boudin, salt is added to the meat and mixed for several minutes. Myosin is the main protein in meat, and plays an important role in the texture of the overall product (Knipe, 1987). Myosin unfolds when it interacts with the chloride anion, creating a more sticky texture. When cooked, cross-linking occurs and the system forms a gel (Sullivan et al., 2021). Myosin is present when the animal is still alive, and once death occurs the myosin binds with actin to form actomyosin. At this point, the pH is typically at the isoelectric point, which is when the meat has the least water holding capacity (WHC) (Knipe, 1987). It is also thought to have an increasing effect on ionic strength, and potentially cause the pH to rise (Offer & Trinick, 1983). The addition of salt increases the WHC when it creates a charge imbalance (Knipe, 1987). The chloride anion can increase juiciness and decrease water loss as the negative charge attracts the positive charges of the sodium ions (Sullivan et al., 2021).

1.4. Byproducts

As sustainability is of growing concern to the public, the food industry struggles to find production techniques that are both efficient and meet consumer approval. The practice of fish farming is suggested by some to be more sustainable than traditional fishing practices (National Oceanic and Atmospheric Administration, 2020). Commercial aquaculture originated in Norway during the 1970's, and Atlantic salmon has been a primary focus of the country's total

production of aquaculture (Tarranger et al., 2015). Prices for salmon have additionally decreased as a result of farming, making it more affordable (Goldburg & Naylor, 2005). However, fisheries have raised environmental concerns within the seafood community particularly when farms are not located in the open ocean. Farms on land rather than the ocean are at greater risk for pests such as sea lice, and expected to experience more stress which increases likelihood of disease (Cho, 2016). The circulation systems for fish waste are also a cause of concern. Land management systems use a high quantity of water for circulation. New techniques have emerged that use less water, however money and regulation constraints can cause limitations in the adaptation (Cho, 2016).

While food byproducts are typically sent to landfill, food upcycling has become increasingly popular, bringing repurpose to byproducts. The EPA lists upcycling and the prevention of food waste as the most preferred method of reducing food waste, and estimates that about 58% of methane emissions into the atmosphere from landfills are created by food discards (Environmental Protection Agency, 2015). Other reuse methods include using waste for animal feed, anaerobic digestion, compost, and as a nutrient application to soil (Environmental Protection Agency, 2015). The EPA estimated that in 2019 around 66 million tons of food waste were produced, and around 60% was sent to landfills (Environmental Protection Agency, 2017). The high quantity of waste is of concern, given that gas emissions generated from food waste contribute to greenhouse gasses, which can lead to temperature changes both globally and in specific climates (Climate Action, 2022; Kaur et al., 2023). While fruit and vegetable discards are estimated to contribute the most to food waste with around 492 million tons produced per year, fish and fish products still contribute and are calculated at approximately 8 million tons (Segrè & Falasconi, 2011; Kaur et al., 2023). It is estimated that nearly 75% of fish byproducts

are thrown away, or used for non-human consumption purposes (Caruso, 2015; Kaur et al., 2023). The head and the frames makeup the greatest percentage of byproducts by weight, at 10% each of total byproducts for Atlantic salmon (IFFO, 2023).

In addition to the environmental threat food waste poses, food waste additionally can present challenges nutritionally, economically, and socially (Kaur et al., 2023). Nutrient rich food items can be ultimately wasted. Cooper et al. (2018) found that meat and fish were one of the primary sources for wasted iron among food waste. They also estimate that in the UK there is enough waste discarded annually to represent 37 daily diets per capita (Cooper et al., 2018). Vitamins B12, thiamin, and phosphorus were calculated to be the most wasted nutrients (Cooper et al., 2018). Consumers often waste food due to many reasons, including poor purchasing decisions, improper storage, and over preparing when cooking (Kaur et al., 2023).

Currently, most upcycled products available for human consumption come from non-seafood sources. Fruit and vegetable waste are thought to contribute the most to total food waste, and many food upcycling organizations focus on finding a new use for produce discards. Unfortunately, there are many limitations to successful seafood snack products. Most fish, including salmon, have a high fat content that leads to lipid oxidation. As a result, the rancidity causes a short shelf life and unappealing sensory characteristics. Seafood additionally struggles much more for consumer acceptance when compared to produce, particularly in the United States. ChicP is an example that uses England's vegetable waste and upcycles it into hummus (ChicP, 2015). Barnana is another example of a company that takes bananas that are considered too ripe for consumer liking and develops them into banana and plantain snacks, such as chips (Barnana, 2015). However, there are some upcycling based companies within the seafood industry. GoodFish Seafood is a company that has sold snacks made from salmon skin, which

are typically considered a byproduct and discarded by salmon processing companies (Goodfish, 2022).

1.5. Antioxidants

Lipid oxidation is a common issue with any meat product, particularly those high in unsaturated fats. Oxidation occurs when free radicals participate in an interaction between oxygen and unsaturated fatty acids, and hydroperoxides are formed and ultimately lead to oxidative rancidity (Gibson & Newsham, 2018). The hydroperoxides are considered the first oxidation products, and the secondary compounds formed as the peroxides decompose are known as the secondary oxidation products. Hydrocarbons, alcohols, aldehydes, and ketones are some common examples (Gardner, 1989). The initial peroxides are odorless, however the secondary products are what can be identified as the cause of off smells and flavors (Domínguez et al., 2019). The rancidity is understood to occur when light or heat breaks the hydrogen bond, resulting in a free radical that peroxides bond with in place of the hydrogen. A chemical chain reaction is then initiated as the peroxides continue to adsorb hydrogen, and food products quickly experience changes in color, texture, and taste (Gibson & Newsham, 2018). Geosmin and 2-methylisoborneol are considered two primary compounds for off flavors in freshwater fish (Howgate, 2004). The hydrolysis of triglycerides and release of free fatty acids results in hydrolytic rancidity, and is more common in short-chain fatty acids (Gibson & Newsham, 2018). Gas chromatography and HPLC are often used methods to quantify lipid oxidation (Domínguez et al., 2019). GC-MS is useful for determining the presence of cholesterol oxidation products (Domínguez et al., 2019).

1.6. Rosemary Extract

There are several methods that can be utilized to delay lipid oxidation, however consumers have been increasingly more concerned about methods of food preservation and in favor of more natural ingredient use (Ritota & Manzi, 2020). An emerging ingredient for meat preservation is rosemary extract. The extract is prepared from dried rosemary leaves. Several methods of extraction have been developed to conduct this process. Carnosic acid and carnosol are considered to be the primary components that make rosemary extract an antioxidant (Addis & Warner, 1991; Richeimer et al., 1996).

A study on carnosic acid antioxidant mechanisms discovered a high reactivity toward reactive oxygen species (ROS), which causes it to be oxidized and converted into metabolites (Loussouarn et al., 2017). Its ability to seek out and eliminate ROS contributes to carnosic acid's high antioxidant abilities. It is suggested that this function is carried out in both high and low levels of light. Carnosol is an oxidation product of carnosic acid and was also found to prevent lipid oxidation. The mechanism of carnosol is suggested to be different from the mechanism of carnosic acid, and potentially blocks the lipid peroxidation chain via interaction with lipid radicals. Rosemary is also suggested to block quorum-sensing (Szabó et al., 2010). Carnosic acid and carnosol were tested in their ability to block RNA and gene expression pathways used for quorum sensing of *Staphylococcus aureus* and were found to have significant inhibition abilities (Nakagawa et al, 2020).

Rosemary extract has a variety of uses just within the food industry, including meat, sauces, and seafood. It was found in a salmon pate that the addition of rosemary extract reduced secondary oxidation products of cholesterol oxidation, and discoloration (Cedeño-Pinos et al, 2022). The reduction of secondary lipid oxidation was further confirmed in a separate study that additionally found that rosemary extract treated salmon was able to maintain a consistent fatty

acid ratio, while the untreated sample showed decreases after 6 days of storage (Tironi et al., 2009). A study on the effects of adding 400 ppm of rosemary extract to pork Bologna sausages concluded that the extract reduced TBARS by 73% when samples were stored for up to 4 weeks with modified atmosphere packaging at -80°C (Jongberg et al., 2013). TBARS are a measure of lipid peroxide end products (Trevisan et al., 2001). Rosemary extract was further demonstrated to reduce lipid oxidation in a beef sausage made up of 25% fat. The control contained only beef, beef fat, and ice. The experimental samples containing 200 ppm of rosemary extract had a reduction in TBARS at the day 0 and 3 week time points after being vacuum-packaged and stored at 4°C for up to 3 months (Nacak et al., 2021). The sulfhydryl and carbonyl peroxide groups were measured specifically, and both were found to be of lower values than the control with addition of rosemary extract at the 3 month post-storage time point (Nacak et al., 2021).

A salmon jerky study treated experimental samples with rosemary extract, mixed tocopherols, tertiary butylhydroquinone, and ascorbyl palmitate via extrusion at amounts calculated to be 0.02% of lipid content (Kong et al., 2011). The rosemary extract sample had greater amounts of astaxanthin at each time point over the course of 24 weeks stored at 35°C and 75% humidity in barrier pouches (Kong et al., 2011). These are desirable results given that astaxanthin provides the red color of salmon and is suggested to have several health benefits (Donoso et al., 2021; Galasso et al., 2018; Iwamoto et al., 2000). In regards to lipid oxidation, by week 12 the rosemary extract was the only tested antioxidant treatment that had significantly lower lipid oxidation than the control (Kong et al., 2011). The rosemary extract treated sample continued to have lower lipid oxidation than the control throughout the rest of the 24 weeks (Kong et al., 2011). The addition of rosemary extract was found to significantly lower the TBAR values within a frozen pork sausage experiment, however the application to frozen seafood

sausage is limited (Sabranek et al., 2005). Rosemary extract shows potential to combat lipid oxidation in high fat foods such as salmon, yet research on the application of rosemary extract to boudin or blood sausage in regards to physicochemical properties, microbial reduction, or consumer liking has not been conducted.

1.7 Allergens in Sausage

As food allergies in the United States have become increasingly common, the food industry has been given an incentive to find allergen-free ingredients for food products. A 2023 CDC report found that over 6% of American adults are estimated to have a food allergy (National Center for Health Statistics, 2023). Eggs and breadcrumbs are common emulsifiers of blood sausages that are unfortunately major allergens (Sicherer & Sampson, 2006). An economic analysis study concluded that in some areas, milk, egg, and/or wheat allergies were much more costly when compared to the expenses of other allergens (Fong et al., 2022). Cost of food and food insecurity have increased within recent years, making the development of allergen friendly options at cost effective prices even more crucial (World Bank Group, 2023).

While the salmon itself is considered an allergen, a salmon boudin product void of any other allergens has potential to add value to the diet. Salmon is rich in unsaturated fats and protein, in addition to several vitamins and minerals. Meat is often considered one of the easiest ways to consume adequate protein, however most animal meats are also a high source of saturated fats. Cooked pork contains approximately 7.72 g of saturated fat per 100 g, while the same serving has 7.58 g of saturated fat in ground beef with 20% fat (Agricultural Research Service, 2019a; Agricultural Research Service, 2019c). Chicken breast is estimated to have 1.5 g of saturated fat for 100 g (Agricultural Research Service, 2019b). Farmed, cooked Atlantic salmon has approximately 2.4 g of saturated fat in 100 g (Agricultural Research Service, 2018).

Although chicken may have a lower amount of estimated saturated fat, there are many benefits to including salmon in the diet as well when considering the elevated amount of unsaturated fat (Agricultural Research Service, 2018; Agricultural Research Service, 2019b). Chicken and salmon additionally have different vitamin profiles. Chicken is generally a better source of iron, niacin, and zinc, and salmon is richer in selenium, vitamin C, and folate (Agricultural Research Service, 2018; Agricultural Research Service, 2019b).

Rising concerns around the high levels of saturated fat in addition to some practices within the meat industry has led to a movement toward the pescatarian diet for many Americans. The pescatarian diet excludes any meat or poultry products, but still includes fish and seafood. Research suggests that the pescatarian diet scores higher on the Healthy Eating Index and lower carbon footprint when compared to an omnivore diet (O'Malley et al., 2023). A common motivator for the exclusion of animal and poultry products from the diet is perceived unethical behaviors concerning the slaughtering and maintenance practices of terrestrial animals. Some potential explanations behind pescatarian willingness to consume fish, despite these issues, are the perception that fish cannot feel pain, health benefits, and speciesism (Rosenfield & Tomiyama, 2021).

Several religious denominations also restrict the consumption of certain meat products, however allow consumption of fish. For example, many practicing the Islamic and Jewish faith refrain from consumption of pork products. Cows and chickens are permitted by Islamic practices if prepared in Halal manner. The Halal diet prohibits the preparation of food that comes into contact with anything considered to be 'haram' (American Halal Foundation, 2024). Haram qualifications include carnivorous animals, any type of swine, animals slaughtered unethically, in addition to other regulations (American Halal Foundation, 2024). There are several sects of

Islam with different attitudes towards consumption of seafood. Some permit consumption of all aquatic animals, while others only allow fish, or specially fish with scales. Specific beliefs on consumption can be classified as divided, however salmon would be permitted by most sects (Bashir et al., 2018). Similarly, the Jewish Kosher diet allows some meat consumption within certain regulations. Kosher meat includes domesticated fowl and ruminant animals with split hooves that chew cud. Certain parts of kosher animals are also not allowed to be eaten. Shellfish are not considered kosher, however fish that have fins and scales, such as salmon, are permitted (Jewish Virtual Library, 2001).

Many animal-based products are subject to leakage of moisture and lipid content as they undergo cooking. Binding agents have a plethora of uses in the food industry, such as reducing cooking loss, texture enhancement, and flavor enhancement. As food allergies are becoming an increasingly prevalent public health concern, the usage of ingredients free of the nine major allergens may increase product marketability (Sansweet et al., 2024). A common challenge for product developers is finding allergen friendly ingredients that are cost effective, functionally effective, and liked by consumers. The incorporation of carrot fiber into beef and turkey sausages resulted in an improvement in general consumer acceptability when compared to a control with no carrot fiber, and did not alter the smell or color (Slima et al., 2019). Furthermore, when quinoa, amaranth, and cornstarch were compared in beef sausages, consumers indicated that they liked the texture, taste, juiciness, color, and aroma of the cornstarch treatment, in addition to cornstarch having the highest overall liking score (Muchekeza et al., 2021). A study that evaluated the addition of varying amounts of flaxseed flour (FF) into restructured mutton chops found that incorporating 1% and 1.5% FF improved the general appearance, binding, texture, and overall acceptability of consumers (Sharma et al., 2014). The indicated consumer acceptability

and lack of major allergens suggest that further exploration into meat application may result in a marketable product.

In regards to the functionality, cornstarch is well known for its ability to bind and thicken products. The amylose and amylopectin content of cornstarch enables it to absorb liquids and hold them, creating a thicker texture. Swelling occurs more quickly at higher temperatures, and is limited in swelling capacity when at lower temperatures (Mason, 2009). The branched structure of amylopectin and amylose found in abundance within cornstarch promotes adhesion, which is the force of attraction between the cornstarch and a liquid such as water or oil (Frabetti et al., 2021). Cornstarch is also a relatively low-cost ingredient, priced at approximately 11 cents per ounce (Walmart, 2024).

The use of carrot fiber in sausages has been researched some in land animal meats, but not extensively in relation to seafood or salmon products (Johnson, 2022). Non-cellulosic polysaccharides, or pectin, and cellulose are the primary polysaccharides found in carrot fiber (Encalda et al., 2016). Their ability to function as a binding agent is due to the formation of a gel in which water can be held within the structure of the gel (Said et al., 2023). Carrot fiber can be obtained for approximately two dollars per ounce, and further evaluation of its effect on seafood sausage and marketability is needed (Walton's, 2024). Similarly, flaxseed seed's polysaccharide composition creates hydrocolloid behavior when mixed with water, forming a gel (Lorenc et al., 2022). Flaxseed meal can be obtained at some retail locations for approximately seventy-one cents per ounce (Walmart, 2025).

Minimal research has been done on flaxseed meal, carrot fiber, or cornstarch application in sausage or seafood, creating a gap in research regarding the incorporation of these binding agents into boudin sausage to make an allergen friendly product.

REFERENCES

Addis, P. B., & Warner, G. J. (1991). The potential health aspects of lipid oxidation products in food. In *free radicals and food additives* (pp. 77-119).

Agricultural Research Service. (2018). Fooddata central-Fish, salmon, Atlantic, farmed, cooked, dry heat. *United States Department of Agriculture*. https://fdc.nal.usda.gov/fdc-app.html#/food-details/175168/nutrients

Agricultural Research Service. (2019a). Beef, ground, 80% lean meat / 20% fat, raw. *United States Department of Agriculture*. https://fdc.nal.usda.gov/food-details/174036/nutrients

Agricultural Research Service. (2019b). Chicken, broilers or fryers, breast, meat only, cooked, roasted. *United States Department of Agriculture*. https://fdc.nal.usda.gov/food-details/171477/nutrients

Agricultural Research Service. (2019c). Fooddata central- Pork, fresh, ground, cooked. *United States Department of Agriculture. https://fdc.nal.usda.gov/food-details/167903/nutrients*

Agricultural Research Service. (2023). Fooddata central- Smoked wild Alaskan sockeye salmon. *United States Department of Agriculture.* https://fdc.nal.usda.gov/fdc-app.html#/food-details/712072/nutrients

Agricultural Research Service. (2024a). Fooddata central-fish, salmon, Atlantic, farmed, raw. *United States Department of Agriculture.* https://fdc.nal.usda.gov/fdc-app.html#/food-details/175167/nutrients

Agricultural Research Service. (2024b). Fooddata central-fish, salmon, sockeye, wild caught, raw. *United States Department of Agriculture.* https://fdc.nal.usda.gov/fdc-app.html#/food-details/2684440/nutrients

Albert, R.S. (1979). A Franco-American overview, Volume 1. *National Assessment and Dissemination Center.*

Ambati, R. R., Siew Moi, P., Ravi, S., & Aswathanarayana, R. G. (2014). Astaxanthin: Sources, extraction, stability, biological activities and its commercial applications—a review. *Marine Drugs*, *12*(1), 128–152. https://doi.org/10.3390/md12010128

American Halal Foundation. What is halal? What halal means. (2024). *American Halal Foundation*. https://halalfoundation.org/insights/what-is-halal/

American Heart Association. (2024). *Fish and omega-3 fatty acids*. https://www.heart.org/en/healthy-living/healthy-eating/eat-smart/fats/fish-and-omega-3-fatty-acids

Barnana. (2015). *Snacks*. Barnana. https://barnana.com/collections/snacks

Bashir, K. M. I., Kim, J.-S., Mohibbullah, M., Sohn, J. H., & Choi, J.-S. (2018). Strategies for improving the competitiveness of Korean seafood companies in the overseas halal food market. *Journal of Islamic Marketing*, *10*(2), 606–632. https://doi.org/10.1108/JIMA-03-2018-0056

Bell, J. G., Strachan, F., Roy, W. J., Matthew, C., McDonald, P., Barrows, F. T., & Sprague, M. (2016). Evaluation of barley protein concentrate and fish protein concentrate, made from trimmings, as sustainable ingredients in Atlantic salmon (*salmo salar* l.) feeds. Journal of *Aquaculture Nutrition and Research*, *22*(2), 326–334. https://doi.org/10.1111/anu.12250

Calder, P. C. (2013). Omega-3 polyunsaturated fatty acids and inflammatory processes: Nutrition or pharmacology? *British Journal of Clinical Pharmacology*, *75*(3), 645–662. https://doi.org/10.1111/j.1365-2125.2012.04374.x

Calder, P. C. (2014). Very long chain omega-3 (N-3) fatty acids and human health. *European Journal of Lipid Science and Technology*, *116*(10), 1280–1300. https://doi.org/10.1002/ejlt.201400025

Caruso, G. (2015). Fishery wastes and by-products: a resource to be valorised. *Journal of Fisheries Science,* 9(4): 080-083

Cedeño-Pinos, C., Martínez-Tomé, M., Mercatante, D., Rodríguez-Estrada, M. T., & Bañón, S. (2022). Assessment of a diterpene-rich rosemary (Rosmarinus officinalis L.) extract as a natural antioxidant for salmon pâté formulated with linseed. *Antioxidants*, *11*(6), 1057. https://doi.org/10.3390/antiox11061057

ChicP. (2015). *Our Mission.* ChicP. https://www.chicp.co.uk/pages/ethos

Cho, R. (2016). Making fish farming more sustainable. *State of the planet*. https://news.climate.columbia.edu/2016/04/13/making-fish-farming-more-sustainable/

Choe, J.-H., & Kim, H.-Y. (2016). Effects of swelled pig skin with various natural vinegars on quality characteristics of traditional Korean blood sausages (Sundae). *Journal of Food Science and Biotechnology*, *25*(6), 1605–1611. https://doi.org/10.1007/s10068-016-0247-8

Cladis, D. P., Kleiner, A. C., Freiser, H. H., & Santerre, C. R. (2014). Fatty acid profiles of commercially available finfish fillets in the United States. *Journal of Lipids*, *49*(10), 1005–1018. https://doi.org/10.1007/s11745-014-3932-5

Climate Action. (2022). Causes and effects of climate change. *United Nations*. https://www.un.org/en/climatechange/science/causes-effects-climate-change

Cooper, K. A., Quested, T. E., Lanctuit, H., Zimmermann, D., Espinoza-Orias, N., & Roulin, A. (2018). Nutrition in the bin: A nutritional and environmental assessment of food wasted in the UK. *Frontiers in Nutrition*, *5*, 19. https://doi.org/10.3389/fnut.2018.00019

Crowley, R. (2024). What do fats do in the body? *National Institute of General Medical Sciences. https://biobeat.nigms.nih.gov/2024/01/what-do-fats-do-in-the-body/*

Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W., & Lorenzo, J. M. (2019). A comprehensive review on lipid oxidation in meat and meat products. *Antioxidants*, 8(10), 429. https://doi.org/10.3390/antiox8100429

Donoso, A., González-Durán, J., Muñoz, A. A., González, P. A., & Agurto-Muñoz, C. (2021). Therapeutic uses of natural astaxanthin: An evidence-based review focused on human clinical trials. *Pharmacological Research*, *166*, 105479. https://doi.org/10.1016/j.phrs.2021.105479

Encalada, A.M.I., M.F. Basanta, E.N. Fissore, M.D. De'Nobili, and A.M. Rojas. (2016). Carrot fiber (CF) composite films for antioxidant preservation: 22 particle size effect. *Carbohydrate Polymers*. 136:1041-1051. doi: 10.1016/j.carbpol.2015.09.109.

Environmental Protection Agency. (2015). Wasted food scale [overviews and factsheets]. *Environmental Protection Agency.* https://www.epa.gov/sustainable-management-food/wasted-food-scale

Environmental Protection Agency. (2017). Food: Material-specific data [overviews and factsheets]. *Environmental Protection Agency.* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/food-material-specific-data

Fomena Temgoua, N. S., Sun, Z., Okoye, C. O., & Pan, H. (2022). Fatty acid profile, physicochemical composition, and sensory properties of Atlantic salmon fish (*Salmo*

salar) during different culinary treatments. *Journal of Food Quality*, *2022*, 1–16. https://doi.org/10.1155/2022/7425142

Fong, A. T., Ahlstedt, S., Golding, M. A., & Protudjer, J. L. P. (2022). The economic burden of food allergy: What we know and what we need to learn. *Current Treatment Options in Allergy*, *9*(3), 169–186. https://doi.org/10.1007/s40521-022-00306-5

Frabetti, A. C. C., de Moraes, J. O., Jury, V., Boillereaux, L., & Laurindo, J. B. (2021). Adhesion of food on surfaces: Theory, measurements, and main trends to reduce it prior to industrial drying. *Food Engineering Reviews*, *13*(4), 884–901. https://doi.org/10.1007/s12393-021-09286-9

Galasso, C., Orefice, I., Pellone, P., Cirino, P., Miele, R., Ianora, A., Brunet, C., & Sansone, C. (2018). On the neuroprotective role of astaxanthin: New perspectives? *Marine Drugs*, *16*(8), 247. https://doi.org/10.3390/md16080247

Gardner, H. W. (1989). Oxygen radical chemistry of polyunsaturated fatty acids. *Free Radical Biology and Medicine*, 7(1), 65–86. https://doi.org/10.1016/0891-5849(89)90102-0

Gibson, M., & Newsham, P. (2018). Chapter 16—Lipids, oils, fats, and extracts. In M. Gibson & P. Newsham (Eds.), *Food Science and the Culinary Arts* (pp. 323–340). Academic Press. https://doi.org/10.1016/B978-0-12-811816-0.00016-6

Goldburg, R., & Naylor, R. (2005). Future seascapes, fishing, and fish farming. *Frontiers in Ecology and the Environment*, *3*(1), 21–28. https://doi.org/10.1890/1540-9295(2005)003[0021:FSFAFF]2.0.CO;2

GoodFish Seafood. (2022). Sustainability at sea. *GoodFish Seafood*. https://goodfish.co/en-us/pages/sustainability

Hermann, J. (2021). Carbohydrates in the diet. *Oklahoma State University*. https://extension.okstate.edu/fact-sheets/carbohydrates-in-the-diet.html

Higuera-Ciapara, I., Félix-Valenzuela, L., Goycoolea, F.M. (2006). Astaxanthin: a review of its chemistry and applications. *Critical Reviews in Food Science and Nutrition*, 46(2), 185-196.

Howgate, P. (2004). Tainting of farmed fish by geosmin and 2-methylisoborneol: a review of sensory aspects and uptake/depuration. *Aquaculture, 234 (1-4)*, 155−181.

Iacumin, L., Manzano, M., Stella, S., & Comi, G. (2017). Fate of the microbial population and the physico-chemical parameters of "Sanganel" a typical blood sausages of the Friuli, a north-east region of Italy. *Food Microbiology*, *63*, 84–91. https://doi.org/10.1016/j.fm.2016.10.034

Iwamoto T., Hosoda K., Hirano R., Kurata H., Matsumoto A., Miki W., Kamiyama M., Itakura H., Yamamoto S., Kondo K. (2000). Inhibition of low-density lipoprotein oxidation by astaxanthin. *Journal of Atherosclerosis and Thrombosis.* 7 (4), 216–222.

The Nutrition Source. (2015). Sustainability. *Harvard School of Public Health*. https://nutritionsource.hsph.harvard.edu/sustainability/

Jakobsen, J., Smith, C., Bysted, A., & Cashman, K. D. (2019). Vitamin D in wild and farmed atlantic salmon (Salmo salar)—What do we know? *Nutrients*, *11*(5), 982. https://doi.org/10.3390/nu11050982

Jensen, I. J., Mæhre, H. K., Tømmerås, S., Eilertsen, K. E., Olsen, R. L., & Elvevoll, E. O. (2012). Farmed Atlantic salmon (*salmo salar l.*) Is a good source of long chain omega-3 fatty acids. *Nutrition Bulletin*, *37*(1), 25–29. https://doi.org/10.1111/j.1467-3010.2011.01941.x

Jewish Dietary Laws (Kashrut): Overview of laws & regulations (2001). *Jewish Virtual Library.* https://www.jewishvirtuallibrary.org/overview-of-jewish-dietary-laws-and-regulations

Johnson, J. A. (2022). Physical and chemical effects of carrot fiber as a binder in cooked sausage. (Order No. 29064767). *ProQuest Dissertations & Theses Global. (2674758566).*

Jongberg, S., Tørngren, M. A., Gunvig, A., Skibsted, L. H., & Lund, M. N. (2013). Effect of green tea or rosemary extract on protein oxidation in Bologna type sausages prepared from oxidatively stressed pork. *Meat Science*, 93(3), 538–546. https://doi.org/10.1016/j.meatsci.2012.11.005

Kaur, M., Singh, A. K., & Singh, A. (2023). Bioconversion of food industry waste to value added products: Current technological trends and prospects. *Food Bioscience*, *55*, 102935. https://doi.org/10.1016/j.fbio.2023.102935

Kennedy, D. O. (2016). B vitamins and the brain: Mechanisms, dose and efficacy—a review. *Nutrients*, *8*(2), 68. https://doi.org/10.3390/nu8020068

Kishimoto, Y., Yoshida, H., & Kondo, K. (2016). Potential anti-atherosclerotic properties of astaxanthin. *Marine Drugs*, *14*(2), 35. https://doi.org/10.3390/md14020035

Knipe, C.L. (1987). Meat emulsions. *Ohio State University.* https://meatsci.osu.edu/node/130

Kong, J., Perkins, L. B., Dougherty, M. P., & Camire, M. E. (2011). Control of lipid oxidation in extruded salmon jerky snacks. *Journal of Food Science*, *76*(1). https://doi.org/10.1111/j.1750-3841.2010.01896.x

Kris-Etherton, P. M., Harris, W. S., & Appel, L. J. (2002). Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. *Circulation*, *106*(21), 2747–2757. https://doi.org/10.1161/01.CIR.0000038493.65177.94

Lorenc, F., Jarošová, M., Bedrníček, J., Smetana, P., & Bárta, J. (2022). Structural characterization and functional properties of flaxseed hydrocolloids and their application. *Foods*, *11*(15), 2304. https://doi.org/10.3390/foods11152304

Loussouarn, M., Krieger-Liszkay, A., Svilar, L., Bily, A., Birtić, S., & Havaux, M. (2017). Carnosic acid and carnosol, two major antioxidants of rosemary, act through different mechanisms. *Plant Physiology*, *175*(3), 1381–1394. https://doi.org/10.1104/pp.17.01183

Mason, W. R. (2009). Chapter 20—Starch use in foods: Starch (edition 3). *Journal of Chemistry and Technologies,* (pp. 745–795). https://doi.org/10.1016/B978-0-12-746275-2.00020-3

Molversmyr, E., Devle, H. M., Naess-Andresen, C. F., & Ekeberg, D. (2022). Identification and quantification of lipids in wild and farmed Atlantic salmon (Salmo salar), and salmon feed by GC-MS. *Food Science & Nutrition*, *10*(9), 3117–3127. https://doi.org/10.1002/fsn3.2911

Muchekeza, J. T., Jombo, T. Z., Magogo, C., Mugari, A., Manjeru, P., & Manhokwe, S. (2021). Proximate, physico-chemical, functional and sensory properties OF quinoa and amaranth flour AS potential binders in beef sausages. *Food Chemistry*, *365*, 130619. https://doi.org/10.1016/j.foodchem.2021.130619

MyPlate. (2021). Food Group Gallery. *United States Department of Agriculture*. https://www.myplate.gov/eat-healthy/food-group-gallery

Nacak, B., Kavuşan, H. S., & Serdaroğlu, M. (2021). Effect of α-tocopherol, rosemary extract and their combination on lipid and protein oxidation in beef sausages. *IOP Conference Series: Earth and Environmental Science*, *854*(1), 012062. https://doi.org/10.1088/1755-1315/854/1/012062

Nakagawa, S., Hillebrand, G. G., & Nunez, G. (2020). Rosmarinus officinalis l. (Rosemary) Extracts containing carnosic acid and carnosol are potent quorum sensing inhibitors of staphylococcus aureus virulence. *Antibiotics*, *9*(4), 149. https://doi.org/10.3390/antibiotics9040149

National Center for Health Statistics. (2023). More than a quarter of U.S. Adults and children have at least one allergy. *Centers for Disease Control and Prevention.* https://www.cdc.gov/nchs/pressroom/nchs_press_releases/2022/20220126.htm

National Institute of Health. (2022a). Office of dietary supplements—Potassium. *U.S. Department of Health and Human Services.* https://ods.od.nih.gov/factsheets/Potassium-HealthProfessional/

National Institute of Health. (2022b). Office of dietary supplements—Omega-3 fatty acids. *U.S. Department of Health and Human Services.* https://ods.od.nih.gov/factsheets/Omega3FattyAcids-Consumer/

National Institute of Health. (2023). Office of dietary supplements—Omega-3 Fatty Acids. *U.S. Department of Health and Human Services.* https://ods.od.nih.gov/factsheets/Omega3FattyAcids-HealthProfessional/

National Institute of Health. (2024a). Office of dietary supplements—Selenium. *U.S. Department of Health and Human Services.* https://ods.od.nih.gov/factsheets/Selenium-Consumer/

National Institute of Health. (2024b). Office of dietary supplements—Vitamin D. *U.S Department of Health and Human Services.* https://ods.od.nih.gov/factsheets/VitaminD-HealthProfessional/

National Oceanic and Atmospheric Administration. (2020). Aquaculture supports a sustainable Earth. *National Oceanic and Atmospheric Administration.* https://www.fisheries.noaa.gov/feature-story/aquaculture-supports-sustainable-earth

Offer, G., & Trinick, J. (1983). On the mechanism of water holding in meat: The swelling and shrinking of myofibrils. *Meat Science*, 8(4), 245–281. https://doi.org/10.1016/0309-1740(83)90013-X

O'Malley, K., Willits-Smith, A., & Rose, D. (2023). Popular diets as selected by adults in the United States show wide variation in carbon footprints and diet quality. *The American Journal of Clinical Nutrition*, *117*(4), 701–708. https://doi.org/10.1016/j.ajcnut.2023.01.009

Pereira, C. P. M., Souza, A. C. R., Vasconcelos, A. R., Prado, P. S., & Name, J. J. (2021). Antioxidant and anti-inflammatory mechanisms of action of astaxanthin in cardiovascular diseases (Review). *International journal of molecular medicine*, *47*(1), 37–48. https://doi.org/10.3892/ijmm.2020.4783

Pereira, J.A., Ferreira-Dias, S. and Matos, T.J.S. (2008). Application of unsteady-state heat transfer equations to Portuguese traditional meat products from *Monchique* region. *Proceedings of 54th International Congress of Meat Science and Technology*.

Richeimer, S.L., Bernart, M.W., King, G.A., Kent, M.C. and Bailey, D.T. (1996). Antioxidant activity of lipid-soluble phenolic diterpenes from rosemary. *Journal of American Oil Chemist's Society*, 73, 507-513.

Ritota, M., & Manzi, P. (2020). Natural preservatives from plant in cheese making. *Animals : An Open Access Journal from MDPI*, *10*(4), 749. https://doi.org/10.3390/ani10040749

Rosenfeld, D. L., & Tomiyama, A. J. (2021). How proximal are pescatarians to vegetarians? An investigation of dietary identity, motivation, and attitudes toward animals. *Journal of Health Psychology*, *26*(5), 713–727. https://doi.org/10.1177/1359105319842933

Said, N. S., Olawuyi, I. F., & Lee, W. Y. (2023). Pectin hydrogels: Gel-forming behaviors, mechanisms, and food applications. *Gels*, *9*(9), 732. https://doi.org/10.3390/gels9090732

Sansweet, S., Jindal, R., & Gupta, R. (2024). Food allergy issues among consumers: a comprehensive review. *Frontiers in Nutrition*, *11*, 1380056. https://doi.org/10.3389/fnut.2024.1380056

Segreé, A., & Falasconi, L. (2011). Il libro nero dello spreco in Italia: Il cibo. *Edizioni Ambiente*.

Sebranek, J. G., Sewalt, V. J. H., Robbins, K. L., & Houser, T. A. (2005). Comparison of a natural rosemary extract and BHA/BHT for relative antioxidant effectiveness in pork sausage. *Meat Science*, *69*(2), 289–296. https://doi.org/10.1016/j.meatsci.2004.07.010

Sharma, H., Sharma, B. D., Mendiratta, S. K., Talukder, S., & Ramasamy, G. (2014). Efficacy of flaxseed flour as bind enhancing agent on the quality of extended restructured mutton chops. *Asian-Australasian Journal of Animal Sciences*, *27*(2), 247–255. https://doi.org/10.5713/ajas.2013.13319

Sicherer, S. H., & Sampson, H. A. (2006). 9 Food allergy. *Journal of Allergy and Clinical Immunology*, *117*(2, Supplement 2), S470–S475. https://doi.org/10.1016/j.jaci.2005.05.048

Silva, F. A. P., Amaral, D. S., Guerra, I. C. D., Arcanjo, N. M. O., Bezerra, T. K. A., Ferreira, V. C. S., Araújo, I. B. S., Dalmás, P. S., & Madruga, M. S. (2014). Shelf life of cooked goat blood sausage prepared with the addition of heart and kidney. *Meat Science*, *97*(4), 529–533. https://doi.org/10.1016/j.meatsci.2014.03.018

Slima, SB., Ktari, N., Triki, M., Trabelsi, I., Moussa, H., Makni, S., Abdeslam, A., Herrero, A. M., Jiménez-Colmenero, F., Ruiz-Capillas, C., & Ben Salah, R. (2019). Effects of two fibers used separately and in combination on physico-chemical, textural, nutritional and sensory properties of beef fresh sausage. *British Food Journal*, *121*(6), 1428–1440. https://doi.org/10.1108/BFJ-06-2018-0388

The sources of marine ingredients: Whole fish & by-products. (2023). *The Marine Ingredients Organization*. https://www.iffo.com/sources-marine-ingredients-whole-fish-products#:~:text=Fish%20destined%20to%20direct%20human,%2C%20mince%2C%20blood%2C%20etc.

Stonehouse, W., Pauga, M. R., Kruger, R., Thomson, C. D., Wong, M., & Kruger, M. C. (2011). Consumption of salmon v. salmon oil capsules: effects on n-3 PUFA and selenium status. *The British Journal of Nutrition, 106*(8), 1231-9. https://doi.org/10.1017/S000711451100153X

Sullivan, G., Reiling, B., Conner, N., Ruth, T., & Stripling, C. (2021). Why do most foods contain salt? *The University of Tennessee Knoxville*. https://alec.tennessee.edu/wp-content/uploads/sites/40/2022/06/Meats-Chemistry-Lecture-Notes.pdf

Szabó, M. Á., Varga, G. Z., Hohmann, J., Schelz, Z., Szegedi, E., Amaral, L., & Molnár, J. (2010). Inhibition of quorum-sensing signals by essential oils. *Phytotherapy Research*, *24*(5), 782–786. https://doi.org/10.1002/ptr.3010

Taranger, G. L., Karlsen, Ø., Bannister, R. J., Glover, K. A., Husa, V., Karlsbakk, E., Kvamme, B. O., Boxaspen, K. K., Bjørn, P. A., Finstad, B., Madhun, A. S., Morton, H. C., & Svåsand, T. (2015). Risk assessment of the environmental impact of Norwegian Atlantic

salmon farming. *ICES Journal of Marine Science*, *72*(3), 997–1021. https://doi.org/10.1093/icesjms/fsu132

Tironi, V., Tomás, M., & Añón, M. (2009). Lipid and protein changes in chilled sea salmon (*pseudopercis semifasciata*): Effect of previous rosemary extract a(*rossmarinus officinalis* l.) application. *International Journal of Food Science & Technology*, *44*(6), 1254–1262. https://doi.org/10.1111/j.1365-2621.2009.01955.x

Trevisan, M., Browne, R., Ram, M., Muti, P., Freudenheim, J., Carosella, A.M., Armstrong, D. (2001). Correlates of markers of oxidative status in the general population. *American Journal of Epidemiology*, 154(4), 348–356. https://doi.org/10.1093/aje/154.4.348

Ueshima, H., Stamler, J., Elliott, P., Chan, Q., Brown, I. J., Carnethon, M. R., Daviglus, M. L., He, K., Moag-Stahlberg, A., Rodriguez, B. L., Steffen, L. M., Horn, L. V., Yarnell, J. & Zhou, B. (2007). Food omega-3 fatty acid intake of individuals (total, linolenic acid, long-chain) and their blood pressure: INTERMAP study. *Hypertension, 50* (2), 313-319. doi: 10.1161/HYPERTENSIONAHA.107.090720.

Ulleberg, D., Sletten, I. B., Jakobsen, A. N., Svenning, J. B., & Lerfall, J. (2023). Co-products from the Atlantic salmon filleting industry – Their properties, stability and potential as human food ingredients. *LWT- Food Science and Technology*, *180*, 114673. https://doi.org/10.1016/j.lwt.2023.114673

U.S. Department of Health and Human Services and U.S. Department of Agriculture. (2015). 2015–2020 dietary guidelines for Americans. *Dietary Guidelines for Americans,* 8th Edition.

Walmart. (2024). Great Value corn starch, 16 oz. *Walmart.* Retrieved Dec 18 2024, from https://www.walmart.com/ip/Great-Value-Corn-Starch-16-

oz/54802256?wmlspartner=wlpa&selectedSellerId=0&wl13=1355&gclsrc=aw.ds&adid=22222222277548022256_161193766053_21214199653&wl0=&wl1=g&wl2=c&wl3=697173827980&wl4=pla2348450966064&wl5=9010167&wl6=&wl7=&wl8=&wl9=pla&wl10=8175035&wl11=local&wl12=54802256&veh=sem_LIA&gad_source=1&gclid=CjwKCAiAgoq7BhBxEiwAVcW0LMvfASsLB6W4AI4sZYiw9kPk-7LCwvQwg-91KRGWdX_HC9bZ6hq8gxoCsA8QAvD_BwE

Walmart (2025). Bob's Red Mill flaxseed meal, 16 oz shelf-stable bag. *Walmart.* Retrieved August 27 2025, from https://www.walmart.com/ip/Bob-s-Red-Mill-Flaxseed-Meal-16-oz-Shelf-Stable-Bag/842557136?wmlspartner=wlpa&selectedSellerId=101188175&wmlspartner=wlpa&cn=FY25-ENTP-PMAX_cnv_dps_dsn_dis_ad_entp_e_n&gclsrc=aw.ds&adid=22222222297842557136_101188175_0000000000_21407473164&wl0=&wl1=x&wl2=c&wl3=&wl4=&wl5=9010167&wl6=&wl7=&wl8=&wl9=pla&wl10=678420623&wl11=online&wl12=842557136_101188175&veh=sem&gad_source=1&gad_campaignid=21690411341&gbraid=0AAAAADmfBIqGjLd7UXBVXPAmYcMQpIgg5&gclid=CjwKCAjw2brFBhBOEiwAVJX5GBi9efupXmWE1v9jtvx4PQLP1TA531_mCuMfWcZn-AA8_qi9bSTnQBoCa8kQAvD_BwE .

Walton’s. (2024). Carrot fiber binder. *Walton’s*. Retrieved December 18 2024, from https://waltons.com/carrot-fiber-binder/?srsltid=AfmBOopESa3zGWYAEPceik5499X5zU5EG2Y4qUVonyCWXnW2tVbG3ekG

World Bank Group. (2023). Food security update | World bank solutions to food insecurity *World Bank Group*. https://www.worldbank.org/en/topic/agriculture/brief/food-security-update

Wu, G. (2016). Dietary protein intake and human health. *Food & function*, *7*(3), 1251–1265. https://doi.org/10.1039/c5fo01530h

Wu, T. H., Nigg, J. D., Stine, J. J., & Bechtel, P. J. (2011). Nutritional and chemical composition of by-product fractions produced from wet reduction of individual red salmon (*oncorhynchus nerka*) heads and viscera. *Journal of Aquatic Food Product Technology*, *20*(2), 183–195. https://doi.org/10.1080/10498850.2011.557524

Zhang, Z., Fulgoni, V. L., Kris-Etherton, P. M., & Mitmesser, S. H. (2018). Dietary intakes of epa and dha omega-3 fatty acids among us childbearing-age and pregnant women: An analysis of nhanes 2001–2014. *Nutrients*, *10*(4), 416. https://doi.org/10.3390/nu10040416

CHAPTER 2: EFFECT OF EMULSIFICATION AND VARIOUS BINDING AGENTS ON THE QUALITY OF BOUDIN MADE FROM COLD-SMOKED SALMON TRIMMINGS

2.1. Abstract

Smoked salmon processors produce significant amounts of trimmings as byproducts of smoked salmon production that typically go to landfills. These trimmings are high in protein, unsaturated fats, and salt. This makes them nutritionally rich, but difficult to incorporate into food products without separating the components. The trimmings may be fully utilized to replace pork in a boudin sausage that also traditionally contains rice, vegetables, and seasonings. The objective of this study was to evaluate the functionality of various binding agents without major allergens in boudin made from cold-smoked salmon trimmings. The following binding agents were incorporated at 1.03% to test against a control (no binder) for ingredient functionality: carrot fiber (CF), cornstarch (CS), and flaxseed meal (FM). An emulsion-based (EM) treatment was also evaluated by altering processing parameters. Smoked salmon boudin was tested for cook loss, proximate composition, shear force with Warner-Bratzler blade, color, in addition to water holding capacity (WHC) of cooked sausages, and oil binding capacity (OBC) and WHC of dry binding agents. No significant differences were observed in regards to sausage WHC, texture, or proximate composition with the exception of protein content being lower in CT, CS, and EM when compared with CF and FM. Cook loss was reduced significantly from the control (8.91%±0.50%) in the EM treatment (4.28%±0.80%). The L^* value of EM was found to be significantly higher than all other samples and was likely attributable to better emulsion formation prior to cooking the sausage. Due to EM having the lowest cook loss, and the lack of practically significant differences in any other tests for smoked salmon boudin, an emulsion-based sausage appears most suitable for further product evaluation.

2.2. Introduction

A global interest in food sustainability has inspired the use of byproducts and minimization of food waste. Gutting, scaling, and filleting are common practices by fish production companies, and often result in waste that will most likely go unused and cost the company money. During the filleting process, it is estimated that 30 - 40% of the product is discarded and only 10% approximately of the entire fish contributes to the minced portion after the filleting process (Bazarnova et al., 2020; Coppola et al., 2021). Creating a food product that utilizes byproducts, and which consumers are willing to eat is beneficial to both company and consumers when an increase in financial gain and decrease in greenhouse gas emissions takes place.

The general public and environmentalists alike are concerned about the long term implications of food waste on the environment, yet there still remain barriers to convince consumers to actually purchase upcycled products when making purchasing decisions (Neff et al., 2015). When upcycled foods are perceived to be healthy, consumers are more likely to purchase value-added products (Moshtaghian, 2021). Salmon trimmings are rich in unsaturated fats and protein, making them an excellent resource for upcycled product creation (Fomena Temgoua et al., 2022). Salmon is additionally a good source of omega-3 fatty acids EPA and DHA, which are found in fish. The American Heart Association recommends that 2 servings of fatty fish be consumed per a week by adults to maintain ideal levels of EPA and DHA (American Heart Association, 2024).

Seafood byproducts are most often used for aquaculture feed production, however fish are high in vitamins and unsaturated fats, providing an excellent nutrient profile for human food products as well (Agricultural Research Service, 2010; Fomena Temgoua et al., 2022). The Food and Agriculture Organization estimates that in 2023, around 733 million people globally suffered

from hunger (Food and Agriculture Organization, 2024). Food insecurity and malnourishment rates continue to increase, and a plethora of health issues accompany this rise, such as anemia, wasting, and low birthweight (Food and Agriculture Organization, 2024). Alarmingly, as malnourishment persists, so do obesity rates (Food and Agriculture Organization, 2024). High intake of low nutrient food products that are high in sugar and fat is leading many individuals to experience an unhealthy weight, and a lack of adequate nutrition (Bradley et al., 2023). Bariatric studies have found at least one vitamin or mineral deficiency in 85.5% of patients prior to procedure (Argyrakopoulou et al., 2022). Vitamin D and several B vitamins in particular were observed to be in inadequate levels (Bradley et al., 2023). Salmon is a rich source of both of these nutrients (Agricultural Research Service, 2024). Smoked salmon is rich in nutrients, yet food processors face the issue of handling food waste (National Center for Health Statistics, 2023; Kaur et al., 2023). Finding ways to incorporate salmon byproducts into food products would be beneficial in reducing waste and providing a nutrient dense product.

The cold-smoked smoked salmon trimmings used for this study were generously provided by Acme Smoked Fish Corporation, Wilmington, NC. Their production facilities in several states produce both cold-smoked and hot-smoked salmon, however the majority is cold-smoked. The cold-smoking process typically takes place over 12-72 hours, and at temperatures below 90 ºF (Durham, 2001). A range between 70 ºF - 90 ºF is considered ideal (Durham, 2001). Longer smoking periods may occur, depending on the facility (Durham, 2001). In contrast, hot-smoking is performed at temperatures ranging from 160 ºF-190 ºF (Durham, 2001). The smoking process is preceded by a curing process, resulting in a high product salt content as a barrier to bacterial growth (Durham, 2001). While smoked fish has a longer shelf life than cooked fish that are not cured, a characteristic that must be acknowledged regarding any application of cold-

smoked salmon is that the sodium levels are most likely relatively high compared to the daily values set by health authorities (Agricultural Research Service, 2023).

Boudin was selected for product development with the intention of finding a use for cold-smoked salmon trimmings. Boudin-style sausage has been historically used in Cajun regions with pork as a way to use the whole animal and avoid waste. Typical ingredients for boudin include rice, vegetables, and seasonings. When considering the high sodium and nutrient rich oil content of the trimmings, boudin sausage is an excellent potential solution to make what would otherwise be waste into a nutritious meal. Boudin is traditionally expected to be somewhat oily, however the presence of a binding agent still may be necessary to bind some of the oil and moisture. Cooking loss is expected to an extent in any meat product, as moisture evaporates and muscle fibres release oil when exposed to high temperatures. The minimization of any cooking loss is desirable in that it creates less waste for the company and consumers to handle, and utilizes a greater percentage of the raw product's ingredient makeup. The crude fat content for smoked Atlantic salmon trimmings on a wet basis was shown to be 40.63%±4.89%, while the salt content was 5.61%±0.43% (Neagle et al., 2025). As previously mentioned, the high salt content may initially seem undesirable, however it ise essential to extending product shelf life by preventing microbial growth and the onset of rancidity.

Eggs and breadcrumbs are often used as binding agents in meat products, however, as food allergies increasingly cause dietary concerns within American populations, allergen-friendly foods become necessary (National Center for Health Statistics, 2023; Sicherer & Sampson, 2006). As a result, alternative allergen-friendly binding agents may be more prudent to employ in the development of a smoked salmon boudin sausage, especially when considering the major allergen status of fish. Carrot fiber, cornstarch, and flaxseed meal have all been

demonstrated to have water and oil binding capabilities, yet research profiling within meat products and seafood is limited (Slima et al., 2019, Muchekeza et al., 2021, Sharma et al., 2014). They are also free of ingredients categorized as one of the nine major allergens (Sicherer & Sampson, 2006). The objective of this study was to evaluate the functionality of various binding agents without major allergens in boudin made from cold-smoked salmon trimmings. An emulsion-based method to make the boudin using less processing steps and no binding agent was also compared.

2.3. Materials and Methods

2.3.1. Materials

Smoked salmon trimmings were kindly provided by Acme Smoked Fish Corporation (Wilmington, NC). Black pepper, chili powder, canola oil, cayenne pepper, cornstarch, jasmine rice, paprika, parsley, and soybean oil were purchased from Walmart Great Value (Bentonville, AR). Green bell peppers and yellow onions were purchased at Walmart (Morehead City, NC). Garlic was obtained as the Spice World brand (Orlando, FL). Pickling & canning salt was obtained as the Morton Salt brand (Chicago, IL). Whole ground flaxseed meal was obtained as the Bob's Red Mill brand (Milwaukie, OR). Carrot fiber was purchased from Walton's (Wichita, KS). Pork casings were purchased from Oversea Casing Company (San Antonio, TX), and Quality Casing Co., Inc. (Hebron, KY).

2.3.2. Methods

2.3.2.1. Preparation of smoked salmon boudin

Three batches of boudin were prepared using the ingredients listed in Table 1. Each batch consisted of 3–4 100g sausages per treatment. Smoked salmon trimmings were ground using a 5/16 inch die with the Fleetwood Slicing Machine model H-12-H (Newark, NJ). Green peppers,

onions, and garlic were ground up using a Chaffano Meat Grinder model AZ-MG091 (China) in bulk, and frozen until needed. A 3/16 inch die was used to process the garlic, and a 1/4 inch die for the onions and green bell peppers. After thawing, bell pepper, onion, and garlic were cooked for 10 minutes via stove top on medium heat with canola oil, and allowed to cool to 0°C via refrigeration. For each treatment, the spices were mixed with salmon trimmings for 10 minutes using a Cook Lee Stand Mixer model SM-1551 (China). Next, vegetables, tap water, and the appropriate binding agent were added and mixed for another 5 minutes. The binding agents included carrot fiber, cornstarch, flaxseed meal, or no binder for the control batch. Jasmine rice cooked using Aroma Rice Cooker model ARC-150SB (China) was cooked, and then refrigerated until reaching 0°C before being added and mixed with other ingredients for another 5 minutes. The mixture was then stuffed into pork casings via meat stuffer (Avantico, Meridian, ID) until the total sausage weighed approximately 100g. The sausages were then cooked for 12 minutes with a Cuisinart CookFresh Digital Glass Steamer, model STM-1000 (Glendale, AZ).

An emulsion-based sausage was also prepared using the same ingredients and no binding agent. Smoked salmon trimmings were added first into a Mado Supra 35 industrial bowl cutter machine (MADO Maschinenfabrik Dornhan, Germany) operating at 3750 blade rpm and 6.5°C, and mixed as seasoning and salt were added, followed by water and seasonings. The mixture was homogenized for 2 minutes at high speed. Vegetables and rice were then added and mixed for an additional minute. Handtmann VF 50 vacuum filler (Biberach an der Riss, Germany) was used to stuff sausages into 35/38 mm natural hog casings to approximately 100 g per sausage (Quality Casing Co., Inc., Hebron, KY). Sausages were then steamed using the same procedure as previously described.

2.3.2.2. Smoked salmon boudin and binding agent analyses

2.3.2.2.1. Cook loss of smoked salmon boudin

Sausages were steamed for 12 minutes to ensure they reached an internal temperature of 71°C. The cook loss was completed using the method of Pietrasik & Soladoye (2021). Sausages were weighed prior to cooking and re-weighed afterwards. Cook loss was measured as a percentage of the initial raw sausage weight lost in the cooking process (Equation 1). For each treatment, four sausages weighing approximately 100 g each were used per replication. A total of three replications were completed.

$$Cook\ loss\ (\%) = \left(\frac{Weight\ before\ cooking - Weight\ after\ cooking}{Weight\ before\ cooking}\right) \text{ x } 100 \quad (1)$$

2.3.2.2.2. Texture of smoked salmon boudin

A shearing test was performed using the flat side of a TA-7 Warner-Bratzler blade (Texture Technologies, Hamilton, MA) and a TA.XTplusC Texture Analyzer (Stable Micro System, UK). Each treatment had three replications, and five 30 mm x 30 mm samples per replication. Sausages were cooked the same day and cooled to room temperature before analysis. The following test settings were used as recommended by the manufacturer: pre-test speed: 1.00 mm/s; test speed: 2.00 mm/s; post-test speed: 10.00 mm/s; target mode: distance; distance: 30.000 mm; trigger type: auto (force) trigger type; trigger force: 5.0 g; 5 kg load cell. Warner Bratzler Shear Force (WBSF) measurements were analyzed using Exponent Connect software.

2.3.2.2.3. Color of smoked salmon boudin

Color was measured using a Konica Minolta CM-5 Spectrophotometer (Tokyo, Japan) with a 10° observer angle, 8 mm aperture, and illuminant D65. Color measurements were completed using L^*, a^*, b^* measurements once sausages had cooled to room temperature. Per each of the replications, six samples were used for each measurement, for a total of 18 L^*, a^*, and b^* readings for each treatment. Samples were placed on Form P300-4NT Clear Polyester

Panel purchased from Leneta (Mahwah, New Jersey) to prevent samples from causing destruction to the colorimeter. SCE mode was applied to cancel any color-altering effects from the clear panel.

2.3.2.2.4. Water holding capacity of smoked salmon boudin

The water holding capacity (WHC)was modeled using the method of Chattopadhyay et al. (2019) with modifications . Sausages were cooked the day of testing, and 10 g for each treatment were measured into their respective 50 mL tubes. Centrifugation was conducted at 4°C for 30 minutes at 10,000 × g. Afterwards, the tubes were left upside-down for three hours and reweighed. Three repetitions were completed for each treatment. The WHC was calculated as a percentage using the formula below, in which W_2 is indicated by the weight of the sausage after centrifugation, and W_1 is the weight of the sausage before centrifugation (Equation 2).

$$WHC\ (\%) = \frac{Sausage\ weight\ after\ centrifuge}{Sausage\ weight\ before\ centrifuge}\ x\ 100 \quad (2)$$

2.3.2.2.5. Oil binding capacity and water holding capacity of binding agents

The OBC and WHC of the binding agents was determined with a modified method of Li et al. (2020). With three repetitions per treatment of flaxseed meal (FM), cornstarch (CS), and carrot fiber (CF), 80 mg of binding agent (M_0) was added with 800 mg of soybean oil or deionized water to an empty 1.5 mL Corning Axygen tube (M_1) (Corning, NY). Tubes were vortexed until homogenous and then heated in a Corning LSE digital dry bath (Corning, NY) set at 73°C for 32 minutes. The time was determined beforehand so that all the treatments would reach 70°C, and an additional 2 minutes was added to the time it took the last treatment to reach 70°C. Then tubes were centrifuged in an Ohaus Frontier model FC5916R (Parsippany NJ) at 10,000 × g and 22°C for 20 minutes. After centrifuging, tubes were left upside down to drain for

three hours before the weight of the tube with wet powder and were recorded (M_2). The binding capacities were calculated according to Equation 3.

$$OBC/WHC\ (g/g) = \frac{M_2 - M_1 - M_0}{M_0} \quad (3)$$

2.3.2.2.6. Proximate composition of smoked salmon boudin

Moisture and ash analysis were conducted in a similar manner to Chen et al. (2020). In a VWR 1330FM mechanical oven (Radnor, PA), 5 g of each sample were dried at 105°C prior to heating for 6 hours at 550°C in a benchtop furnace (Thermolyne, Thermo Scientific, Asheville, NC). Three replicates were performed per treatment. The Bligh and Dyer (1959) method was used to obtain lipid content. Protein content was determined using the method of King-Brink and Sebranek (1993) in triplicate for each treatment. The Dumas combustion method was followed using a Rapid N Exceed analyzer (Elementar Americas Inc., Ronkonkoma, NY, USA) (Elementar, n.d). After removing carbon dioxide and water from N2 via reduction and purification carrier columns, the total nitrogen content was quantified and protein was calculated using a nitrogen to protein conversion factor of 6.25 (King-Brink and Sebranek, 1993).

2.3.3. Statistical analysis

Analysis was conducted with SAS software (Version 9.4, SAS Institute Inc., Cary, NC) using one-way analysis of variance (ANOVA) and Tukey's studentized range test with mean separation at $\alpha = 0.05$.

2.4. Results and Discussion

2.4.1. Cook loss of smoked salmon boudin

The minimization of cook loss is desired by meat processors, as the loss of water, oil, and other solids is considered a loss of saleable product and excess of waste. The control had the highest cook loss (8.91%±0.50%), while only the emulsion (EM) treatment showed a significant

reduction (4.28%±0.80%) in comparison (Figure 1). The amount of tested binders incorporated into the boudin (1.03%) also could have been too low to elicit a significant effect on cook loss under the utilized processing conditions for this particular food matrix. It should be considered that the EM treatment had a different processing procedure than the other treatments. The inclusion of superior temperature control while working in a 40°F laboratory room and improved mixing procedure may have contributed to EM having the lowest cook loss. In a meat emulsion, the fat particles are coated by protein that acts as a barrier between the oil and water (Knipe, 1987). The chopping operation for the emulsion sausages cuts the salmon trimmings into a tacky, paste-like substance that greatly increases the surface area. As a result, the fat particles are reduced to a smaller size that exhibits improved uniformity and is more ideal for extracted protein to coat and entrap. Processing methods such as grinding and emulsification generates heat, as friction acts as a catalyst for kinetic energy into thermal energy, and can result in degradation of the sensitive meat proteins (Agriculture.Institute, 2023). When protein functionality suffers, the binding capabilities and texture will as well. Lower processing facility temperatures also help to ensure fat particles are evenly distributed throughout the matrix, as unfavorably warm conditions may cause the protein-fat separation if the fat begins to melt. Additionally, enzymatic reactions that degrade fat and protein are forcefully stunted by cold temperatures, leading to preservation of meat structure integrity (Agriculture.Institute, 2023). Since the other treatments were prepared with ground salmon trimmings and a kitchen mixer operating at room temperature, the salmon trimmings also can be inferred to have less surface area, and the fat globules were likely not as well coated due to larger size and a warmer environment.

Pietrasik et al. (2012) did not find a difference in cook loss in restructured beef products when comparing the addition of 3 g cornstarch/100 g product to a control with no starch. When a 0.5%, 1.0%, and 1.5% flaxseed meal added treatment was compared to a control with no binding agent in restructured mutton chops, differences in cook loss were not found (Sharma et al., 2014). A similar pattern was observed when a control with no binding agent was compared to 2% and 3.5% CF addition in both pork and chicken sausages. It was found that all treatments were not different in terms of cook loss, including the control (Johnson, 2022).

2.4.2. Texture of smoked salmon boudin

Texture is an important factor many consumers take into consideration when purchasing a product, and in some cases may cause consumers to purchase a more expensive product with preferable texture (Sasaki et al., 2010). Warner-Bratzler shear force (WBSF) use is supported by Ashton et al., (2010) who found that the traditional TPA texture analysis was not as sensitive as cutting methods at detecting increases in firmness in Atlantic salmon muscle. Texture Technologies has also published an article criticizing the widespread use of the TPA probe for several products other than what it can be appropriately used for (Texture Technologies, 2019). There is very minimal published research that utilizes the Warner-Bratzler shear force (WBSF) method for sausage, but Perales-Jasso et al. (2018) used it to measure the texture of fresh pork chorizo sausages encased in cellulose synthetic casings, and may have experienced the same issue as the current study, as they did not include the standard deviation in their results. Their shear force values for sausage made and tested on the same day were 244.35 g and 216.99 g, and increased to 270.79 g and 277.87 g on day 7, which is somewhat similar to the high shear force values of our study. Our high standard deviations obtained during testing suggest that the boudin samples may not be uniform enough to discern treatment differences using this method.

From a USDA study that aimed to standardize the collection and interpretation of WBSF, it appears that meat samples with much less initial tenderness, such as steak and certain muscles, have greater success using WBSF (Wheeler et al., 1997). It can be concluded that finding an ideal texture measurement method for most food applications is a gap in literature yet to be filled, especially for such a unique product as the cold-smoked salmon boudin sausage. Firmness (g) ranged from 352.96±229.02 (EM) to 762.73±561.36 (FM) (Table 2). None of the treatments, including control, had a significantly different firmness, although the EM treatment value was the lowest and FM was the highest (p>0.05).

2.4.3. Color of smoked salmon boudin

Color characteristics play an important role in consumer purchasing decisions (Grebitus et al., 2013). Colorimeters measure the amount of light transmitted or reflected by a sample, which then allows for the calculation of light absorption, and determination of objective color analysis (Choudhury, 2014). *L*, a*,* and *b** values respectively measure darkness and whiteness, greenness and redness, and blueness and yellowness, with more positive values indicating a sample is more white, red, or yellow (Konica Minolta, 2015). The *L** value in the EM treatment was significantly higher than for the other treatments, indicating greater lightness (Table 3). The *a** value did not show a significant difference between any of the treatments. The *b** values of FM and EM treatments were significantly lower than the control, while EM also had a lower *b** value than CF and CS, indicating greater blueness. The *a** values for boudin align with the findings of Smith (2017) for smoked chicken sausage, which concluded that there were no significant differences in *L*, a**, or *b** values when sausage with the addition of modified cornstarch was compared to a control. Smith (2017) presented similar findings to Johnson (2022), showing only a difference in *L** value trends. Johnson (2022) found that when 3.5% CF

treatment in a chicken sausage was compared to a control without CF, the *a** and *b** values were not significantly different which aligns with our findings. However, they also indicated that the 3.5% CF treatment had lower *L** values than the control and other treatments. The results differ from Ghafouri-Oskuei et al. (2020) and Suleman et al. (2025), who both found that *b** values were increased to some extent in beef sausages and goat meat patties with the addition of flaxseed meal. However there are hundreds of genotypes of the flax plant, and a study that measured color in 144 different flax genotypes found diverse results in regards to color values, indicating color measurements are unlikely to be completely uniform across all studies that utilize a flaxseed product (Abtahi et al., 2022).

Our color values for CS align with Pietrasik et al. (2012) who found that the addition of cornstarch to beef did not have an impact on color compared to a control. The greater *L** value for the EM treatment in our study may be explained by superior emulsion formation prior to cooking the sausage. While gels hold water within a solid to semi-solid network, emulsions consist of one liquid dispersed within another immiscible liquid (Abdullah et al., 2022). Cooked boudin therefore has a combined gel and emulsion structure influenced by its uncooked properties. Light scattering plays a key role in determining the lightness of an emulsion (McClements, 2002). Emulsions typically scatter less light than gels, resulting in higher *L** values since more light reaches the detector (Jones, 1999; Xu & Mason, 2023). Proper emulsification leads to a more uniform distribution of fat particles. Bumsted et al. (2023) found that instrumental color measurements relate to fat smearing in fresh pork-based sausage, suggesting that sausages with higher *L** values tend to have less fat smearing, which is associated with better fat particle definition.

2.4.4. Oil binding capacity and water holding capacity of binding agents, and water holding capacity of smoked salmon boudin

Effective binding agents are characterized by their capacity to retain moisture and fat, enhance protein interactions, and stabilize the meat matrix. When the oil binding capacity (OBC) was tested for the dry binding agents, OBC values for CF, FM, and CS were calculated to be 5.00±0.19 (g/g), 2.57±0.73 (g/g), and 2.35±0.21 (g/g), respectively (Table 4). The CF had significantly higher OBC than the other samples. The water holding capacity (WHC) values were 8.95±0.72 (g/g) (CF), 5.54±0.59 (g/g) (FM), and 7.81±3.70 (g/g) (CS), with no significant differences shown between samples (Table 4). Each binding agent possesses a unique primary binding component. The fiber content of carrot fiber was reported to be 3.88% pectin, 12.3% hemi-cellulose, 51.6% cellulose, 32.1% lignin (Nawirska & Kwasnieswka, 2005). Cornstarch is estimated to be composed of 75% branched amylopectin and 25% linear amylose (Yu & Moon, 2021). The mucilage of flaxseed is rich in soluble fiber made up of water soluble polysaccharides (Kajla et al. 2014). Hydrogen bonds are estimated to be 4-100x stronger than van der Waal forces, which may explain the greater WHC values for all three tested binding agents when compared to their OBC (University of Hawaii at Mānoa, 2015). When cornstarch interacts with oil or water, it forms a gel network that can hold liquid from interactions and entanglements between chains via swollen granules (Lan et al., 2024). Non-starch polysaccharides such as carrot fiber and flaxseed meal also bind water through hydrophilic properties, such as hydrogen bonds formation or dipole interactions (Bieniek & Buksa, 2023). Zhu et al. (2015) found that smaller sized particles had greater WHC and OBC when comparing regular grinding to superfine grinding of hull-less barley bran. Particle size and surface roughness are suggested to have an impact on oil absorption performance of cornstarch (Zhang et al., 2022). Smaller particles tend to

increase the surface area available to interact with oil, and therefore variations in powder particle size may have influenced the binding agents' ability to retain water or oil (Zhang et al., 2022). Additionally, greater porosity within a binding agent is suggested to increase water and oil holding ability, and may be a factor as well (Richards et al., 2024).

The WHC of cooked boudin was also tested. Although no statistically significant differences were observed, the WHC values in order from greatest to least, were 95.20%±1.39% (CF), 94.70%±1.01% (EM), 94.22%±1.40% (CT), 92.37%±1.27% (FM), and 92.37%±1.27% (CS) (Table 5). The WHC of cooked sausage is suggested to increase with salt content due to proportional ionic stress and myofibrillar extraction with salt, and can result in the formation of harder and more elastic gel matrix (Galván-Navarro, 2023; Kim et al., 2021; Puolanne & Peltonen, 2013). The smoked salmon trimmings used in the current study contain 5.61% salt, and a nearly equal amount of additional salt was added to each treatment (Neagle et al., 2025). Salt exhibits greater attraction to water than to oil due to polarity, forming stronger bonds between water and salt (University of Hawaii at Mānoa, 2015). The uniformity in salt concentration between treatments may explain the general lack of significant differences in cook loss and WHC within the sausage matrix.

2.4.5. Proximate composition of smoked salmon boudin

Moisture, ash, and lipid content showed no significant differences between treatments (Table 6). Ash values ranged from 1.92%±0.06% (CF) to 1.68%±0.08% (EM) and 1.68%±0.23% (FM). Moisture content ranged from 68.29%±0.72% (EM) to 65.16%±0.91% (CS). The lipid values ranged from 10.32%±1.20% (CS) to 7.82%±2.11% (FM). Carbohydrate values were between 11.96%±0.85% (CT) and 10.51%±0.33% (FM). Protein values were the only measured

parameter showing differences, with 12.83%±0.36% (CF) being the highest, and 11.09%±0.26% (EM) being the lowest.

Very limited data on the proximate analysis of salmon-based sausages is currently available for direct comparison with findings from other studies. However, the lack of differences in moisture, lipid, and ash content resulted from the cook loss not being different for any treatment except EM, and the similar ingredient compositions of each sausage. Additionally, the similar WHC results for binding agent and sausage support the observed minimal changes in most proximate composition components. The reduced cook loss of EM and greater resulting retention of non-protein weight likely contributed to it having the lowest protein content, which was significantly lower than that of CF and FM. While not having significantly different moisture and lipid contents than other boudin samples, the CF treatment's combined moisture and lipids were the lowest. This possibly contributed to CF possessing the highest protein value.

Jung et al. (2022) reported similar findings in regards to the association between cook loss and proximate composition of emulsion-based pork sausages when comparing a negative control treatment without an emulsifying agent to sausages made with 1% and 2% oyster mushroom powder (OMP). Despite significant reduction in cook loss in both experimental treatments, the crude fat content did not vary, and they found that the moisture content was indirectly proportional to the cooking loss. Additionally, the 2% OMP treatment not only had the lowest value of cook loss, but highest moisture and lowest protein content (Jung et al., 2022). These findings align closely with the EM treatment's proximate composition patterns and suggest that differences in cook loss may be closely related to some proximate composition values.

2.5. Conclusions

Liquid loss during cooking poses complications for industry partners as it results in waste and revenue loss, thus reduction of cook loss is critical for a successful product. Our results suggest that an emulsion-based method has potential for application in smoked salmon boudin, given that it was the only treatment to demonstrate significant reduction in cook loss compared with the control. The lower cook loss of the emulsion sausages can be credited to the high-speed homogenization done prior to forming and cooking that the other treatments did not experience. Conversely, the incorporation of 1.03% carrot fiber, cornstarch, flaxseed meal, or an emulsion did not significantly affect most measured parameters of the smoked salmon boudin, including moisture content, lipid content, ash content, WHC, texture, and *a** color value. Therefore, producing an emulsion-based smoked salmon boudin without an additional binder would mitigate ingredient costs while enhancing product yield. The equipment used for making emulsion-based sausages is standard for commercial production and can be scaled up. Moving forward, sensory analysis and shelf life studies will be necessary to determine product marketability and stability.

Tables

Table 1. Ingredient makeup of smoked salmon boudin.

Ingredient	CT and EM sausages (%)	CF, CS, and FM Sausages (%)
Cold-smoked salmon trimmings	34.36	34.00
Rice	22.90	22.66
Water	15.15	14.99
Yellow onion	12.62	12.49
Green bell pepper	12.62	12.49
Binding agent	0	1.03
Garlic	0.88	0.87
Canola oil	0.35	0.35
Salt	0.33	0.32
Paprika	0.30	0.30
Black pepper	0.20	0.20
Chili powder	0.13	0.12
Cayenne pepper	0.08	0.07
Parsley	0.08	0.07

CT = control, CF = carrot fiber, CS = cornstarch, FM = flaxseed meal, and EM = emulsion sausages.

Table 2. Firmness of smoked salmon boudin.

Treatment	Firmness (g)
CT	616.10±442.88[a]
CF	703.97±438.49[a]
CS	409.19±300.88[a]
FM	762.73±561.36[a]
EM	352.96±229.02[a]

Means±SD with the same lowercase letter (a) within a column indicate no significant difference (p>0.05). CT = control, CF = carrot fiber, CS = cornstarch, FM = flaxseed meal, and EM = emulsion.

Table 3. Color of smoked salmon boudin.

Treatment	*L**	*a**	*b**
CT	46.57±3.14[a]	9.11±2.78[a]	27.05±3.71[a]
CF	48.67±2.33[a]	8.96±1.41[a]	25.85±2.61[ab]
CS	46.30±2.96[a]	8.82±2.37[a]	24.64±3.97[ab]
FM	46.32±3.41[a]	7.83±2.10[a]	23.16±3.47[bc]
EM	52.56±1.92[b]	8.32±0.64[a]	21.55±1.56[c]

Means±SD with different lowercase letters (a-c) within a column indicate a significant difference (p<0.05). CT = control, CF = carrot fiber, CS = cornstarch, FM = flaxseed meal, and EM = emulsion. L^* represents lightness (0 = black, 100 = white), a^* represents the red–green spectrum (positive values indicate more redness), and b^* represents the yellow–blue spectrum (positive values indicate more yellowness).

Table 4. Oil binding capacity and water holding capacity of binding agents.

Binding agent	Oil binding capacity (g/g)	Water holding capacity (g/g)
CF	5.00 ±0.19[a]	8.95 ±0.72[a]
CS	2.35 ±0.21[b]	5.54 ±0.59[a]
FM	2.57 ±0.73[b]	7.81 ±3.70[a]

Means±SD with different lowercase letters (a,b) within a column indicate a significant difference (p<0.05). CF = carrot fiber, CS = cornstarch, and FM = flaxseed meal. Ratio expresses the amount (g) of water or oil retained per 1 g binding agent.

Table 5. Water holding capacity of smoked salmon boudin.

Treatment	Water holding capacity (%)
CT	94.22±1.40[a]
CF	95.20±1.39[a]
CS	92.67±2.26[a]
FM	92.37±1.27[a]
EM	94.70±1.01[a]

Means±SD with the same lowercase letter (a) within a column indicate no significant difference (p>0.05). CT = control, CF = carrot fiber, CS = cornstarch, FM = flaxseed meal, and EM = emulsion.

Table 6. Proximate composition of smoked salmon boudin.

Treatment	Moisture (%)	Lipids (%)	Ash (%)	Protein (%)	Carbohydrates (%)
CT	65.27±1.25[a]	9.60±0.90[a]	1.85±0.13[a]	11.31±0.20[b]	11.96±0.85[a]
CF	65.68±1.15[a]	8.30±1.20[a]	1.92±0.06[a]	12.83±0.36[a]	11.27±0.72[a]
CS	65.16±0.91[a]	10.32±1.20[a]	1.86±0.04[a]	11.36±0.32[b]	11.30±0.42[a]
FM	67.75±2.20[a]	7.82±2.11[a]	1.68±0.23[a]	12.25±0.37[a]	10.51±0.33[a]
EM	68.29±0.72[a]	8.31±0.57[a]	1.68±0.08[a]	11.09±0.26[b]	10.63±0.34[a]

Means±SD with different lowercase letters (a,b) within a column indicate a significant difference (p<0.05). CT = control, CF = carrot fiber, CS = cornstarch, FM = flaxseed meal, and EM = emulsion. All values are on a wet basis.

Figures

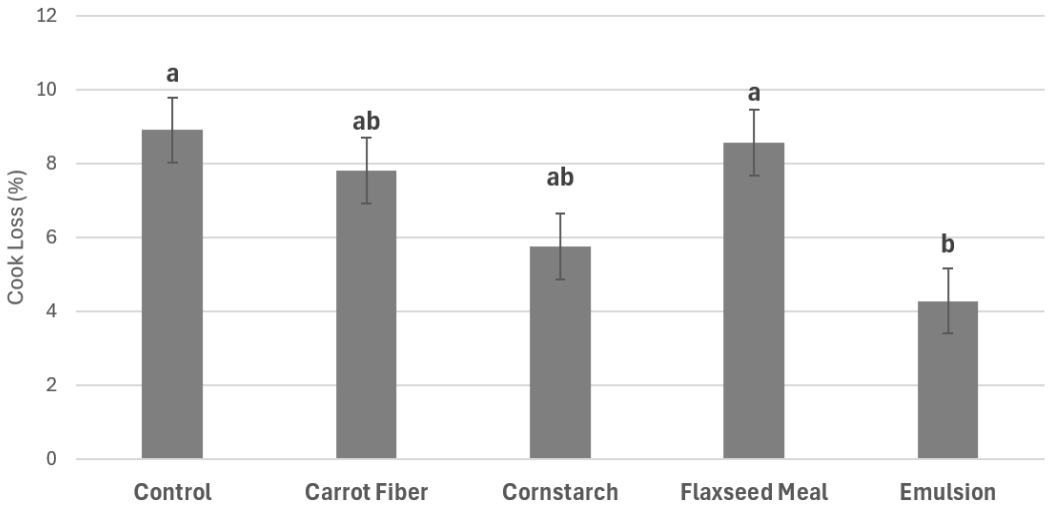

Figure 1. Cook loss of smoked salmon boudin.

Means±SD with no lowercase letter in common between bars indicate a significant difference (p<0.05).

REFERENCES

Abbasi, E., Amini Sarteshnizi, R., Ahmadi Gavlighi, H., Nikoo, M., Azizi, M. H., & Sadeghinejad, N. (2019). Effect of partial replacement of fat with added water and tragacanth gum (*astragalus gossypinus* and *astragalus compactus*) on the physicochemical, texture, oxidative stability, and sensory property of reduced fat emulsion type sausage. *Meat Science*, *147*, 135–143. https://doi.org/10.1016/j.meatsci.2018.09.007

Abdullah, Liu, L., Javed, H. U., & Xiao, J. (2022). Engineering emulsion gels as functional colloids emphasizing food applications: A review. *Frontiers in Nutrition*, *9*, 890188. https://doi.org/10.3389/fnut.2022.890188

Abtahi, M., Mirlohi, A., Sharif-Moghaddam, N., & Ataii, E. (2022). Revealing seed color variation and their possible association with yield and quality traits in a diversity panel of flax (*Linum Usitatissimum* L.). *Frontiers in plant science*, *13*, 1038079. https://doi.org/10.3389/fpls.2022.1038079

Agriculture Institute. (2023). The importance of chilled water or ice in meat processing. *Agriculture Institute.* https://agriculture.institute/processed-meat-technology/importance-chilled-water-ice-meat-processing/.

Agricultural Research Service. (2010). Fish Leftovers: New life ahead for today's discards? *USDA ARS online magazine. 58 (9*), from https://agresearchmag.ars.usda.gov/2010/oct/leftovers

Agricultural Research Service. (2023) Food data central-smoked salmon. *United States Department of Agriculture. https://fdc.nal.usda.gov/food-details/2594868/nutrients*

Agricultural Research Service. (2024). Fooddata central-Fish, salmon, Atlantic, farmed, raw. *United States Department of Agriculture.* https://fdc.nal.usda.gov/fdc-app.html#/food-details/175167/nutrients

American Heart Association. (2024). Fish and omega-3 fatty acids. *American Heart Association.* https://www.heart.org/en/healthy-living/healthy-eating/eat-smart/fats/fish-and-omega-3-fatty-acids

Argyrakopoulou G., Konstantinidou S.K., Dalamaga M., Kokkinos A. (2022). Nutritional deficiencies before and after bariatric surgery: prevention and treatment. *Current Nutrition Reports,* 11(2):95–101. doi: 10.1007/s13668-022-00400-9.

Ashton, T. J., Michie, I., & Johnston, I. A. (2010). A novel tensile test method to assess texture and gaping in salmon fillets. *Journal of Food Science*, *75*(4). https://doi.org/10.1111/j.1750-3841.2010.01586.x

Bazarnova, J., Timoshenkova, I., Eliseeva, S., Nesmelova, S., Muizniece-Brasava, S. (2020). Recycling of secondary salmon fish processing waste. *Journal of Hygienic Engineering and Design,* 32, 69-73.

Bieniek, A., & Buksa, K. (2023). Properties and functionality of cereal non-starch polysaccharides in breadmaking. *Applied Sciences*, *13*(4), 2282. https://doi.org/10.3390/app13042282

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian journal of biochemistry and physiology*, *37*(8), 911–917. https://doi.org/10.1139/o59-099

Bradley, M., Melchor, J., Carr, R., & Karjoo, S. (2023). Obesity and malnutrition in children and adults: A clinical review. *Obesity Pillars*, *8*, 100087. https://doi.org/10.1016/j.obpill.2023.100087

Bumsted, J., Ford, E., Blair, A., Underwood, K., & Zuelly, S. M. (2023). Instrumental color measurements have relationships to fat smearing in fresh sausage. *Foods, 12*(14), 2813.

Chattopadhyay, K., Xavier, K.A.M., Layana, P., Balange, A.K., Nayak, B.B. (2019). Chitosan hydrogel inclusion in fish mince based emulsion sausages: Effect of gel interaction on functional and physicochemical qualities. *International Journal of Biological Macromolecules*. 134, 1063-1069. https://doi.org/10.1016/j.ijbiomac.2019.05.148.

Chelu, M., & Musuc, A. M. (2023). Polymer gels: Classification and recent developments in biomedical applications. *Gels*, *9*(2), 161. https://doi.org/10.3390/gels9020161

Chen, M., Chen, X.-Q., Tian, L.-X., Liu, Y.-J., & Niu, J. (2020). Improvement of growth, intestinal short-chain fatty acids, non-specific immunity and ammonia resistance in Pacific white shrimp (*litopenaeus vannamei*) fed dietary water-soluble chitosan and mixed probiotics. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, *236*, 108791. https://doi.org/10.1016/j.cbpc.2020.108791

Choudhury, A. K. R. (2014). 6—Colour measurement instruments. In A. K. R. Choudhury (Ed.), *Principles of colour and appearance measurement* (pp. 221–269). Woodhead Publishing. https://doi.org/10.1533/9780857099242.221

Coppola, D., Lauritano, C., Esposito, F. P., Riccio, G., Rizzo, C., & Pascale, D. de. (2021). Fish waste: From problem to valuable resource. *Marine Drugs*, *19*(2), 116. https://doi.org/10.3390/md19020116

Durham, T. R. (2001). Salt, smoke, and history. *Gastronomica*, *1*(1), 78–82. https://doi.org/10.1525/gfc.2001.1.1.78

Elementar. (n.d). Dumas – A well-established method for N/protein analysis. *Elementar.*

Fomena Temgoua, N. S., Sun, Z., Okoye, C. O., & Pan, H. (2022). Fatty acid profile, physicochemical composition, and sensory properties of atlantic salmon fish (Salmo salar) during different culinary treatments. *Journal of Food Quality*, *2022*, 1–16. https://doi.org/10.1155/2022/7425142

Food and Agriculture Organization. (2024). Hunger numbers stubbornly high for three consecutive years as global crises deepen: UN report. *United Nations*. https://www.fao.org/newsroom/detail/hunger-numbers-stubbornly-high-for-three-consecutive-years-as-global-crises-deepen--un-report/en

Funami, T., Yada, H., & Nakao, Y. (1998). Thermal and rheological properties of curdlan gel in minced pork gel. *Food Hydrocolloids*, 12 (1); 55-64. https://doi.org/10.1016/S0268-005X(98)00045-9.

Galván-Navarro, A., Sosa-Morales, M. E., Delgado-García, J., Lorenzo, J. M., Campagnol, P. C. B., & Gómez-Salazar, J. A. (2023). Ultrasound and salt reduction effect on physicochemical and rheological properties of meat emulsions. *Journal of Food Science*, *88*(12), 5176–5190. https://doi.org/10.1111/1750-3841.16820

Ghafouri-Oskuei, H., Javadi, A., Asl, M.R.S., Azadmard-Damirchi, S., & Armin, M. (2020). Quality properties of sausage incorporated with flaxseed and tomato powders. *Meat Science*, 161, 107957. https://doi.org/10.1016/j.meatsci.2019.107957.

Grebitus, C., Jensen, H. H., Roosen, J., & Sebranek, J. G. (2013). Fresh meat packaging: Consumer acceptance of modified atmosphere packaging including carbon monoxide.

Journal of Food Protection, 76(1), 99-107. https://proxying.lib.ncsu.edu/index.php?url=https://www.proquest.com/scholarly-journals/fresh-meat-packaging-consumer-acceptance-modified/docview/1269694081/se-2

Jin, S.-K., Ha, S.-R., Hur, S.-J., & Choi, J.-S. (2016). Effect of the ratio of raw material components on the physico-chemical characteristics of emulsion-type pork sausages. *Asian-Australasian Journal of Animal Sciences*, *29*(2), 263–270. https://doi.org/10.5713/ajas.15.0129

Johnson, J. A. (2022). Physical and chemical effects of carrot fiber as a binder in cooked sausage (Order No. 29064767). *Available from ProQuest Dissertations & Theses Global.* (2674758566). https://proxying.lib.ncsu.edu/index.php?url=https://www.proquest.com/dissertations-theses/physical-chemical-effects-carrot-fiber-as-binder/docview/2674758566/se-2

Jones, A. R. (1999). Light scattering for particle characterization. *Progress in Energy and Combustion Science*, *25*(1), 1–53. https://doi.org/10.1016/S0360-1285(98)00017-3

Jung, D. Y., Lee, H. J., Shin, D.-J., Kim, C. H., & Jo, C. (2022). Mechanism of improving emulsion stability of emulsion-type sausage with oyster mushroom (*pleurotus ostreatus*) powder as a phosphate replacement. *Meat Science*, *194*, 108993. https://doi.org/10.1016/j.meatsci.2022.108993

Kajla, P., Sharma, A., & Sood, D. R. (2015). Flaxseed—A potential functional food source. *Journal of Food Science and Technology*, *52*(4), 1857–1871. https://doi.org/10.1007/s13197-014-1293-y

Kaur, M., Singh, A. K., & Singh, A. (2023). Bioconversion of food industry waste to value added products: Current technological trends and prospects. *Food Bioscience*, *55*, 102935. https://doi.org/10.1016/j.fbio.2023.102935

Kim, T.-K., Yong, H. I., Jung, S., Kim, H.-W., & Choi, Y.-S. (2021). Effect of reducing sodium chloride based on the sensory properties of meat products and the improvement strategies employed: A review. *Journal of Animal Science and Technology*, *63*(4), 725–739. https://doi.org/10.5187/jast.2021.e74

King-Brink, M. & Sebranek J.G. (1993). Combustion method for determination of crude protein in meat and meat products: Collaborative study. *Journal of AOAC International. 76(4); 787.*

Knipe, C.L. (1987). Meat emulsions. *Ohio State University.* https://meatsci.osu.edu/node/130

Kong, J., Dougherty, M. P., Perkins, L. B., & Camire, M. E. (2008). Composition and consumer acceptability of a novel extrusion-cooked salmon snack. *Journal of Food Science*, *73*(3). https://doi.org/10.1111/j.1750-3841.2007.00651.x

Konica Minolta. (2015). Identifying Color Differences Using L*a*b* or L*C*H* Coordinates. *Konica Minolta. https://sensing.konicaminolta.us/us/blog/identifying-color-differences-using-l-a-b-or-l-c-h-coordinates/*

Kultys, E., & Moczkowska-Wyrwisz, M. (2022). Effect of using carrot pomace and beetroot-apple pomace on physicochemical and sensory properties of pasta. *LWT- Food Science and Technology*, *168*, 113858. https://doi.org/10.1016/j.lwt.2022.113858

Lan, G., Xie, S., Duan, Q., Huang, W., Huang, W., Zhou, J., Chen, P., & Xie, F. (2024). Effect of soybean polysaccharide and soybean oil on gelatinization and retrogradation properties

of corn starch. *International Journal of Biological Macromolecules*, *264*, 130772. https://doi.org/10.1016/j.ijbiomac.2024.130772

Li, G., Guo, W., Gao, X., Wang, Y., & Sun, S. (2020). Effect of superfine grinding on physicochemical and antioxidant properties of soybean residue powder. *Food Science & Nutrition*, *8*(2), 1208–1214. https://doi.org/10.1002/fsn3.1409

McClements, D. J. (2002). Theoretical prediction of emulsion color. *Advances in Colloid and Interface Science*, *97*(1), 63–89. https://doi.org/10.1016/S0001-8686(01)00047-1

Moshtaghian, H., Bolton, K., & Rousta, K. (2021). Challenges for upcycled foods: Definition, inclusion in the food waste management hierarchy and public acceptability. *Foods*, *10*(11), 2874. https://doi.org/10.3390/foods10112874

Muchekeza, J. T., Jombo, T. Z., Magogo, C., Mugari, A., Manjeru, P., & Manhokwe, S. (2021). Proximate, physico-chemical, functional and sensory properties OF quinoa and amaranth flour AS potential binders in beef sausages. *Food Chemistry*, *365*, 130619. https://doi.org/10.1016/j.foodchem.2021.130619

National Center for Health Statistics. (2023). More than a quarter of U.S. Adults and children have at least one allergy. *Centers for Disease Control and Prevention.* https://www.cdc.gov/nchs/pressroom/nchs_press_releases/2022/20220126.htm

National Institute of Health. (2023). Office of dietary supplements—Omega-3 Fatty Acids. *U.S. Department of Health and Human Services.* https://ods.od.nih.gov/factsheets/Omega3FattyAcids-HealthProfessional/

Nawirska, A., & Kwaśniewska, M. (2005). Dietary fibre fractions from fruit and vegetable processing waste. *Food Chemistry*, *91*(2), 221–225. https://doi.org/10.1016/j.foodchem.2003.10.005

Neagle, C., Chouljenko, A., Bolton, G., Mirtalebi, S., Frinsko, M. O., Hall, S. G., Reading, B. J., Joseph, M. (2025). Effect of pilot-scale decanter centrifuge processing parameters on the quality of fish meal produced from smoked salmon processing by-products. *Processes, 13*(2), 511. https://doi.org/10.3390/pr13020511

Neff, R. A., Spiker, M. L., & Truant, P. L. (2015). Wasted food: U. S. Consumers' reported awareness, attitudes, and behaviors. *Public Library of Science ONE*, *10*(6), e0127881. https://doi.org/10.1371/journal.pone.0127881

Perales-Jasso, Y. J., Gamez-Noyola, S. A., Aranda-Ruiz, J., Hernandez-Martinez, C. A., Gutierrez-Soto, G., Luna-Maldonado, A. I., Silva-Vazquez, R., Hume, M. E., & Mendez-Zamora, G. (2018). Oregano powder substitution and shelf life in pork chorizo using Mexican oregano essential oil. *Food science & nutrition*, *6*(5), 1254–1260. https://doi.org/10.1002/fsn3.668

Pietrasik, Z., Pierce, D. L., & Janz, J. A. M. (2012). The effect of selected starches on hydration, textural and sensory characteristics of restructured beef products. *Journal of Food Quality*, *35*(6), 411–418. https://doi.org/10.1111/jfq.12000

Pietrasik, Z., & Soladoye, O. P. (2021). Functionality and consumer acceptability of low-fat breakfast sausages processed with non-meat ingredients of pulse derivatives. *Journal of the Science of Food and Agriculture*, *101*(11), 4464–4472. https://doi.org/10.1002/jsfa.11084

Puolanne, E., & Peltonen, J. (2013). The effects of high salt and low pH on the water-holding of meat. *Meat Science*, *93*(2), 167–170. https://doi.org/10.1016/j.meatsci.2012.08.015

Richards, J., Lammert, A., Madden, J., Kang, I., & Amin, S. (2024). Physical treatments modified the functionality of Carrot Pomace. *Foods*, *13*(13), 2084.

Sasaki, K., Motoyama, M., Yasuda, J., Yamamoto, T., Oe, M., Narita, T., Imanari, M., Fujimura, S., & Mitsumoto, M. (2010). Beef texture characterization using internationally established texture vocabularies in ISO5492:1992: Differences among four different end-point temperatures in three muscles of Holstein steers. *Meat Science*, *86*(2), 422–429. https://doi.org/10.1016/j.meatsci.2010.05.028

Sharma, H., Sharma, B. D., Mendiratta, S. K., Talukder, S., & Ramasamy, G. (2014). Efficacy of flaxseed flour as bind enhancing agent on the quality of extended restructured mutton chops. *Asian-Australasian Journal of Animal Sciences*, *27*(2), 247–255. https://doi.org/10.5713/ajas.2013.13319

Sicherer, S. H., & Sampson, H. A. (2006). 9. Food allergy. *Journal of Allergy and Clinical Immunology*, *117*(2, Supplement 2), S470–S475. https://doi.org/10.1016/j.jaci.2005.05.048

Slima, SB., Ktari, N., Triki, M., Trabelsi, I., Moussa, H., Makni, S., Abdeslam, A., Herrero, A. M., Jiménez-Colmenero, F., Ruiz-Capillas, C., & Ben Salah, R. (2019). Effects of two fibers used separately and in combination on physico-chemical, textural, nutritional and sensory properties of beef fresh sausage. *British Food Journal*, *121*(6), 1428–1440. https://doi.org/10.1108/BFJ-06-2018-0388

Smith, J. E. (2017). Evaluating the effects of oat fiber and modified corn starch on the characteristics of smoked sausage utilizing mechanically separated chicken (Order No. 30262560). Available from ProQuest Dissertations & Theses Global. (2779137229). Retrieved from https://proxying.lib.ncsu.edu/index.php?url=https://www.proquest.com/dissertations-theses/evaluating-effects-oat-fiber-modified-corn-starch/docview/2779137229/se-2

Suleman, R., Choudhary, H., Garcia-Galicia, I. A., Ismail, T., Qamar, M., Zahoor, M. A., Zulfiqar, S., Mohamed Ahmed, I. A., & Aljobair, M. O. (2025). Utilization of flaxseed powder in controlling lipid oxidation and quality deterioration of fried goat meat patties. *Cogent Food & Agriculture*, *11*(1), 2444340. https://doi.org/10.1080/23311932.2024.2444340

Texture Technologies. (2019). Texture Profile Analysis. *Texture Technologies. https://texturetechnologies.com/resources/texture-profile-analysis*

University of Hawaii at Mānoa. (2015). Comparison of water with other liquids. *University of Hawaii at Mānoa.*

Wheeler T.L., Schakelford S.D.,& Koohmaraie, M. (1997). Standardizing collections and interpretation of Warner-Bratzler Shear Force and sensory tenderness data. *United States Department of Agriculture.* 50:68-77.

Xu, Y., & Mason, T. G. (2023). Complex optical transport, dynamics, and rheology of intermediately attractive emulsions. *Scientific Reports*, *13*(1), 1791. https://doi.org/10.1038/s41598-023-28308-6

Xue, S., Park, J., Tuell, J. R., Maskal, J. M., Johnson, J. S., Dinh, T., & Kim, Y. H. B. (2022). In utero heat stress has minimal impacts on processed pork products: A comparative study. *Foods*, *11*(9), 1222. https://doi.org/10.3390/foods11091222

Yu, J. K., & Moon, Y. S. (2021). Corn Starch: Quality and quantity improvement for industrial uses. *Plants (Basel, Switzerland)*, *11*(1), 92. https://doi.org/10.3390/plants11010092

Zaini, H. B. M., Sintang, M. D. B., & Pindi, W. (2020). The roles of banana peel powders to alter technological functionality, sensory and nutritional quality of chicken sausage. *Food science & nutrition*, *8*(10), 5497–5507. https://doi.org/10.1002/fsn3.1847

Zhang, S., Li, Q., Zhao, Y., Qin, Z., Zheng, M., Liu, H., & Liu, J. (2022). Preparation and characterization of low oil absorption corn starch by ultrasonic combined with freeze-thaw treatment. *Food chemistry: X*, *15*, 100410. https://doi.org/10.1016/j.fochx.2022.100410

Zhu, F., Du, B., & Xu, B. (2015). Superfine grinding improves functional properties and antioxidant capacities of bran dietary fibre from Qingke (Hull-less barley) grown in Qinghai-Tibet Plateau, China. *Journal of Cereal Science*, *65*, 43–47. https://doi.org/10.1016/j.jcs.2015.06.006

CHAPTER 3: IMPACT OF ROSEMARY EXTRACT ON SENSORY QUALITY AND FROZEN STORAGE STABILITY OF BOUDIN MADE FROM COLD-SMOKED SALMON TRIMMINGS

3.1. Abstract

This study evaluated the effects of rosemary extract on the sensory quality and frozen storage stability of boudin sausage made from cold-smoked salmon trimmings. Boudin made from cold-smoked salmon trimmings may be rich in polyunsaturated fatty acids (PUFAs), which are highly susceptible to lipid oxidation and the development of off-flavors. Rosemary extract has been used in traditional sausage formulations to inhibit lipid oxidation and maintain product quality during storage, but limited information exists regarding its use in seafood-based sausages. Three formulations containing 0, 40, or 60 ppm carnosic acid rosemary extract were produced, vacuum-packaged, and stored at −18°C for up to 120 days. Thawed samples were objectively analyzed for thaw loss, texture, color, and lipid oxidation (TBARS). Consumers (N = 107) evaluated sensory liking (nine-point hedonic scale), attribute intensity (JAR scale), and purchase intent (five-point scale) of thawed and reheated samples stored frozen for 7 days. All treatments maintained acceptable physicochemical quality during storage, with TBARS and thaw loss values generally remaining within acceptable ranges reported in previous studies. Instrumental color changes were minor, and texture parameters tended to stabilize after significant increases in early storage. Sensory evaluation revealed no major perceptible differences among treatments in JAR or specific attribute liking scores aside from texture, which was generally the least liked attribute. Slight but statistically significant consumer preferences were observed for the 40 and 60 ppm carnosic acid rosemary extract boudins in overall liking (6.6 and 6.7, respectively, vs. 6.3 for 0 ppm) and purchase intent (3.4 and 3.5 vs. 3.1), while penalty analysis suggested opportunities for improvement in flavor balance and color through formulation or processing adjustments. These findings highlight the potential of smoked salmon trimmings as a stable,

high-value ingredient in frozen boudin under the storage conditions tested, and point to opportunities for further innovation in sustainable, fish-based emulsified sausages.

3.2. Introduction

Food waste is a longstanding issue from both an environmental and financial standpoint. Statistical data indicate a global increase in seafood consumption, accompanied by a corresponding rise in byproduct waste (Coppola et al., 2021). The importance of preventing and minimizing food waste has been expressed by several government agencies, including the Environmental Protection Agency (EPA), Federal Food and Drug Administration (FDA), and United States Department of Agriculture (USDA) (FDA, 2025).

Food discards are estimated to contribute to nearly a quarter of municipal solid waste in landfills and approximately 58% of the methane emissions in the atmosphere (Environmental Protection Agency, 2015). Once fish are caught, over 70% of world capture production undergo further processing prior to becoming available for sale (Hou et al., 2016). Between 20-80% of the fish are estimated to be wasted, with muscle trimmings being the predominant byproduct (Coppola et al., 2021; Martínez-Alvarez et al., 2015). The World Food Programme estimates that globally, the equivalent of approximately 1 billion meals are wasted per day, financially totaling around $1 trillion in waste worldwide every year (World Food Programme, 2024). However, since the American Heart Association (2024) recommends consuming fatty fish twice a week, seafood companies have an opportunity to develop nutritious food products using what would otherwise be waste.

A common issue food companies face is that consumers indicate a preference for products that follow what they perceive as “natural” guidelines, such as the absence of food preservation additives (Liu et al., 2017). However, preservative additives are often necessary to

extend product shelf life. Preservatives help to maintain color and texture, in addition to reducing thaw loss and oxidation (Que & Chin, 2020; Tironi et al., 2009; Wang et al., 2017; Whalin et al., 2022). When analyzing consumer purchasing preferences in animal meat products across several locations, taste and the best-before date were found to be most important to consumers (Török et al., 2023). Endara et al. (2023) found similar patterns in consumer willingness to pay more money for longer shelf life in milk. Consumers' desire for a longer shelf life conflicts with their desire for products that do not contain preserving agents, creating a unique obstacle for food manufacturers to overcome. Identifying an ingredient that achieves greater shelf life, stability, and consumer approval has the potential to make meat products more marketable and increase revenue for food production companies, in addition to reducing food waste on account of spoiled meat.

Developing sausages from fish byproducts offers a potential solution for reducing the excess processing waste created by seafood companies. However, without any preserving agents, the sausage may become subject to spoilage and rancidity. Rosemary extract is a promising antioxidant addition for sausage due to affordability, functionality, and positive sensory data (Hoelscher et al., 2024; Schilling et al., 2018; Sharma et al., 2017). Lipid oxidation decreased in chicken sausages that utilized a combination of rosemary and tocopherol, and in pork sausages containing a combination of rosemary extract and green tea extract (Hoelscher et al., 2024; Schilling et al., 2018). The spice-complex and aroma are suggested to be key drivers of liking, while rancidity and off-flavors, and odors can be viewed negatively by consumers (Schilling et al., 2018).

A consumer liking test with dry cured pork sausages found that the most important attributes to consumers were taste, animal health, and addition of preservatives (Braghieri et al.,

2016). Visible fat content and nutritional value were also found to be somewhat important, with reduced amounts of visible fat being preferred (Braghieri et al., 2016; Girolami et al., 2014). More ideal flavor, odor, and texture could improve consumer attitudes toward visible fat (Braghieri et al., 2016; Girolami et al., 2014). The addition of nitrite/nitrate preservatives in the dry cured sausages did not have a significant effect on overall liking, taste, flavor, or texture when compared to control sausages without a preservative, and caused the liking score concerning appearance to significantly increase, suggesting that the addition of an appropriate preservative will either maintain or improve attribute scores of a control without a preserving agent (Braghieri et al., 2016). In a similar study, Schilling et al. (2018) evaluated the ingredient functionality and shelf life of pork sausages containing several variations of rosemary extract with green tea extract compared to a control sausage with a synthetic antioxidant mix of butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and propyl gallate (PG) in heat sealed packaging that was stored frozen over 3 months. It was found that the aroma, flavor, and texture of all the experimental treatments was preferred over the control. However, none of the experimental treatments varied from each other, suggesting that the inclusion of rosemary extract could improve consumer liking, but more precise determination of the ideal inclusion amount requires further research (Schilling et al., 2018).

Carnosic acid and carnosol are responsible for the majority of antioxidant behaviors in rosemary extract (Nieto et al., 2018). Carnosic acid is a scavenger of reactive oxygen species (ROS), which makes it an effective antioxidant through its role in chemical quenching (Loussouarn et al., 2017). ROS are unstable compounds that can easily react with other molecules and result in the formation of undesirable compounds in food products due to their ability to cause formation of volatile compounds and carcinogens, reduce nutritional value, and

alter macromolecule function (Choe & Min, 2006; National Cancer Institute, 2010). High cooking temperatures often encourage the formation of free radicals and ROS (Leung et al., 2018). Products such as peroxides are released upon initial cooking, and secondary products are formed as oxidation continues (Leung et al., 2018). Carnosol, an oxidation product of carnosic acid, is suggested to more directly interact with mechanisms of lipid peroxidation, which occurs when electrons are removed from lipids by free radicals and produces intermediates that can also participate in reactions (Loussouarn et al., 2017; Su et al., 2019). The mechanisms of carnosic acid and carnosol suggest that they may be successful in reducing oxidation and rancidity in fish sausage products.

Lipids are typically composed of fatty acids, which are fat-soluble molecules found in both plant and animal sources (Kapoor et al., 2021). The presence or absence of double bonds determines if a fatty acid is saturated or unsaturated. In unsaturated fatty acids, the number of double bonds determines whether a fatty acid is classified as monounsaturated or polyunsaturated. Omega-6 and Omega-3 fatty acids are examples of polyunsaturated fatty acids (PUFAs) and cannot be produced by the body; therefore, they must be consumed through the diet (Kapoor et al., 2021). EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) are both omega-3 fatty acids suggested to be important for healthy heart function (Galan et al., 2010). EPA and DHA are commonly found in marine animals, such as cold water fish, and play an important role in cell membrane structure and intercellular communication (Kapoor et al., 2021; Lunn & Theobald, 2006). PUFAs are highly susceptible to lipid peroxidation (Su et al., 2019). Smoked salmon is estimated to have approximately 1 g of PUFAs per 1 oz (Agricultural Research Service, 2023), suggesting a need for a preserving agent to reduce the extent of oxidation in sausage products containing smoked salmon or its byproducts.

There is a wide range of rosemary extract dosages to be found in sausage shelf life literature. This is primarily because each formulation of rosemary extract will contain different quantities of the effective antioxidant that enables the preserving ability. The exact dosage of carnosic acid is often undisclosed, which limits ability to compare across literature. Schilling et al. (2018) included rosemary extract ppm values of 1500, 2000, and 2500 in heat-sealed and frozen pork sausages. In beef products, Stoick et al. (1991) added rosemary extract at 500–1000 ppm, while Sánchez-Escalante et al. (2001) used 1000 ppm rosemary extract combined with 500 ppm vitamin C. Many studies utilizing rosemary extract as a preserving agent have reported the dosage of rosemary extract without disclosure of the carnosic acid makeup, which limits direct comparisons. To our knowledge, the use of rosemary extract as a preservative in smoked salmon sausage has not been studied, indicating a clear research gap. The objective of this study was to evaluate the impact of rosemary extract (40 and 60 ppm carnosic acid) on the sensory quality and frozen storage stability of boudin made from cold-smoked salmon trimmings.

3.3. Methods and Materials

3.3.1. Materials

Cold-smoked salmon trimmings were provided by Acme Smoked Fish Corporation (Wilmington, NC). Black pepper, chili powder, cayenne pepper, cornstarch, jasmine rice, paprika, parsley, and canola oil were purchased from Walmart, Great Value Brand (Bentonville, AR). Frozen diced green and red bell peppers and onions were purchased from Cheney Brothers, Inc. (Greensboro, NC). Minced garlic was purchased from Spice World (Orlando, FL). Pickling & Canning Salt were purchased from Morton Salt (Chicago, IL).

3.3.2. Methods

3.3.2.1. Preparation of boudin sausage

Three batches of each boudin sample were prepared: a control with no rosemary extract (CR), boudin containing 40 ppm carnosic acid rosemary extract (R40), and boudin containing 60 ppm carnosic acid rosemary extract (R60). Rosemary extract was incorporated into experimental treatment sausages using dosages of carnosic acid that were recommended by the manufacturer. The boudin sausages were formulated according to the ingredient amounts listed in Table 1. All nine repetitions were prepared separately. Vegetables were prepared by cooking with canola oil for 15 minutes on medium heat via the stovetop. Rice was cooked in an Aroma Rice Cooker, model ARC-150SB (China) using the white rice setting. Smoked salmon trimmings, water, and spices were added to a Mado Supra 35 industrial bowl cutter machine (MADO Maschinenfabrik Dornhan, Germany) operating at 3,750 blade rpm and 6.5°C machine temperature, and homogenized for 2 minutes at high speed. Cooked vegetables and rice were added and homogenized for an additional minute. Sausage fillings were then stuffed into 35/38 mm natural hog casings using a Handtmann VF 50 vacuum filler (Handyman, Biberach an der Riss, Germany). Each of the 9 batches were allocated into 7 sausage coils, then steamed at one time in an Enviropak MiniPak 650 (Enviropak, Earth City, MO) for 30 minutes until the internal temperature of sausages reached 72.22°C.

Following overnight cooling to 40.0°F, sausages were packaged for freezing. Of the 7 sausages per treatment batch, 6 were vacuum-packaged, and 1 was sealed under ambient air conditions in a 2-gallon plastic bag. The treatments were frozen at −18°C and stored for 120 days, except for those analyzed at the initial storage time point (day 2), which were kept for up to 2 days at 4.0°C. All other samples were transferred from the freezer to a 4.0°C refrigerated incubator to thaw for 48 hours prior to analysis on their designated testing days. Thaw loss, texture, color, and oxidation measurements were recorded in triplicate on days 2, 15, 30, 60, 90,

and 120 of storage for the vacuum-packaged control boudin containing no rosemary extract (CRV), vacuum-packaged boudin containing 40 ppm carnosic acid rosemary extract (R40V), and vacuum-packaged boudin containing 60 ppm carnosic acid rosemary extract (R60V). On day 120, the control non-vaccuum-packaged (CRNV), 40 ppm carnosic acid rosemary extract non-vaccuum-packaged (R40NV), and 60 ppm carnosic acid rosemary extract non-vaccuum-packaged (R60NV) were also tested using the same experimentation so that the 2-gallon bag storage method could be compared to the vacuum-packaging.

3.3.2.2. Boudin Analysis

3.3.2.2.1. Sensory analysis of smoked salmon boudin

The CRV, R40V, and R60V boudin sausages were all evaluated in a consumer liking test to determine preferences for color, texture, aroma, and the flavor profiles of smoked salmon, rosemary, and spiciness. Testing protocols were approved by the North Carolina State University Institutional Review Board for the Protection of Human Subjects in Research Regulations beforehand (reference #28233). Consumer acceptance testing was all conducted within one day, and every consumer tasted a sample of all three treatments. Samples were administered in clear plastic cups with 3-digit blinding codes so that consumers did not know which sample they were tasting. However, each sample was administered in the order CRV, R40V, and R60V so that a stronger rosemary flavor would not skew results if provided before a sample with lower rosemary dosage. Participants were recruited using a survey database, and all consumers indicated they did not have a seafood allergy. Compensation was provided to participants in the form of frozen 3 oz smoked salmon packs obtained from Acme Smoked Fish Corporation, Wilmington, NC. Demographic information is included in Appendix A.

Samples were prepared as described in section 3.3.2.1. Sausage treatments were made in duplicate, cooked, and frozen 7 days prior to the sensory data collection day, and set out so that they had been thawing for 48 hours at the time they were reheated to prepare to serve to participants. Sausages were randomly selected between duplicates. Before serving to participants, sausages were reheated to at least 165°F during a 13 minute cook period in a skillet containing 157.7 mL (about ⅔ cup) water. Afterward, sausages were cut open to break the casing, and the filling was allocated into styrofoam cups with 3 digit blinding codes in approximately 30 g samples measured via ice cream scoop, and kept at 165°F in a warming cabinet prior to being served to participants.

A total of 107 panelists filled out the ballot described in Appendix B. They evaluated overall appearance liking, overall color liking, overall flavor liking, overall liking, aroma liking, rosemary liking, texture liking, heat/spiciness liking, purchase intent, outside color JAR, aroma JAR, smoked salmon flavor JAR, heat/spiciness JAR, rosemary flavor JAR, firmness JAR, in addition to being asked to rank all three treatments from best (1) to worst (3).

All statistical analysis was conducted using XLSTAT (XLSTAT version 2025.1.3; Addinsoft, Paris, France) at a 95% confidence interval ($p < 0.05$). Liking questions were scored on a 9 point hedonic scale where 1 = dislike extremely and 9 = like extremely. Statistical lettering was determined using by ANOVA with Fisher's LSD post-hoc test. JAR questions were scored on a 5 point scale where 1 or 2 = too little, 3 = just about right, and 4 or 5 = too much, and statistical lettering was determined by Chi-square with Marascuilo procedure. Purchase Intent was also on a 5 point scale, with 1 or 2 = would not purchase, 3 = maybe/maybe not purchase, and 4 or 5 = would purchase, and statistical lettering was determined using Kruskal-Wallis testing with Dunn's post-hoc test. Meanwhile, statistical lettering of ranking was determined by

Kruskal-Wallis testing with Dunn's post-hoc test. Samples marked "a" are considered higher than "b".

3.3.2.2.2. Cook loss of smoked salmon boudin

The cook loss was conducted using a modification of the method of Pietrasik & Soladoye (2021). Three sausage treatments were made in triplicate, including a control with 0 ppm rosemary extract (CR), a treatment with 40 ppm carnosic acid rosemary extract (R40), and one containing 60 ppm carnosic acid rosemary extract (R60). Each of the 9 batches were weighed individually for the raw batch treatment weight after stuffing and prior to cooking, then steamed for 30 minutes to reach 72.22°C. Sausages were allowed to cool to 4.44°C overnight, and then re-weighed. Cook loss was measured as a percentage of the initial raw sausage weight lost in the cooking process, as depicted in Equation 1.

$$Cook\ loss\ (\%) = \left(\frac{Weight\ before\ cooking - Weight\ after\ cooking}{Weight\ before\ cooking}\right) \text{ x } 100 \quad (1)$$

3.3.2.2.3. Thaw loss of smoked salmon boudin

Thaw loss was measured using a modification of the method of Stormo & Skåra (2021). Individual cooked sausages coils were weighed prior to freezing (m_0), and reweighed after thawing for 48 hours in sealed packaging within an incubator set to 4°C (m_s), as depicted in Equation 2.

$$\text{Thaw loss } (\%) = [(m_o - m_s)/m_o] \ 100 \quad (2)$$

3.3.2.2.4. Lipid oxidation of smoked salmon boudin

Lipid oxidation was measured using the TBARs assay method of Sanchez-Gutierrez et al. (2024), with modifications. Sausages were blended in a food processor (Model 702R, Hamilton Beach, Glen Allen, VA) to ensure homogeneity before measuring out 1 g and homogenizing with 6 mL trichloroacetic acid (TCA) extraction solution (7.5% TCA, 0.1% propyl gallate, and 0.1%

EDTA) using a rotary tool (Dremel 3000, Dremel, Mount Prospect, IL) with a Biospec Tissue Tearor Homogenizer attachment (Biospec Products Inc., Bartlesville, OK) at a rotor speed of 35,000 rpm for 30 seconds in a 15 mL tube. Samples were then centrifuged at 2,590 × *g* for 10 minutes. Supernatant was filtered through filter papers (Whatman 1, Cytiva, Marlborough, MA) and 1.5 mL filtrate was mixed with an equal volume of 0.02 M thiobarbituric acid (TBA) and heated for 40 minutes in a 100°C water bath. After samples were cooled, absorbance was measured using a spectrophotometer (Genesys 30, Thermo Scientific, Waltham, MA) at 532 nm against a blank (1.5 mL TCA extraction solution and 1.5 mL TBA solution). A standard curve of 0 to 0.00625 µmoles/mL 1, 1, 3, 3-tetraethoxypropane (TEP) was created and mm of malondialdehyde (MDA) per kg oil is the method of result expression. The average values of two TEP standard curves were used to form a calibration curve, and results were also expressed as mg MDA equivalent/kg sample. Experiments were conducted in triplicate.

3.3.2.2.5. Color of smoked salmon boudin

Color was measured using a Konica Minolta CM-5 Spectrophotometer (Tokyo, Japan) with a 10° observer angle, 8 mm aperture, and illuminant D65. Color measurements (*L**, *a**, *b**) were taken once the sausages reached room temperature. Per each of the replications, 6 samples of the boudin filling were analyzed, for a total of 18 color readings for each treatment. Samples were placed on Form P300-4NT Clear Polyester Panel purchased from Leneta (Mahwah, NJ) to prevent samples from causing destruction to the colorimeter. SCE mode was applied to cancel any color-altering effects from the clear panel.

3.3.2.2.6. Texture of smoked salmon boudin

Sausage ends were cut off before 20 g of sausage filling was squeezed out of the casing by hand onto a paper plate and left to reach room temperature before measuring. For each batch,

5 sample repetitions were completed. A compression test was performed with a TA-025n probe (Texture Technologies, Hamilton, MA) attached to a TA.XTplusC Texture Analyzer (Stable Micro System, UK) to measure firmness (g), resilience (%), and springback (%). The following test settings were applied as recommended by the manufacturer: test speed = 3.00 mm/second; post-test speed = 3.00 mm/second; target mode = gap; gap = 3.00 mm; trigger type = button. Measurements were analyzed using Exponent Connect Software (Stable Micro Systems, UK).

3.3.3 Statistical Analysis

Each analysis was performed using SAS software (Version 9.4, SAS Institute Inc., Cary, NC). A two-way ANOVA with Tukey's post-hoc test was performed for values of analyses which evaluated vacuum-packaged treatments during 2-120 days of frozen storage. Additionally, a two-way ANOVA with Tukey's post-hoc test was performed for values of analyses which evaluated vacuum-packaged and non-vacuum-packaged treatments at both day 2 and day 120 of storage. Cook loss values were analyzed using a one-way ANOVA followed by Tukey's post-hoc test.

3.4. Results and Discussion

3.4.1. Sensory analysis of smoked salmon boudin

Overall, there were minimal significant differences when comparing treatments. The textural differences were the primary attribute that demonstrated variation, as the R40V liking and JAR scores were significantly higher than CRV (Table 2). The CRV treatment is suggested to be the least liked, as the ranking and purchase intent were significantly lower than R40V and R60V. The overall liking of the R60V was also significantly greater than CRV.

The JAR scores within each attribute of a given treatment provide further insight into areas of potential concern to consumer liking. Within the CRV treatment, a significant amount of

participants indicated that the smoked salmon flavor was too strong and the heat/spiciness too weak (Table 3). Meanwhile, a significant amount of participants considered the R40V treatment too weak in smoked salmon flavor, and the R60V treatment too light in color (Table 4; Table 5). All treatments were considered too soft in texture by a significant number of participants.

The scores for each treatment were relatively positive, and the ideal treatment formulation will vary for each industry based on individual goals. In regards to the 5-point JAR scale and 9-point hedonic liking scale, each food company will vary in their consideration of what is acceptable. In general, a "just about right" score on the JAR scale suggests that a trait or attribute is not considered by participants to be in need of further alteration of intensity according to the participant (Johnson, 2021a). If the total percentage of participants who indicate an attribute is either "just about right", "slightly too weak", or "slightly too strong" on a 7-point JAR scale is less than 75%, some may consider this an indication that an attribute is grounds for reformulation (Gilbert & Prusa, 2021). Meanwhile, a score of 6 or higher on the 9-point hedonic liking scale indicates the consumer at least "likes slightly" the attribute or product in question (Johnson, 2021b).

If increased consumer liking to address the areas where a statistical amount of consumers found an attribute "too strong" or "too weak" is desired within each formulation, the CRV treatment would likely need a greater quantity of spices, while the R40V treatment could benefit from the addition of a higher concentration of cold-smoked salmon, and an extra ingredient of darker hue may be added to R60V. If texture JAR and liking scores are unfavorable, adding in a binding agent that can maintain tenderness but increase firmness would be ideal. Between the three treatment recipes, R60V and R40V were not statistically different in terms of purchase intent and ranking, however R60V had statistically higher overall liking scores than CRV, and

both R60V and R40V were statistically higher in purchase intent. Therefore, it can be concluded that if consumer liking is a driving factor of which formulation a company should select that R40V or R60V are preferable. Since no developments were made in regards to oxidation prevention within the rosemary extract treatments, there are limitations in selecting a recipe based on ideal quality considerations. Between the R40V and R60V treatments, the quantity of salmon trimmings available to the company is a likely factor to dictate which recipe to further pursue, since the R40V recipe could incorporate an even greater percentage and make increased use of company waste if there is an abundance. However, an increase in trimming content will also likely require an increase in spices to maintain a well-liked ratio. Facilities that have a limited use of trimmings may find the R60V treatment more beneficial. Production companies wanting to use as much cold-smoked salmon trimmings as possible should select R40V since a greater quantity of cold-smoked salmon is found desirable by a significant number of consumers. Company willingness to purchase rosemary extract may make the CRV treatment a more suitable option if the extra cost is considered unnecessary or undesirable. Increasing the quantity of spices would likely improve the “too strong” smoked salmon flavor and overall liking of CRV, and would make a suitable option for companies that were inclined to purchase more spices rather than rosemary extract. However, rosemary extract cost is generally considered to be relatively cheap, so it is more likely that the rosemary extract treatments will align more closely with company goals. Further research on the quality over a longer storage time necessary to make a fully informed decision on the overall success of a product with an expected shelf life greater than 120 days.

3.4.2. Cook loss and thaw loss of smoked salmon boudin

Minimization of cook loss is an important aspect of meat product development, as the loss of oil, water, and other materials creates more waste for companies to handle and can be considered a loss of revenue. CRV, R40V, and R60V did not demonstrate significant differences in cook loss, having respective values of 13.20%±8.89%, 9.53%±0.14%, and 9.17%±0.87% (Table 6). Once a meat product has been cooked, packaged, and frozen for consumers to purchase, it is expected that there will be some excess liquid if the product is thawed. Thaw loss changes over time are necessary to investigate when evaluating shelf life, as it provides understanding of how the quality of a food item holds up over time. In regards to thaw loss when comparing CRV, R40V, and R60V at each storage time point, differences did not emerge until CRV thaw loss was significantly greater than R60V on day 30 (Table 7). During days 60 and 90, no differences between the three treatments occurred, however at day 120, R40V had greater thaw loss than CRV and R60V. Meanwhile, when evaluating the same treatment over time, thaw loss significantly increased from day 2 to day 30 in the control treatment, day 2 to day 15 in the R40V treatment, and day 2 to day 90 in the R60V treatment. However, only R40V experienced greater within treatment loss at day 120 compared to day 2.

A study that analyzed how the freezing time and thawing time affected the shelf life of ostrich steaks vacuum-packaged and frozen at either −20°C or −25°C for 4 weeks found that as frozen storage time increased, the moisture loss did as well (Leygonie & Hoffman, 2020). This somewhat aligns with the findings of this study. All of the treatments significantly increased in thaw loss at some time point over the course of 120 days. However, in the current study, the thaw loss measured at day 120 recorded for R40V remained the only significant increase within treatments. Freezing causes the formation of ice crystals within meat fibres, which can result in damage to the protein structure as moisture is drawn from the protein structure via osmotic

pressure as the freezing process causes a greater concentration of solutes to surround the structure. The damage disables the protein from uptaking moisture again during the thawing process, leading to liquid loss (Leygonie et al., 2012). The sudden increase in thaw loss of CRV compared to R60V at day 30 may be attributed to an uneven distribution of ice crystals for different samples during storage in the manual defrost freezer. The minor temperature fluctuations resulting from regular use of the freezer could have led to localized thaw-refreeze cycles or ice crystal reorganization. Water migration and protein denaturation caused by intermittent freezing and thawing can progress non-linearly, contributing to fluctuations in thaw loss during frozen storage (Zhang et al., 2022). Despite these variations, the observed thaw loss values remained relatively low overall when compared to previous studies. Kluth et al. (2021) reported that raw turkey meat sausages stored at −18°C for 12 and 24 weeks had thaw losses of 2.6%±0.5% and 1.9%±0.2%, respectively. In another study, cooked fish sausages made with the addition of textured soy protein were stored at −18°C and evaluated for quality during 180 days (You et al., 2022). Thaw loss values were estimated from the graphical data to be approximately 3%, 7%, 15%, and 16% at days 7, 30, 120, and 180, respectively. Given the limited magnitude of thaw loss change in our smoked salmon boudin sausages, a longer storage time may be necessary to capture more distinct trends and treatment responses.

One treatment group of sausages was non-vacuum-packaged, and tested on day 120 to compare with the first and last storage days of the vacuum-package sausages. CRV, R40V, and R60V represent the vacuum-packaged treatments, while CRNV, R40NV, and R60NV represent the treatments that were sealed in ambient air conditions. In regards to thaw loss, when comparing all the values among CRV, CRNV, R40V, R40NV, R60V, and R60NV on a given day, there were no differences on day 2 (Table 8). However on day 120, CRNV and R60NV had

statistically lower thaw loss than the R40V vacuum-packaged treatment. When comparing within the same treatments from day 2 to 120, there was a significant increase in thaw loss in all the vacuum-packaged treatments, as well as the R60NV treatment. CRNV and R40NV did not change. The mechanical pressure applied to the vacuum-packaged sausages during the packaging process may have contributed to the increase in thaw loss. Stasiewicz et al. (2014) evaluated the drip loss of pork and beef sausages over 15 days in various MAP and vacuum-packaged conditions. They found that the drip loss was significantly greater in the vacuum-packaged conditions compared to gas conditions, and was explained by the mechanical pressure applied during air removal.

3.4.3. Lipid oxidation of smoked salmon boudin

Exposure to oxygen promotes lipid oxidation, which can lead to rancidity in meat products. The formation of thiobarbituric acid reactive substances (TBARS) over time serves as an indicator of oxidative deterioration in meat products and can help define the timeframe during which they remain suitable for consumption. No differences were observed when comparing CRV, R40V, and R60V to each other at days 2-60 of frozen storage (Table 9). On day 90, the CRV treatment had significantly higher TBARS than the R40V and R60V treatments, which were similar to each other. When comparing within treatments over time, a significant rise in TBARS value was observed for CRV from day 60 to 90, however the other treatments had no significant differences throughout the entire storage time. The increase in TBARS for CRV on day 90 was followed by a significant decrease at day 120 where all samples had statistically similar values again. This trend was also observed by Lima et al. (2021) and Nacak et al. (2021) who respectively evaluated TBARS in sheep meat sausages with pre-emulsified linseed oil stored at −18±1°C for 60 days, and beef-based emulsified sausages containing peanut and

linseed oil emulsion gels stored at 4°C for 90 days. In both cases, certain treatments showed a significant increase in TBARS values from one time point to the next, followed by a subsequent decrease. These results can potentially be related to the decomposition of accumulated malondialdehyde due to interactions with other products like alcohols, ketones, and acids that are not reactive with thiobarbituric acid. Additionally, the interaction between key reactants in the TBARS analysis (e.g., malondialdehyde) and polymers such as proteins may be a contributing factor (Lima et al., 2021). TBARS values for fish products have been related to degrees of rancidity where <0.58 mg/kg is deemed not rancid, 0.58-1.51 mg/kg is considered slightly rancid but acceptable, and >1.51 mg/kg is considered rancid (Zaki et al., 2021). All TBARS values in the current study, with the exception of the day 90 CRV value, fall within the category of slightly rancid but acceptable.

When analyzing the differences between day 2 and day 120 comparing vacuum-packaged and non-vacuum-packaged treatments, there were no changes in regards to TBARS concerning the same treatment over time or different treatments at the same time point (Table 10). de Paula et al. (2011) analyzed the progression of TBARS formation over 151 days in Toscana sausages frozen at −12°C in several packaging in conditions with and without oxygen. It was found that all of the vacuum-packaged treatments experienced a significant change in TBARS at some point over 151 days within a treatment, and was not linear for any of the treatments. The experienced fluctuations in oxidation values over the 151 days but gradually increased over time from the initial TBARS value is much like the findings in this study. It can be concluded that fluctuations in the oxidation measurements of sausage products are to be expected when vacuum packaging over several months. Timeline extensions may be necessary to accommodate each sausage if observation of significant changes are desired.

The lack of significant TBARS changes in the cold-smoked salmon sausages between CRV, R40V, and R60V at each time point other than day 90 differs from some other storage stability research on frozen sausages. Schilling et al. (2018) also evaluated the use of rosemary extract as a preserving agent. They found that the addition of several dosage variations of a rosemary extract and green tea extract blend in pork sausages frozen at −20°C for 3 months before beginning data collection significantly reduced the TBARS value in every treatment compared with the control on the last storage study day, day 21. Additionally, several extract formulation TBARS were also significantly lower than the control values on days 7 and 14. The heat sealing method used to package the pork sausages may have contributed to the dissimilar findings of their study, as oxygen was not removed. Additionally, the higher dosages of rosemary extract (R) and green tea extract (G) (R1500 + G100, R1500 + G200, R1500 + G300, R2000 + G100, R2000 + G200, R2500 + G100, R2500 + G200, and R2500 + G300) of extract may have significantly reduced the TBARS formation (Schilling et al., 2018). Another study that analyzed vacuum-packaged tilapia sausages over 60 days of frozen storage also demonstrated developments in TBARS values over time (Lago et al., 2019). Additionally, salmon oil contains astaxanthin, which is suggested to promote oxidation stability (Seo et al., 2021).

When comparing our results to those of relevant literature, our findings indicate that a four month frozen storage period may not have been sufficient to see changes in TBARS formation. Current studies have primarily focused on using traditional raw meat cuts treated with minimal preserving agents that are expected to be used promptly. In the case of our study, the salmon trimmings had already been thoroughly processed via cold-smoking when they were received. The removal of moisture during the cold-smoking process, high salt content, and antioxidant compounds from the salmon oil can contribute to oxidative stability, and likely

created an environment that is unfavorable for many microorganisms that would otherwise result in an increase in rancidity. The high lipid content of the salmon trimmings was hypothesized to result in expedited oxidation. Further investigation into additional lipid oxidation tests, such as primary and secondation oxidation experimentation, in upcoming research would provide a more complete understanding of the oxidation chemistry. It is also possible that a 4 month shelf life period was not sufficient to detect more pronounced changes in TBARS, and a longer storage period may reveal more pronounced and statistical developments.

TBA tests have also faced some criticism that they can be inaccurate and exhibit low sensitivity (Mozzon et al., 2024). As hydroperoxides degrade during lipid oxidation, aldehydes such as MDA are formed, which can react with specific reagents to produce color changes that are measurable by spectrophotometry (Mozzon et al., 2024). TBARS values primarily reflect MDA formation, although other secondary oxidation products may also contribute, and MDA may not always be the predominant compound formed during lipid oxidation (Mozzon et al., 2024). Inaccuracies can also emerge because food components may react with TBA or form secondary products that produce additional color, potentially leading to overestimation of lipid oxidation (Abeyrathne et al., 2021).

3.4.4. Color of smoked salmon boudin

When comparing CRV, R40V, and R60V at each time point, no differences were observed in regards to *L*, a*,* or *b** values (Table 11). Additionally, no color values changed for R60V when compared across the 120 days. The CRV and R40V treatments did significantly increase from day 2 to day 15 in regards to the *L** value, and both experienced a significant increase in *b** value by day 30 as well. On day 120, the R40V treatment had significantly lower *a** and *b** values than the other two treatments. However, the sensory analysis results suggest

that these changes are not apparent to the human eye, and do not impact consumer perception of the sausage color.

Between day 2 to day 120, the CRV, CRNV, R40V, and R60V values had greater *L** values at the last day of storage (Table 12). None of the six treatments were different from each other at day 2 concerning *L*, a*,* or *b** value, however CRV and R60V were statistically lighter than R40NV on day 120. When evaluating the *a** value, CRNV and R60NV both experienced a decrease from the first to last storage day, indicating a greener hue. On day 120, R60V was statistically more red than R40NV and CRNV. The *b** value did not change for any treatment from day 2 to 120. Some color variation is expected in a product containing multiple ingredients of differing hues, but there was an overall lack of significant color differences among treatments, indicating that none demonstrated superior color stability over the 120-day storage period.

Color is affected by many different parameters, including the matrix ingredients. The cold-smoked salmon boudin sausages included many different ingredients of different colors, and it is to be expected that there will be some variation in the color profile as a result. Non-linear developments in oxidation and thaw loss can impact color as well. Loss of lipid content in the thawing process may result in the loss of astaxanthin, which contributes an orange-red hue (Donoso et al., 2021). Meanwhile, oxidation can result in the breakdown of color pigments upon exposure to light and oxygen, as was the case with the sausage samples in this study as they were allowed to come to room temperature before measurements were recorded (United States Department of Agriculture, 2013). Significant fluctuations were observed for both the thaw loss and TBARS values for the sausage treatments, and may explain the similar findings in regards to the *LAB* color values.

3.4.5. Texture of smoked salmon boudin

Assessing texture throughout the shelf life is critical, as instrumental measurements provide insight into potential changes that may influence consumer acceptance over time. As sausages lose liquid content, it is expected that an increase in firmness, resilience, and springback will subsequently occur. The CRV and R40V treatments significantly increased in relation to all of these texture values from days 2 to 15, whereas R60V did not significantly increase in firmness until day 60, and springback on day 15 (Table 13). The firmness values of CRV and R60V significantly decreased on day 60. The R40V treatment also experiences a significant decrease in resilience value on day 30. Typically, after a significant change in texture, most treatments remained stagnant at the following measurements.

When comparing treatments at each storage time point, R60V exhibited significantly greater firmness than the other treatments on day 2, whereas R40V showed significantly greater firmness from days 30 to 120. The springback value of R40V was significantly higher than that of CRV on day 90, and its resilience was significantly greater than that of CRV on days 15, 90, and 120. While moisture loss association with firmness, resilience, and springback textural changes are not widely researched, a loss of moisture is overall acknowledged to impact the texture, and in several cases texture changes such as increase in hardness have been attributed to a loss of moisture (Cook et al., 2024; Liu et al., 2025, Simunovic et al., 2021). The exact cause of the increase in texture values within the R40V treatments needs to be explored with further research, such as proximate composition.

For both vacuum-packaged and non-vacuum-packaged sausages, all texture parameter values generally increased significantly from days 2 to 120, with the exceptions of firmness and resilience in R60V, firmness in R60NV, and resilience in CRV (Table 14). On day 2, the firmness values of R60V and R60NV were significantly higher than those of the other

treatments. On day 120, CRNV and R40V were significantly firmer than all other treatments, while CRV and R60NV were also significantly firmer than R60V. In addition, CRNV and R40NV exhibited significantly greater resilience values than R60V and CRV. The R40NV springback value was significantly higher than those of all other treatments except R60NV, which was also significantly higher than CRV and R60V.

Increase in thaw loss may have contributed to some textural changes, as well as high variability within the sausage matrix. Although homogenized, the boudin sausage is a multi-component mixture and may have differences in the proximate composition and areas of localized water retention that can contribute to textural changes (Colfrades et al., 2000; Zhu et al., 2025). Representative samples are crucial for quality texture data, suggesting that a highly variable sample that is hard to replicate may be limited in the exact uniformity between samples within a treatment or between different treatments (Stable Micro Systems, 2025).

The texture findings somewhat align with the sensory analysis findings in which the texture liking and JAR scores of the R40V treatment were significantly higher than CRV, however it should be noted that the sensory analysis was conducted on day 15 of frozen storage, on day 15 that there were no texture differences between treatments. The higher resilience values observed for R40V at day 15 of storage may indicate a more cohesive and elastic matrix, which could align with its higher sensory texture ratings; however, instrumental and sensory texture relationships are often complex for multi-component products like boudin. Further research is warranted to clarify the analytical differences in texture among treatments and to determine whether consumers can perceive textural changes between freshly prepared boudin and those stored frozen for extended periods.

3.5. Conclusions

Significant analytical differences were observed among CR, R40, and R60 smoked salmon boudin sausages over 120 days of frozen storage, with respect to thaw loss, lipid oxidation (TBARS), color, and texture. However, the numerical differences were small, suggesting limited practical impact for consumers. Overall, TBARS and thaw loss values remained within acceptable ranges compared with the literature.

Sensory evaluation of boudin stored frozen for 7 days and thawed for 2 days indicated that participants generally could not distinguish between treatments in JAR or specific attribute liking scores, except for texture, which was consistently the most disliked attribute. Overall liking and purchase intent trends suggested slight preference for R40 and R60 formulations, although the small numerical differences may not be commercially meaningful. Penalty analysis indicated that CRV boudin lacked heat/spiciness, R40V had insufficient smoked salmon flavor, while R60V was perceived as “too light” in color, which could be addressed with ingredient or processing modifications.

In summary, cold-smoked salmon boudin containing 0, 40, or 60 ppm carnosic acid rosemary extract demonstrated acceptable physicochemical quality over 120 days of frozen storage. Future research could explore longer storage periods and assess potential sensory concerns over time. This boudin also has potential to be evaluated as a refrigerated ready-to-eat product. Production of cold-smoked salmon boudin may be a way for seafood processors to utilize smoked salmon trimmings and generate additional revenue by turning byproduct waste into a sustainable product.

Tables

Table 1. Ingredient makeup of smoked salmon boudin.

Ingredient	**CRV (%)**	**R40V (%)**	**R60V (%)**
Cold-smoked salmon trimmings	34.36	34.34	34.33
Rice	22.90	22.88	22.88
Water	15.15	15.14	15.13
Yellow onion	12.62	12.61	12.61
Green bell pepper	12.62	12.61	12.61
Garlic	0.88	0.88	0.88
Canola oil	0.35	0.35	0.35
Salt	0.33	0.33	0.33
Paprika	0.30	0.30	0.30
Black pepper	0.20	0.20	0.20
Rosemary extract	0	0.07	0.10
Chili powder	0.13	0.13	0.13
Cayenne pepper	0.08	0.08	0.08
Parsley	0.08	0.08	0.08

CRV = control boudin sausage with 0 ppm carnosic acid rosemary extract, R40V = 40 ppm carnosic acid rosemary extract boudin sausage, and R60V = 60 ppm carnosic acid rosemary extract boudin sausage.

Table 2. Consumer acceptance scores for smoked salmon boudin.

		CRV	R40V	R60V
Appearance Liking		6.2[a]	6.5[a]	6.4[a]
Color Liking		6.2[a]	6.3[a]	6.4[a]
Outside Color JAR	Too Light	30.8%[a]	29.9%[a]	30.8%[a]
	Just About Right	61.7%[a]	65.4%[a]	63.6%[a]
	Too Dark	7.5%[a]	4.7%[a]	5.6%[a]
Aroma Liking		6.5[a]	6.8[a]	6.8[a]
Aroma JAR	Too Weak	19.6%[a]	15.9%[a]	14.0%[a]
	Just About Right	66.4%[a]	67.3%[a]	74.8%[a]
	Too Strong	14.0%[a]	16.8%[a]	11.2%[a]
Overall Liking		6.3[b]	6.6[ab]	6.7[a]
Purchase Intent		3.1[b]	3.4[a]	3.5[a]
Overall Flavor Liking		6.4[a]	6.5[a]	6.8[a]
Smoked Salmon Flavor JAR	Too Weak	15.0%[a]	22.4%[a]	15.9%[a]
	Just About Right	63.6%[a]	60.7%[a]	68.2%[a]
	Too Strong	21.5%[a]	16.8%[a]	15.9%[a]
Heat/Spiciness liking		6.5[a]	6.8[a]	6.8[a]
Heat/Spiciness JAR	Not Spicy Enough	24.3%[a]	15.9%[a]	15.9%[a]
	Just About Right	64.5%[a]	73.8%[a]	69.2%[a]
	Too Spicy	11.2%[a]	10.3%[a]	15.0%[a]
Rosemary Liking		5.9[a]	6.0[a]	6.1[a]
Rosemary Flavor JAR	Too Weak	49.5%[a]	43.0%[a]	40.2%[a]
	Just About Right	47.7%[a]	54.2%[a]	57.0%[a]
	Too Strong	2.8%[a]	2.8%[a]	2.8%[a]
Texture Liking		5.5[b]	6.2[a]	6.0[ab]
Firmness JAR	Too Soft	62.6%[a]	37.4%[b]	49.5%[ab]
	Just About Right	36.4%[b]	56.1%[a]	50.5%[ab]
	Too Firm	0.9%[ab]	6.5%[a]	0%[b]
Ranking		2.2[b]	2.0[a]	1.9[a]

CRV = control boudin sausage containing 0 ppm carnosic acid rosemary extract, R40V = boudin sausage containing 40 ppm carnosic acid rosemary extract, and R60V = boudin sausage containing 60 ppm carnosic acid rosemary extract. Data represents 107 consumers. Different lowercase letters (a,b) within a row indicate significant differences ($p < 0.05$).

[1]Liking attributes were scored on a 9-point hedonic scale where 1 = dislike extremely and 9 = like extremely

Table 2 (continued).

[2]JAR questions were scored on a 5-point scale where 1 or 2 = too little, 3 = just about right, and 4 or 5 = too much

Percentage of consumers that selected these options is presented

Statistical lettering was determined by Chi-square with Marascuilo procedure

[3]Purchase Intent question was scored on a 5-point scale where 1 or 2 = would not purchase, 3 = maybe/maybe not purchase, and 4 or 5 = would purchase

Statistical lettering was determined using Kruskal-Wallis testing with Dunn's post-hoc test

[4]Ranking was scored on a 3 point scale with 1 being ranked highest and 3 being ranked lowest.

Statistical lettering was determined using Kruskal-Wallis testing with Dunn's post-hoc test

An "a" indicates a higher ranked sample than a "b"

Table 3. Penalty analysis table for CRV smoked salmon boudin JAR scores.

Variable	Level	%	Mean (Overall Liking)	Mean Drops	Standardized Difference	p-value	Significant
Outside Color	Too light	30.8	6.0	0.6			
	Just About Right	61.7	6.6				
	Too Dark	7.5	5.9	0.7			
Aroma	Too Weak	19.6	5.8	0.9			
	Just About Right	66.4	6.7				
	Too Strong	14.0	5.3	1.5			
Smoked Salmon Flavor	Too Weak	15.0	5.7	1.1			
	Just About Right	63.6	6.8				
	Too Strong	21.5	5.5	1.3	3.9	0.0002	Yes
Heat/Spiciness	Not Spicy Enough	24.3	5.8	0.9	2.6	0.009	Yes
	Just About Right	64.5	6.7				
	Too Spicy	11.2	5.6	1.1			
Rosemary Flavor	Too Weak	49.5	6.1	0.6			
	Just About Right	47.7	6.6				
	Too Strong	2.8	5.7	1.0			
Firmness	Too Soft	62.6	5.9	1.3	4.4	<0.0001	Yes
	Just About Right	36.4	7.2				
	Too Firm	0.9	4.0	3.2			

Table 3 (continued).

CRV = control boudin sausage containing 0 ppm carnosic acid rosemary extract. JAR attributes were scored on a 5-point scale where 1 or 2 = would not purchase, 3 = maybe/maybe not purchase, and 4 or 5 = would purchase. Significant *p* values indicate significant penalties ($p < 0.05$). Sausages were frozen for 8 days and thawed for 48 hours at 40°F prior to data collection.

Table 4. Penalty analysis table for R40V smoked salmon boudin JAR scores.

Variable	Level	%	Mean (Overall Liking)	Mean Drops	Standardized Difference	p-value	Significant
Outside Color	Too light	29.9	6.5	0.2			
	Just About Right	65.4	6.6				
	Too Dark	4.7	6.4	0.2			
Aroma	Too Weak	15.9	6.4	0.4			
	Just About Right	67.3	6.8				
	Too Strong	16.8	6.1	0.7			
Smoked Salmon Flavor	Too Weak	22.4	5.7	1.3	4.3	<0.0001	Yes
	Just About Right	60.7	7.0				
	Too Strong	16.8	6.1	0.9			
Heat/Spiciness	Not Spicy Enough	15.9	6.1	0.4			
	Just About Right	73.8	6.5				
	Too Spicy	10.3	7.6	-1.1			
Rosemary Flavor	Too Weak	43.0	6.4	0.3			
	Just About Right	54.2	6.7				
	Too Strong	2.8	6.3	0.4			
Firmness	Too Soft	37.4	6.1	0.9	3.1	0.003	Yes
	Just About Right	56.1	7.0				
	Too Firm	6.5	6.1	0.8			

Table 4 (continued).

R40V = boudin sausage containing 40 ppm carnosic acid rosemary extract. JAR attributes were scored on a 5-point scale where 1 or 2 = would not purchase, 3 = maybe/maybe not purchase, and 4 or 5 = would purchase. Significant *p* values indicate significant penalties ($p < 0.05$). Sausages were frozen for 8 days and thawed for 48 hours at 40°F prior to data collection.

Table 5. Penalty analysis table for R60V smoked salmon boudin JAR scores.

Variable	Level	%	Mean (Overall Liking)	Mean Drops	Standardized Difference	p-value	Significant
Outside Color	Too light	30.8	6.4	0.6	2.0	0.048	Yes
	Just About Right	63.6	7.0				
	Too Dark	5.6	6.2	0.8			
Aroma	Too Weak	14.0	6.7	0.1			
	Just About Right	74.8	6.9				
	Too Strong	11.2	5.9	0.9			
Smoked Salmon Flavor	Too Weak	15.9	6.4	0.7			
	Just About Right	68.2	7.1				
	Too Strong	15.9	5.5	1.6			
Heat/Spiciness	Not Spicy Enough	15.9	6.4	0.5			
	Just About Right	69.2	6.9				
	Too Spicy	15.0	6.6	0.3			
Rosemary Flavor	Too Weak	40.2	6.7	0.3			
	Just About Right	57.0	6.9				
	Too Strong	2.8	4.7	2.2			
Firmness	Too Soft	49.5	6.4	0.7	2.8	0.006	Yes
	Just About Right	50.5	7.1				
	Too Firm	0.0					

Table 5 (continued).

R60V = boudin sausage containing 60 ppm carnosic acid rosemary extract. JAR attributes were scored on a 5-point scale where 1 or 2 = would not purchase, 3 = maybe/maybe not purchase, and 4 or 5 = would purchase. Significant *p* values indicate significant penalties ($p < 0.05$). Sausages were frozen for 8 days and thawed for 48 hours at 40°F prior to data collection.

Table 6. Cook loss of smoked salmon boudin.

Treatment	Cook loss (%)
CRV	13.20±4.89[a]
R40V	9.53±0.14[a]
R60V	9.17±0.87[a]

Means±SD with the same lowercase letter (a) within a column indicate no significant differences ($p > 0.05$). CRV = control boudin sausage containing 0 ppm carnosic acid rosemary extract, R40V = boudin sausage containing 40 ppm carnosic acid rosemary extract, and R60V = boudin sausage containing 60 ppm carnosic acid rosemary extract.

Table 7. Thaw loss (%) of smoked salmon boudin during 120 days of storage at −18 °C.

Treatment	Time (day)					
	2	**15**	**30**	**60**	**90**	**120**
CRV	0.50 ± 0.42^{Ab}	1.91 ± 0.84^{Aab}	4.21 ± 53.88^{Aa}	2.23 ± 0.92^{Aab}	1.82 ± 0.68^{Ab}	1.91 ± 0.22^{Bb}
R40V	0.27 ± 0.07^{Ab}	2.10 ± 1.00^{Aa}	2.09 ± 0.48^{ABa}	2.64 ± 0.93^{Aa}	2.05 ± 0.42^{Aa}	3.20 ± 0.09^{Aa}
R60V	0.43 ± 0.24^{Ab}	2.22 ± 0.79^{Aab}	2.02 ± 0.74^{Bab}	2.24 ± 0.72^{Aab}	2.65 ± 0.76^{Aa}	1.99 ± 0.77^{Bab}

Means±SD with different lowercase letters (a,b) within a row indicate significant differences ($p < 0.05$). Means±SD with different uppercase letters (A,B) within a column indicate significant differences ($p < 0.05$). CRV = control boudin sausage containing 0 ppm carnosic acid rosemary extract, R40V = boudin sausage containing 40 ppm carnosic acid rosemary extract, and R60V = boudin sausage containing 60 ppm carnosic acid rosemary extract.

Table 8. Thaw loss (%) of vacuum-packaged and non-vacuum-packaged smoked salmon boudin at day 2 and day 120 of storage at −18 °C.

Treatment	Time (day)	
	2	**120**
CRV	0.50 ± 0.42^{Ab}	1.91 ± 0.22^{ABa}
CRNV	0.50 ± 0.42^{Aa}	1.28 ± 0.33^{Ba}
R40V	0.27 ± 0.07^{Ab}	3.20 ± 0.09^{Aa}
R40NV	0.27 ± 0.07^{Aa}	1.85 ± 1.07^{ABa}
R60V	0.43 ± 0.24^{Ab}	1.99 ± 0.77^{ABa}
R60NV	0.43 ± 0.24^{Ab}	1.51 ± 0.30^{Ba}

Means±SD with different lowercase letters (a,b) within a row indicate significant differences ($p < 0.05$). Means±SD with different uppercase letters (A,C) within a column indicate significant differences ($p < 0.05$). CR = boudin sausage containing 0 ppm rosemary extract, CRV = vacuum-packaged CR, CRNV = non-vacuum-packaged CR, R40 = boudin sausage containing 40 ppm carnosic acid rosemary extract, R40V = vacuum-packaged R40, R40NV = non-vacuum-packaged R40, R60 = boudin sausage containing 60 ppm carnosic acid rosemary extract, R60V = vacuum-packaged R60, and R60NV = non-vacuum-packaged R60.

Table 9. TBARS (mg MDA equivalents/kg sample) of vacuum-packaged smoked salmon boudin during 120 days of storage at −18 °C.

Treatment	Time (day)					
	2	**15**	**30**	**60**	**90**	**120**
CRV	1.00 ± 0.14^{Ab}	1.12 ± 0.03^{Ab}	0.81 ± 0.03^{Ab}	0.93 ± 0.00^{Ab}	2.23 ± 0.89^{Aa}	1.06 ± 0.09^{Ab}
R40V	0.97 ± 0.14^{Aa}	1.05 ± 0.14^{Aa}	0.84 ± 0.12^{Aa}	0.91 ± 0.18^{Aa}	0.92 ± 0.04^{Ba}	1.11 ± 0.17^{Aa}
R60V	0.85 ± 0.04^{Aa}	0.94 ± 0.14^{Aa}	0.78 ± 0.12^{Aa}	0.73 ± 0.12^{Aa}	0.93 ± 0.08^{Ba}	1.12 ± 0.30^{Aa}

Means±SD with different lowercase letters (a,b) within a row indicate significant differences ($p < 0.05$). Means±SD with different uppercase letters (A,B) within a column indicate significant differences ($p < 0.05$). CRV = control boudin sausage containing 0 ppm carnosic acid rosemary extract, R40 = boudin sausage containing 40 ppm carnosic acid rosemary extract, and R60 = boudin sausage containing 60 ppm carnosic acid rosemary extract. Sausages were thawed for 48 hours at 4°C prior to data collection. TBARS = thiobarbituric acid reactive substances and MDA = malondialdehyde.

Table 10. TBARS (mg MDA equivalents/kg sample) of vacuum-packaged and non-vacuum-packaged smoked salmon boudin at day 2 and day 120 of storage at −18 °C.

Treatment	Time (day)	
	2	**120**
CRV	1.00 ± 0.14^{Aa}	1.06 ± 0.09^{Aa}
CRNV	1.00 ± 0.14^{Aa}	1.45 ± 0.33^{Aa}
R40V	0.97 ± 0.14^{Aa}	1.11 ± 0.16^{Aa}
R40NV	0.97 ± 0.14^{Aa}	1.33 ± 0.23^{Aa}
R60V	0.85 ± 0.04^{Aa}	1.12 ± 0.30^{Aa}
R60NV	0.85 ± 0.04^{Aa}	1.26 ± 0.52^{Aa}

Means±SD with the same lowercase letter (a) within a row indicate no significant differences ($p > 0.05$). Means±SD with the same uppercase letter (A) within a column indicate no significant differences ($p > 0.05$). CR = boudin sausage containing 0 ppm rosemary extract, CRV = vacuum-packaged CR, CRNV = non-vacuum-packaged CR, R40 = boudin sausage containing 40 ppm carnosic acid rosemary extract, R40V = vacuum-packaged R40, R40NV = non-vacuum-packaged R40, R60 = boudin sausage containing 60 ppm carnosic acid rosemary extract, R60V = vacuum-packaged R60, and R60NV = non-vacuum-packaged R60. Sausages were thawed for 48 hours at 4°C prior to data collection. TBARS = thiobarbituric acid reactive substances and MDA = malondialdehyde.

Table 11. Color of smoked salmon boudin during 120 days of storage at −18 °C.

	Treatment	Time (day)					
		2	**15**	**30**	**60**	**90**	**120**
*L**	CRV	48.57±3.21^{Ab}	51.75±1.65^{Aa}	50.96±2.54^{Aa}	51.06±1.54^{Aa}	50.21±1.85^{Aab}	50.89±1.75^{Aa}
	R40V	48.06±2.22^{Ab}	50.97±3.28^{Aa}	51.29±2.73^{Aa}	50.36±2.53^{Aab}	50.61±1.68^{Aa}	50.23±2.14^{Aab}
	R60V	49.31±2.78^{Aa}	51.41±1.70^{Aa}	50.36±2.64^{Aa}	50.36±2.57^{Aa}	51.39±1.03^{Aa}	51.28±2.87^{Aa}
*a**	CRV	12.04±1.00^{Aa}	12.46±1.07^{Aa}	12.06±1.49^{Aa}	12.71±1.36^{Aa}	12.76±1.60^{Aa}	12.55±1.84^{Aa}
	R40V	12.22±1.61^{Aab}	12.83±2.67^{Aab}	12.78±1.30^{Aab}	12.56±1.32^{Aab}	13.70±1.42^{Aa}	11.82±1.07^{Ab}
	R60V	12.81±1.55^{Aa}	12.72±0.92^{Aa}	13.13±2.83^{Aa}	12.52±1.17^{Aa}	12.55±1.40^{Aa}	13.22±2.90^{Aa}
*b**	CRV	26.13±2.14^{Ab}	28.48±1.92^{Aa}	27.16±1.77^{Aab}	27.82±1.87^{Aab}	27.69±1.56^{Aab}	27.22±2.25^{Aab}
	R40V	25.82±2.44^{Ab}	27.69±2.51^{Aab}	28.43±1.98^{Aa}	27.01±1.60^{Aab}	28.42±1.63^{Aa}	26.19±1.96^{Ab}
	R60V	26.88±2.74^{Aa}	27.90±1.74^{Aa}	28.01±1.60^{Aa}	27.29±1.76^{Aa}	28.17±2.44^{Aa}	27.21±1.82^{Aa}

Means±SD with different lowercase letters (a,b) within a row indicate significant differences ($p < 0.05$). Means±SD with different uppercase letters (A,B) within a column indicate significant differences ($p < 0.05$). CRV = control containing 0 ppm carnosic acid rosemary extract, R40V = boudin sausage containing 40 ppm carnosic acid rosemary extract, and R60V = boudin sausage containing 60 ppm carnosic acid rosemary extract. *L** represents lightness (0 = black, 100 = white), *a** represents the red–green spectrum (positive values indicate more redness), and *b** represents the yellow–blue spectrum (positive values indicate more yellowness). Sausages were thawed for 48 hours at 4°C and then brought to room temperature prior to data collection

Table 12. Color of vacuum-packaged and non-vacuum-packaged smoked salmon boudin at day 2 and day 120 of storage at −18 °C.

	Treatment	Time (day)	
		2	**120**
*L**	CRV	48.57±3.21^{Ab}	50.89±1.75^{Aa}
	CRNV	48.57±3.21^{Ab}	50.57±2.47^{ABa}
	R40V	48.06±2.22^{Ab}	50.23±2.14^{ABa}
	R40NV	48.06±2.22^{Aa}	48.43±2.19^{Ba}
	R60V	49.31±2.78^{Ab}	51.28±2.87^{Aa}
	R60NV	49.31±2.78^{Aa}	49.39±2.32^{ABa}
*a**	CRV	12.04±1.00^{Aa}	12.55±1.84^{ABCa}
	CRNV	12.04±1.00^{Aa}	10.83±1.34^{Cb}
	R40V	12.22±1.61^{Aa}	11.82±1.07^{ABCa}
	R40NV	12.22±1.61^{Aa}	11.39±1.46^{BCa}
	R60V	12.81±1.55^{Aa}	13.22±2.90^{Aa}
	R60NV	12.81±1.55^{Aa}	11.53±1.22^{ABCb}
*b**	CRV	26.13±2.14^{Aa}	27.22±2.25^{Aa}
	CRNV	26.13±2.14^{Aa}	26.66±2.64^{Aa}
	R40V	25.82±2.44^{Aa}	26.19±1.96^{Aa}
	R40NV	25.82±2.44^{Aa}	25.97±2.32^{Aa}
	R60V	26.88±2.74^{Aa}	27.21±1.82^{Aa}
	R60NV	26.88±2.74^{Aa}	25.95±2.66^{Aa}

Means±SD with different lowercase letters (a,b) within a row indicate significant differences ($p < 0.05$). Means±SD with different uppercase letters (A–C) within a column indicate significant differences ($p < 0.05$). CR = boudin sausage containing 0 ppm rosemary extract, CRV = vacuum-packaged CR, CRNV = non-vacuum-packaged CR, R40 = boudin sausage containing 40 ppm carnosic acid rosemary extract, R40V = vacuum-packaged R40, R40NV =

Table 12 (continued).

non-vacuum-packaged R40, R60 = boudin sausage containing 60 ppm carnosic acid rosemary extract, R60V = vacuum-packaged R60, and R60NV = non-vacuum-packaged R60. *L** represents lightness (0 = black, 100 = white), *a** represents the red–green spectrum (positive values indicate more redness), and *b** represents the yellow–blue spectrum (positive values indicate more yellowness). Sausages were thawed for 48 hours at 4°C and then brought to room temperature prior to data collection.

Table 13. Texture of smoked salmon boudin sausage during 120 days of storage at −18 °C.

Treatment		Time (day)					
		2	**15**	**30**	**60**	**90**	**120**
Firmness (g)	CRV	48.61 ± 11.78^{Bc}	235.32 ± 94.02^{Aa}	228.60 ± 70.17^{Ba}	147.06 ± 88.69^{Bb}	210.21 ± 78.20^{Bab}	185.88 ± 70.34^{Bab}
	R40V	54.09 ± 12.77^{Bb}	321.86 ± 211.12^{Aa}	295.19 ± 82.05^{Aa}	281.27 ± 55.21^{Aa}	293.24 ± 22.12^{Aa}	331.78 ± 91.13^{Aa}
	R60V	179.81 ± 103.24^{Aab}	235.07 ± 156.98^{Aa}	227.77 ± 45.75^{Ba}	110.41 ± 72.77^{Bbc}	161.56 ± 127.02^{Babc}	72.78 ± 35.35^{Cc}
Resilience (%)	CRV	5.35 ± 1.08^{Ab}	7.74 ± 1.95^{Ba}	7.45 ± 1.56^{Aa}	7.66 ± 2.28^{Aa}	6.15 ± 1.20^{Bab}	6.11 ± 1.51^{Bab}
	R40V	5.23 ± 0.97^{Ac}	10.11 ± 2.12^{Aa}	7.62 ± 2.01^{Ab}	8.42 ± 2.45^{Aab}	8.79 ± 1.23^{Aab}	8.54 ± 2.29^{Aab}
	R60V	6.16 ± 1.88^{Aa}	8.57 ± 2.45^{ABa}	7.30 ± 1.77^{Aa}	7.84 ± 2.68^{Aa}	6.88 ± 1.75^{Ba}	6.66 ± 2.84^{ABa}
Springback (%)	CRV	0.84 ± 0.25^{Ab}	1.19 ± 0.35^{Aa}	1.23 ± 0.37^{Aa}	1.14 ± 0.25^{Aab}	1.05 ± 0.27^{Bab}	1.09 ± 0.33^{Aab}
	R40V	0.78 ± 0.18^{Ab}	1.46 ± 0.46^{Aa}	1.17 ± 0.22^{Aab}	1.37 ± 0.48^{Aa}	1.42 ± 0.34^{Aa}	1.38 ± 0.44^{Aa}
	R60V	0.88 ± 0.15^{Ab}	1.41 ± 0.49^{Aa}	1.13 ± 0.24^{Aab}	1.51 ± 0.68^{Aa}	1.22 ± 0.26^{ABab}	1.91 ± 0.46^{Aab}

Means±SD with different lowercase letters (a,b) within a row indicate significant differences ($p < 0.05$). Means±SD with different uppercase letters (A–C) within a column indicate significant differences ($p < 0.05$). CR = boudin sausage containing 0 ppm rosemary extract, CRV = vacuum-packaged CR, CRNV = non-vacuum-packaged CR, R40 = boudin sausage containing 40 ppm carnosic acid rosemary extract, R40V = vacuum-packaged R40, R40NV = non-vacuum-packaged R40, R60 = boudin sausage containing 60 ppm carnosic acid rosemary extract, R60V = vacuum-packaged R60, and R60NV = non-vacuum-packaged R60. Sausages were thawed for 48 hours at 4°C and then brought to room temperature prior to data collection. Firmness is the force required to compress the sample, resilience is the 'real time' recovery of the material, whereas the springback is the recovery after a rest period between compressions.

Table 14. Texture of vacuum-packaged and non-vacuum-packaged smoked salmon boudin at day 2 and day 120 of storage at −18 °C.

	Treatment	Time (day)	
		2	120
Firmness	CRV	48.61 ± 11.78^{Bb}	185.88 ± 70.34^{Ba}
	CRNV	48.61 ± 11.78^{Bb}	407.52 ± 113.43^{Aa}
	R40V	54.09 ± 12.77^{Bb}	331.78 ± 91.13^{Aa}
	R40NV	54.09 ± 12.77^{Bb}	125.18 ± 67.95^{BCa}
	R60V	179.81 ± 103.24^{Aa}	72.78 ± 35.35^{Cb}
	R60NV	179.81 ± 103.24^{Aa}	197.78 ± 45.17^{Ba}
Resilience	CRV	5.35 ± 1.08^{Aa}	6.11 ± 1.51^{Ca}
	CRNV	5.35 ± 1.08^{Ab}	9.08 ± 2.15^{Aa}
	R40V	5.23 ± 0.97^{Ab}	8.54 ± 2.29^{ABa}
	R40NV	5.23 ± 0.97^{Ab}	9.19 ± 1.59^{Aa}
	R60V	6.16 ± 1.88^{Aa}	6.66 ± 2.84^{BCa}
	R60NV	6.16 ± 1.88^{Ab}	8.73 ± 1.32^{ABa}
Springback	CRV	0.84 ± 0.25^{Ab}	1.09 ± 0.33^{Ca}
	CRNV	0.84 ± 0.25^{Ab}	1.38 ± 0.40^{BCa}
	R40V	0.78 ± 0.18^{Ab}	1.38 ± 0.44^{BCa}
	R40NV	0.78 ± 0.18^{Ab}	1.93 ± 0.52^{Aa}
	R60V	0.88 ± 0.15^{Ab}	1.19 ± 0.46^{Ca}
	R60NV	0.88 ± 0.15^{Ab}	1.67 ± 0.33^{ABa}

Means±SD with different lowercase letters (a,b) within a row indicate a significant difference ($p < 0.05$). Means±SD with different uppercase letters (A–C) within a column indicate a significant difference ($p < 0.05$). CR = boudin sausage containing 0 ppm rosemary extract, CRV = vacuum-packaged CR, CRNV = non-vacuum-packaged CR, R40 = boudin sausage containing 40 ppm carnosic acid rosemary extract, R40V = vacuum-packaged R40, R40NV = non-vacuum-packaged R40, R60 = boudin sausage containing 60 ppm carnosic acid rosemary extract, R60V = vacuum-packaged R60, and R60NV = non-vacuum-packaged R60. Sausages were thawed for 48 hours at 4°C and then brought to room temperature prior to data collection. Texture measured via compression test with a TA-025n probe. Firmness is determined as the sample is being actively pressed. Resilience is the 'real time' recovery of the material, whereas the springback is the recovery after the material has had time between compressions.

REFERENCES

Abeyrathne, E.D.N, Nam, K., & Ahn, D. U. (2021). Analytical methods for lipid oxidation and antioxidant capacity in food systems. *Antioxidants, 10*(10), 1587. https://doi.org/10.3390/antiox10101587

Agricultural Research Service. (2023). Food data central-smoked salmon. *United States Department of Agriculture. https://fdc.nal.usda.gov/food-details/2594868/nutrients*

American Heart Association. (2024). Fish and omega-3 fatty acids. *American Heart Association.* https://www.heart.org/en/healthy-living/healthy-eating/eat-smart/fats/fish-and-omega-3-fatty-acids

Braghieri, A., Piazzolla, N., Carlucci, A., Bragaglio, A., & Napolitano, F. (2016). Sensory properties, consumer liking and choice determinants of Lucanian dry cured sausages. *Meat Science*, *111*, 122–129. https://doi.org/10.1016/j.meatsci.2015.09.003

Choe, E., & Min, D. B. (2006). Chemistry and reactions of reactive oxygen species in foods. *Critical Reviews in Food Science and Nutrition*, *46*(1), 1–22. https://doi.org/10.1080/10408390500455474

Cofrades, S., Guerra, M. A., Carballo, J., Fernández-Martín, F., & Colmenero, F. J. (2000). Plasma protein and soy fiber content effect on bologna sausage properties as influenced by fat level. *Journal of Food Science*, *65*(2), 281–287. https://doi.org/10.1111/j.1365-2621.2000.tb15994.x

Cook, D., Northcutt, JK. & Dawson, P. (2024). Thawing affects on the quality of animal and plant-based sausage patties. *HSOA Journal of Food Science & Nutrition.* https://www.heraldopenaccess.us/openaccess/thawing-effects-on-the-quality-of-animal-and-plant-based-sausage-patties.

Coppola, D., Lauritano, C., Palma Esposito, F., Riccio, G., Rizzo, C., & de Pascale, D. (2021). Fish waste: from problem to valuable resource. *Marine drugs*, *19*(2), 116. https://doi.org/10.3390/md19020116

de Paula, R., Colet, R., de Oliveira, D., Valduga, E., & Treichel, H. (2011). Assessment of different packaging structures in the stability of frozen fresh brazilian toscana sausage. *Food and Bioprocess Technology*, *4*(3), 481–485. https://doi.org/10.1007/s11947-010-0350-4

Endara, P., Wiedmann, M., & Adalja, A. (2023). Consumer willingness to pay for shelf life of high-temperature, short-time-pasteurized fluid milk: Implications for smart labeling and food waste reduction. *Journal of Dairy Science*, *106*(9), 5940–5957. https://doi.org/10.3168/jds.2022-22968

Environmental Protection Agency. (2015). Wasted food scale [overviews and factsheets]. *Environmental Protection Agency.*

Federal Food and Drug Administration. (2025). Food loss and waste. *Federal Food and Drug Administration.* https://www.fda.gov/food/consumers/food-loss-and-waste

Galan P, Kesse-Guyot E, Czernichow S, Briancon S, Blacher J, Hercberg S. (2010). Effects of B vitamins and omega 3 fatty acids on cardiovascular diseases: a randomised placebo controlled trial. *British Medical Journal*. 341:c6273.

Gilbert K. & Prusa, K. (2021). JAR attribute testing. *Iowa State University.* https://iastate.pressbooks.pub/foodproductdevelopment/chapter/jar-attribute-testing/

Girolami, A., Napolitano, F., Faraone, D., Di Bello, G., & Braghieri, A. (2014). Image analysis with the computer vision system and the consumer test in evaluating the appearance of

Lucanian dry sausage. *Meat Science*, *96*(1), 610–616. https://doi.org/10.1016/j.meatsci.2013.08.006

Hazen, C. (2005). Antioxidants “meat” needs. *Food Product Design*, *15*(1), 61-68.

Hoelscher, H., Fell, E. L., Colet, R., Nascimento, L. H., Backes, Â. S., Backes, G. T., Cansian, R. L., Valduga, E., & Steffens, C. (2024). Antioxidant activity of rosemary extract, acerola extract and a mixture of tocopherols in sausage during storage at 8°C. *Journal of food science and technology*, *61*(1), 69–83. https://doi.org/10.1007/s13197-023-05815-y

Hou, Y., Shavandi, A., Carne, A., Bekhit, A. A., Ng, T. B., Cheung, R. C. F., & Bekhit, A. E. A. (2016). Marine shells: Potential opportunities for extraction of functional and health-promoting materials. *Critical Reviews in Environmental Science and Technology*, *46*(11–12), 1047–1116. https://doi.org/10.1080/10643389.2016.1202669

Johnson, M. (2021a). Just About Right Scales. *Society of Sensory Professionals*. https://www.sensorysociety.org/knowledge/sspwiki/Pages/Just%20About%20Right%20Scales.aspx

Johnson, M. (2021b). The 9-point hedonic scale. *Society of Sensory Professionals,* https://www.sensorysociety.org/knowledge/sspwiki/Pages/The%209-point%20Hedonic%20Scale.aspx

Kapoor, B., Kapoor, D., Gautam, S., Singh, R., & Bhardwaj, S. (2021). Dietary polyunsaturated fatty acids (Pufas): Uses and potential health benefits. *Current Nutrition Reports*, *10*(3), 232–242. https://doi.org/10.1007/s13668-021-00363-3

Kluth, I.-K., Teuteberg, V., Ploetz, M., & Krischek, C. (2021). Effects of freezing temperatures and storage times on the quality and safety of raw turkey meat and sausage products.

Poultry Science, 100(9), 101305. https://doi.org/https://doi.org/10.1016/j.psj.2021.101305

Lago, A. M. T., Teixeira, J. T., Olímpio, B. J. G., Schiassi, M. C. E. V., Pimenta, C. J., & Sousa Gomes, M. E. (2019). Shelf life determination of frozen fish sausage produced with fillet and minced fish derived from the Nile tilapia processing. *Journal of Food Processing and Preservation*, *43*(7). https://doi.org/10.1111/jfpp.13984

Leung, K. S., Galano, J. M., Durand, T., & Lee, J. C. (2018). Profiling of omega-polyunsaturated fatty acids and their oxidized products in salmon after different cooking methods. *Antioxidants (Basel, Switzerland)*, *7*(8), 96. https://doi.org/10.3390/antiox7080096

Leygonie, C., T. J. Britz, and L. C. Hoffman. 2012. Meat quality comparison between fresh and frozen/thawed ostrich *M. iliofibularis*. *Meat Science.* 91:364–368. doi: https://doi.org/10.1016/j.meatsci.2012.02.020

Leygonie, C., & Hoffman, L. C. (2020). Effect of different combinations of freezing and thawing rates on the shelf-life and oxidative stability of ostrich moon steaks (*M. Femorotibialis medius*) under Retail Display Conditions. *Foods (Basel, Switzerland)*, *9*(11), 1624. https://doi.org/10.3390/foods9111624

Lima, T. L. S., Costa, G. F. d., Cruz, G. R. B. d., Araújo, Í. B. d. S., Ribeiro, N. L., Ferreira, V. C. d. S., Silva, F. A. P. d., & Filho, E. M.B. (2021). Effect of storage time on colorimetric, physicochemical, and lipid oxidation parameters in sheep meat sausages with pre-emulsified linseed oil. *Food Science and Technology, 42*, e24721.

Liu, G., Fan, J., Wang, L., Liang, M., Xie, C., & Kang, Z. (2025). Mitigating quality deterioration of reduced-fat pork sausages during cold storage via resistant starch

incorporation: Gel properties and protein conformation study. *Gels*, *11*(10), 763. https://doi.org/10.3390/gels11100763

Liu, Q., Yan, Z., & Zhou, J. (2017). Consumer Choices and Motives for Eco-Labeled Products in China: An Empirical Analysis Based on the Choice Experiment. *Sustainability*, *9*(3), 331. https://doi.org/10.3390/su9030331

Loussouarn, M., Krieger-Liszkay, A., Svilar, L., Bily, A., Birtić, S., & Havaux, M. (2017). Carnosic acid and carnosol, two major antioxidants of rosemary, act through different mechanisms. *Plant Physiology*, *175*(3), 1381–1394. https://doi.org/10.1104/pp.17.01183

Lunn J & Theobald HE. (2006). The health effects of dietary unsaturated fatty acids. *British Nutrition Foundation*, 31(3):178–224.

Mozzon, M., Foligni, R., Mannozzi, C., & Vittori, S. (2024). Assessment of lipid oxidation in fish and fish products processed by cold plasma technologies. *Applied Food Research*, *4*(2), 100646. https://doi.org/10.1016/j.afres.2024.100646

Nacak, B., Öztürk-Kerimoğlu, B., Yıldız, D., Çağındı, Ö., & Serdaroğlu, M. (2021). Peanut and linseed oil emulsion gels as potential fat replacer in emulsified sausages. *Meat Science, 176*, 108464.

National Cancer Institute. (2010). Reactive oxygen species. *National Cancer Institute.* https://www.cancer.gov/publications/dictionaries/cancer-terms/def/reactive-oxygen-species

Nieto, G., Ros, G., & Castillo, J. (2018). Antioxidant and Antimicrobial Properties of Rosemary (*Rosmarinus officinalis,* L.): A Review. *Medicines (Basel, Switzerland)*, *5*(3), 98. https://doi.org/10.3390/medicines5030098

Pan, N., Zhao, X., Luan, C., Bian, C., Yang, Y., Dong, S., Gao, K., Meng, Q., & Sha, S. (2025). Influence of different frozen temperatures and time on the oxidation reaction and mitochondrial integrity of pork. *LWT- Food Science and Technology*, *231*, 118249. https://doi.org/10.1016/j.lwt.2025.118249

Qiu, Z. Z., & Chin, K. B. (2020). Physicochemical properties and shelf-life of regular-fat sausages with various levels of grape tomato powder prepared by different drying methods. *Food Science of Animal Resources*, *40*(5), 722–733. https://doi.org/10.5851/kosfa.2020.e47

Sánchez-Escalante, A., Djenane, D., Torrescano, G., Beltrán, J. A., & Roncalés, P. (2001). The effects of ascorbic acid, taurine, carnosine and rosemary powder on colour and lipid stability of beef patties packaged in modified atmosphere. *Meat Science*, *58*(4), 421–429. https://doi.org/10.1016/S0309-1740(01)00045-6

Sanchez-Gutierrez, M., Rivera-Ruiz, A., Sanchez-Fernandez, L., Rodriguez, A., Carrasco, E. (2024). Evaluation of microbial and oxidative changes of 100% Iberian Spanish salchichon in contact with composite olive-leaf-extract food films and vacuum-packaged. *Future Foods,* 10(100417), 2666-8335. https://doi.org/10.1016/j.fufo.2024.100417.

Schilling, M. W., Pham, A. J., Williams, J. B., Xiong, Y. L., Dhowlaghar, N., Tolentino, A. C., & Kin, S. (2018). Changes in the physiochemical, microbial, and sensory characteristics of fresh pork sausage containing rosemary and green tea extracts during retail display. *Meat Science*, *143*, 199–209. https://doi.org/10.1016/j.meatsci.2018.05.009

Seo, J.-K., Parvin, R., Park, J., & Yang, H.-S. (2021). Utilization of Astaxanthin as a Synthetic Antioxidant Replacement for Emulsified Sausages. *Antioxidants*, *10*(3), 407. https://doi.org/10.3390/antiox10030407

Sharma, H., Mendiratta, S. K., Agrawal, R. K., Gurunathan, K., Kumar, S., & Singh, T. P. (2017). Use of various essential oils as bio preservatives and their effect on the quality of vacuum packaged fresh chicken sausages under frozen conditions. *LWT - Food Science and Technology*, *81*, 118–127. https://doi.org/10.1016/j.lwt.2017.03.048

Stable Micro Systems. (2025). Texture measurement: How to optimise your sample preparation for consistent results. *Stable Micro Systems.* https://www.stablemicrosystems.com/blog/2025/texture-measurement-how-to-optimise-your-sample-preparation-for-consistent-results/#:~:text=Sample%20preparation%20guidelines,homogeneous%20and%20non%2Duniform%20products.

Stangierski, J., Rezler, R., & Kawecki, K. (2023). An analysis of changes in the physicochemical and mechanical properties during the storage of smoked and mould salamis made in Poland. *Molecules*, *28*(13), 5122. https://doi.org/10.3390/molecules28135122

Stasiewicz, M., Lipiski, K., & Cierach, M. (2014). Quality of meat products packaged and stored under vacuum and modified atmosphere conditions. *Journal of Food Science and Technology, 51*(9), 1982-1989. doi:https://doi.org/10.1007/s13197-012-0682-3

Stoick, S. M., Gray, J. I., Booren, A. M., & Buckley, D. J. (1991). Oxidative stability of restructured beef steaks processed with oleoresin rosemary, tertiary butylhydroquinone, and sodium tripolyphosphate. *Journal of Food Science*, *56*(3), 597–600. https://doi.org/10.1111/j.1365-2621.1991.tb05337.x

Stormo, S. K., & Skåra, T. (2021). Liquid loss in thawed cod—Deconvoluting the effects of freezing-rate, freezing cycles, frozen storage time, and thawing-rate through a full

factorial design. *Journal of Food Process Engineering*, *44*(6), e13691. https://doi.org/10.1111/jfpe.13691

Su, L. J., Zhang, J. H., Gomez, H., Murugan, R., Hong, X., Xu, D., Jiang, F., & Peng, Z. Y. (2019). Reactive oxygen species-induced lipid peroxidation in apoptosis, autophagy, and ferroptosis. *Oxidative medicine and cellular longevity*, *2019*, 5080843. https://doi.org/10.1155/2019/5080843

Tironi, V., Tomás, M., & Añón, M. (2009). Lipid and protein changes in chilled sea salmon (*pseudopercis semifasciata*): Effect of previous rosemary extract (*Rossmarinus Officinalis L.*) application. *International Journal of Food Science & Technology*, *44*(6), 1254–1262. https://doi.org/10.1111/j.1365-2621.2009.01955.x

Török, Á., Yeh, CH., Menozzi, D., Balogh., P & Czine, P. (2023). Consumers' preferences for processed meat: a best–worst scaling approach in three European countries. *Journal of Agricultural Economics,* 11(33). https://doi.org/10.1186/s40100-023-00277-4

United States Department of Agriculture. (2013). The color of meat and poultry. *United States Department of Agriculture.* https://www.fsis.usda.gov/food-safety/safe-food-handling-and-preparation/food-safety-basics/color-meat-and-poultry#:~:text=Exposure%20to%20light%20and%20oxygen,%2C%20ham)%20is%20light%20pink.

Wang, T., Li, Z., Mi, N., Yuan, F., Zou, L., Lin, H., & Pavase, T. (2017). Effects of brown algal phlorotannins and ascorbic acid on the physiochemical properties of minced fish (*Pagrosomus major*) during freeze–thaw cycles. *International Journal of Food Science & Technology*, *52*(3), 706–713. https://doi.org/10.1111/ijfs.13325

Whalin, J. G., Liu, L., Rankin, S. A., Zhang, W., & Richards, M. P. (2022). Color stability and lipid oxidation in pork sausage as affected by rosemary extract and phospholipase A_2: A possible role for depletion of neutral lipid hydroperoxides. *Journal of Food Processing and Preservation*, *46*(4). https://doi.org/10.1111/jfpp.15997

World Food Programme. (2024). 5 facts about food waste and hunger. *World Food Programme*. https://www.wfp.org/stories/5-facts-about-food-waste-and-hunger

You, S., Yang, S., Li, L., Zheng, B., Zhang, Y., & Zeng, H. (2022). Processing technology and quality change during storage of fish sausages with textured soy protein. *Foods, 11*(22), 3546.

Zaki, H., Emara, M., & Abdallah, M. (2021). Effect of smoke duration on compositional analysis, deterioration criteria, microbial profile and sensory attributes of marine and freshwater fish: a comparative study. *Advances in Animal and Veterinary Sciences, 9*(8), 1259-1266.

Zhang, Y., Kim, Y. H. B., Puolanne, E., & Ertbjerg, P. (2022). Role of freezing-induced myofibrillar protein denaturation in the generation of thaw loss: A review. *Meat Science, 190*, 108841. https://doi.org/10.1016/j.meatsci.2022.108841

Zhu, Y., Zhu, J., Shi, X., & Fan, M. (2025). Effects of Freezing, Frozen Storage and Thawing on the Water Status, Quality, Nutrition and Digestibility of Meat: A Review. *Food Science & Nutrition*, *13*(8), e70774. https://doi.org/10.1002/fsn3.70774

APPENDICES

Appendix A. Consumer demographics for smoked salmon boudin sensory analysis.

Gender	Male	38.3%
	Female	61.7%
Age	18-21 years old	22.4%
	22-32 years old	26.2%
	33-42 years old	20.6%
	43-52 years old	21.5%
	53-65 years old	9.3%
Ethnicity*	White/Caucasian	50.5%
	Black/African American	10.3%
	Hispanic/Latino	16.8%
	South Asian/Indian	14.0%
	Middle Eastern	1.9%
	Native American/Pacific Islander	0.9%
	Some other ethnicity (please specify)[1]	5.6%
Income	Less than $20,000	8.4%
	$20,000 to $39,999	17.8%
	$40,000 to $59,999	16.8%
	$60,000 to $79,999	11.2%
	$80,000 to $99,999	15.9%
	$100,000 or more	29.9%
Diet	Vegetarian (I do not consume meat)	0.0%

	Pescatarian	0.0%
	Keto-diet	0.9%
	Vegan (I do not consume animal-based products.)	0.0%
	I do not follow any diets or have any dietary restrictions	99.1%
*Products Consumed	Seafood	100.0%
	Coffee	83.2%
	Produce (apples, tomatoes, lettuce, etc.)	99.1%
	Pasta	96.3%
	Meat (beef, chicken, pork, etc.)	100.0%
	Frozen meals	90.7%
	Ready to eat meals	86.9%
	Alcohol	72.9%
	Plant-based products	86.0%
	Pre-packaged snacks	94.4%
Seafood Allergy	Yes	0.0%
	No	100%

Data represents 107 consumers

Demographics may vary due to show rates

*Check all that apply question. Total does not add up to 100%

[1]"Other" comments include: "Southeast Asian" (n = 1), "East Asian" (n = 4), and "Mixed between South Asian/Indian and Caucasian" (n = 1)

Appendix B. Consumer liking test ballot for smoked salmon boudin.

Boudin definition: Cajun style sausage traditionally consisting of meat, vegetables, spices, and rice stuffed into a pork casing

1. How much do you **LIKE** or **DISLIKE** the **OVERALL APPEARANCE** of this Salmon Boudin Sausage? (SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

2. How much do you **LIKE** or **DISLIKE** the **COLOR** of this Salmon Boudin Sausage?

(SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

3. How would you rate the **COLOR** of this Salmon Boudin Sausage? (SELECT ONE)

Much too dark	5
Somewhat too dark	4
Just about right	3
Somewhat too light	2
Much too light	1

4. How much do you **LIKE** or **DISLIKE** the **OVERALL AROMA** of this Salmon Boudin Sausage? (SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

5. How would you rate the **OVERALL AROMA** of this Salmon Boudin Sausage?

(SELECT ONE)

Much too strong	5
Somewhat too strong	4
Just about right	3
Somewhat too weak	2
Much too weak	1

Now, please try this Salmon Boudin Sausage sample

You may continue to eat the sample as you answer all of the questions.

6. How much do you **LIKE** or **DISLIKE** this Salmon Boudin Sausage overall? (SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

7. What, if anything, did you **LIKE** about this Salmon Boudin Sausage? (Please be as specific as possible)

INSERT TEXT BOX TO TYPE IN RESPONSE

8. What, if anything, did you **DISLIKE** about this Salmon Boudin Sausage? (Please be as specific as possible)

INSERT TEXT BOX TO TYPE IN RESPONSE

9. How likely would you be to **BUY** this Salmon Boudin Sausage if it was available for a reasonable price at your local grocery store? (SELECT ONE)

Definitely would buy	5
Probably would buy	4
Might or might not buy	3
Probably would NOT buy	2
Definitely would NOT buy	1

10. How much do you **LIKE** or **DISLIKE** the **OVERALL FLAVOR** of this Salmon Boudin Sausage? (SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

11. How would you rate the **STRENGTH** of the **SMOKED SALMON FLAVOR** of this Salmon Boudin sausage? (PLEASE SELECT ONE)

Much too strong	5
Somewhat too strong	4
Just about right	3
Somewhat too weak	2
Much too weak	1

12. How much do you **LIKE** or **DISLIKE** the **HEAT/SPICINESS** of this Salmon Boudin Sausage? (SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

13. How would you rate the **HEAT/SPICINESS** of this Salmon Boudin Sausage? (PLEASE SELECT ONE)

Much too spicy	5
Somewhat too spicy	4
Just about right	3
Not quite spicy enough	2
Not at all spicy enough	1

14. How much do you **LIKE** or **DISLIKE** the **ROSEMARY FLAVOR** of this Salmon Boudin Sausage? (SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

15. How would you rate the **STRENGTH** of the rosemary flavor? (PLEASE SELECT ONE)

Much too strong	5
Somewhat too strong	4
Just about right	3
Somewhat too weak enough	2
Much too weak	1

16. How much do you **LIKE** or **DISLIKE** the **OVERALL TEXTURE** of this Salmon Boudin Sausage? (SELECT ONE)

Like it extremely	9
Like it very much	8
Like it moderately	7
Like it slightly	6
Neither like nor dislike it	5
Dislike it slightly	4
Dislike it moderately	3
Dislike it very much	2
Dislike it extremely	1

17. How would you rate the **FIRMNESS** of this Salmon Boudin sausage? (PLEASE SELECT ONE)

Much too firm	5
Somewhat too firm	4
Just about right	3
Somewhat too soft	2
Much too soft	1

18. Of the 3 **Salmon Boudin SAUSAGE** samples you tasted, please rank the samples from the one you **LIKED BEST** to the one you **LIKED LEAST**.

19. Why did you prefer the sample that you liked best? (Please be specific)

INSERT TEXT BOX TO TYPE IN RESPONSE