INFLUENCE OF DIFFERENT PROCESSING METHODS AND SPICE TYPES ON THE QUALITY CHARACTERISTICS OF *Merluccius merluccius*

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SUBMITTED TO

THE DEPARTMENT OF AQUACULTURE AND FISHERIES MANAGEMENT, FACULTY OF AGRICULTURE, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE.

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DEDICATION

This project is dedicated to the Almighty God, whose amazing grace, wisdom, and strength have guided me through every stage of this journey. I also lovingly dedicate it to my wonderful parents and my dear siblings whose unwavering love, prayers, and encouragement have been my greatest source of strength and inspiration. I am deeply grateful. Lastly, I dedicate this work to all students and researchers in Aquaculture and Fisheries who continue to strive toward innovation and sustainability for a better future in fish farming.

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ABSTRACT

This study investigated the influence of different processing methods and spice types on the quality characteristics of *Merluccius merluccius* (Hake). The experiment was designed to evaluate how air-frying, deep frying, and smoking, combined with various spice treatments (black pepper, oregano, black pepper + oregano, and control), influences the proximate composition and sensory attributes of the fish. This study was carried out at the Aquaculture and Fisheries Management Processing Unit, and the proximate and sensory analysis were conducted immediately after processing. The result showed that the deep frying produced the best overall results for the sensory attributes, the smoked ranked next because of its protein levels while the air-fried fish was less preferred due to its lighter texture and mild flavour. Among the spices, the black pepper + oregano was the best. Based on the result, it is recommended that deep frying combined with black pepper and oregano should be used as the most effective method for producing nutritionally rich and highly acceptable *Merluccius merluccius* products.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Fish remains one of the most commonly consumed and affordable animal protein sources worldwide (Maulu *et al*., 2020). It supplies the body with high-quality protein, essential fatty acids, vitamins, and minerals, making it vital for nutrition and global food security. Due to its richness in essential amino acids, fish protein is generally easier to digest than the protein found in many other animal foods (Rana *et al*., 2023). The World Health Organization (WHO) advises the population to eat fish rich in omega-3 fatty acids at least once or twice weekly because these fatty acids especially docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) help reduce the risk of coronary heart disease (FAO and WHO, 2011). Lipids naturally present in fish also play a protective role against cardiovascular illnesses and rheumatoid arthritis, further elevating the nutritional importance of fish in human diets (Kumaran *et al*., 2012).

Merluccius merluccius, known commonly as European hake, is a demersal fish of great ecological, nutritional, and commercial relevance. It inhabits temperate waters of the Atlantic and Pacific Oceans, including regions around Europe, South America, and Southern Africa. In Nigeria, the fish is mostly available as imported frozen products and is popularly referred to as "meluza" (derived from the Spanish merluza) or "panla/eja yoyo" in the southwestern part of the country. The fish has a mild flavor, soft texture, and white flesh, making it acceptable and affordable among various consumer groups.

Fish undergoes different processing techniques from the point of harvest until it reaches consumers. Because fish deteriorates rapidly once removed from water, appropriate preservation is essential to maintain quality (Adeyemi *et al*., 2014). Processing techniques such as smoking, deep frying, and air frying influence the nutritional composition, sensory quality, and overall shelf life of the fish. Smoking helps prolong shelf life by lowering moisture content and providing antimicrobial and antioxidant effects, while also adding desirable color and flavor (Goulas and Kontminas, 2005). Deep frying cooks the fish in hot oil, producing a crispy exterior and tender interior. Air frying, on the other hand, relies on rapid hot-air circulation with little or no oil to create a fried-like product with reduced fat content and lower calories (Ferreira *et al*., 2017). However, both traditional and modern frying techniques may cause losses of nutrients such as proteins, lipids, and minerals (Corrissin *et al*., 2005).

Knowledge of fish chemical composition is important in determining appropriate processing methods, designing new products, improving nutritional quality, and ensuring compliance with food standards (Hantoush *et al*., 2014). The proximate composition of fish can differ widely depending on species, diet, environmental conditions, genetics, handling, storage, and exposure to oxygen or light (Ingemanasson *et al*., 1995).

Spices play an important role in fish processing because many possess antioxidant, antiseptic, and bacteriostatic properties that slow down deterioration processes such as rancidity. Plant-based compounds, including polyphenols like flavonoids and tannins, serve as natural preservatives. Common examples are oregano (Origanum vulgare) and black pepper (Piper nigrum), which are known to enhance flavor and also possess antimicrobial benefits (Kumolu-Johnson *et al*., 2011). Apart from preservation, spices contribute to sensory quality and may offer additional medicinal or nutritional value.

1.2 Justification of the Study

Fish such as Merluccius merluccius (Hake) provide essential high-quality protein, beneficial fatty acids, vitamins, and minerals, making them a crucial food source in developing countries like Nigeria (Coppes, 2015). Despite this importance, hake is highly perishable, and poor handling or insufficient preservation often results in spoilage, quality loss, and potential public-health risks.

Air frying is a relatively modern processing technique and is not yet widely applied in fish processing within Nigeria. Its effects on nutritional composition, sensory quality, and overall safety therefore require further research. Local fish processors traditionally rely on spices like garlic, ginger, and pepper (Kumolu-Johnson *et al*., 2011). This study introduces other spices oregano, black pepper, and cinnamon which are less commonly used in Nigerian fish products but are widely recognized internationally for their antioxidant, antimicrobial, and flavor-enhancing properties. Incorporating these spices may improve shelf life, sensory characteristics, and the overall nutritional value of processed hake. This also offers opportunities for developing value-added fish products that can appeal to more specialized or health-conscious markets.

The findings of this study are therefore expected to show how different spice types and processing techniques affect the quality of *Merluccius merluccius,* and to help identify the most effective combination for producing safe, nutritious, and consumer-preferred fish products.

1.3 Aim and Objectives of the Study

The aim of this study was to investigate the influence of different processing methods and spice types on the quality characteristics of *Merluccius spp.* While the specific objectives were to determine the:

1. proximate composition of *Merluccius spp.* subjected to various processing methods (smoking, deep-frying, air-frying) and spices;
2. effects of these processing methods on the sensory properties of *Merluccius spp.* after the application of the different spices used.

CHAPTER TWO

LITERATURE REVIEW

2.1 DEMAND FOR FISH

Global demand for fish and fish-derived foods has continued to rise because of their rich nutritional composition, which includes high-quality proteins, polyunsaturated fatty acids, essential vitamins, and important minerals (FAO, 2022). Fish contributes about 7% of the world's total protein supply and accounts for 17% of all animal protein consumed, making it the single most important source of high-quality protein for human diets (FAO, 2020). In Nigeria, the significance is even greater, with fish supplying nearly 40% of the animal protein needs of the population (WorldFish, 2022). Compared to animal protein sources such as beef, mutton, and poultry, fish remains a more cost-effective option for meeting nutritional requirements, especially among low-income households (Olaleye *et al*., 2019). Beyond its dietary value, fish plays an important role in Nigeria's economic development through its contributions to agriculture and to the nation's Gross Domestic Product (GDP). The fisheries sector accounted for 1.09% of Nigeria's GDP in 2020 and 0.9% in the third quarter of 2021 (Odioko and Becer, 2022). Ensuring adequate access to fish for Nigeria's rapidly increasing population supports healthy living and sustainable socioeconomic development, contributing to Sustainable Development Goals (SDGs) 3, 8, and 16 (Oladimeji *et al*., 2019).

The fisheries value chain also sustains the livelihoods of numerous households, particularly in riverine and coastal communities. According to WorldFish (2022), more than 1,477,651 Nigerians are engaged in fisheries-related activities. Within the aquaculture sub-sector, processing and marketing offer the highest employment opportunities (Omeje *et al*., 2022). Because fish deteriorates quickly after harvest, proper handling and appropriate preservation techniques are essential to reduce spoilage, which has encouraged the growth and adoption of modern fish-processing technologies (Kamaldeen *et al*., 2016).

2.1.1 Habitat and biology *of Merluccius Merluccius*

Merluccius merluccius, commonly known as European hake, is a demersal fish species of considerable economic and nutritional value, consumed in various forms across many countries. Like other marine species, it is highly perishable, with quality deteriorating quickly after harvest due to microbial growth, enzymatic activity, and lipid oxidation (Suarez-Medina *et al*., 2024). The European hake *Merluccius merluccius* (Linnaeus, 1758) belongs to the family Merlucciidae within the genus Merluccius and is widely distributed in the Eastern Atlantic, the Mediterranean Sea, and the southern Black Sea (Froese and Pauly, 2016).

European hake is one of the primary target species for commercial trawlers due to its high market value, leading to intensive exploitation in both Atlantic and Mediterranean waters (Oliver and Massuti, 1995; Boudjadi and Rachedi, 2021). The species inhabits a broad depth range, from coastal areas down to 1000 m, typically on muddy seabeds (Cohen *et al*., 1990; Philips, 2012; Froese and Pauly, 2016). In the Egyptian Mediterranean deep sea, European hake is generally caught between 200 m and 500 m depth (Sabrah *et al*., 2017). Larger individuals are usually found in waters deeper than 200 m, whereas smaller hake tend to inhabit coastal shelves (Belcaid and Ahmed, 2011; Boudjadi and Rachedi, 2021). European hake exhibits both vertical movements at night and horizontal migrations in search of food. As a carnivorous predator, its diet includes fish, crustaceans, algae, and plant detritus (Carpentieri *et al*., 2005; Philips, 2012).

Plate 1: *Merluccius merluccius*

2.2 FISH QUALITY AND HANDLING

Aquatic foods continue to gain prominence in global markets as international demand steadily increases (Pal *et al*., 2016). These products provide high-quality protein, omega-3 fatty acids, and numerous essential nutrients, making them an important component of a balanced and healthy diet (Rhea, 2009). However, despite their nutritional value, consuming raw, insufficiently cooked, or poorly processed fish and seafood can lead to significant health concerns (Pal *et al*., 2016). Fish that is not fresh or has been improperly handled may expose consumers to infections or foodborne illnesses (Adebayo-Tayo *et al*., 2012a). The freshness and overall quality of fish are commonly assessed through organoleptic evaluation methods that rely on human senses to detect spoilage and determine suitability for consumption (Lougovois and Kyrana, 2005). Fresh fish typically has a mild taste and smell, both of which become stronger and more unpleasant as spoilage advances (Lindsay, 1990, 1994). This makes proper handling immediately after harvest essential for preserving quality and reducing post-harvest losses (Espejo-Hermes, 2004) Huwaida *et al*. (2023) stressed that crew members involved in the fishing process must be knowledgeable in good handling techniques and fundamental food-safety practices. According to Ilham *et al*. (2023), effective fish handling follows a sequence of actions designed to maintain freshness, quality, and safety from the point of capture until it reaches the consumer. Furthermore, Sartika, Amirai, and Rozi (2022) pointed out the necessity of complying with regulations related to fishing activities, including minimum catch sizes, catch quotas, and waste management practices. Such guidelines help ensure that fish is handled properly and reaches consumers in good condition.

Once fish is captured, immediate and appropriate handling is crucial to slow down deterioration, as prompt action decreases the likelihood of rapid decomposition (Nurrachman *et al*., 2023). Maintaining low temperatures commonly through the application of ice or onboard cooling plays a major role in controlling bacterial growth (Sifatullah *et al*., 2023). The use of solid ice blocks without added water is particularly common in the fishing industry, as this method preserves freshness during storage and transport while reducing moisture-related contamination (Zulaihah *et al*., 2019). Wahyudi (2022) also reported that using block ice minimizes leakage or spillage compared to liquid ice. Sanitation is equally important in ensuring proper fish handling. Routine cleaning and disinfection of fishing equipment, processing tools, and distribution materials prevent bacterial contamination and help retain product quality (Nuryanti *et al*., 2017). Sartika, Amirai, and Rozi (2022) further highlighted that strict adherence to sanitation procedures maintains hygiene standards and supports the delivery of safe, high-quality fish to consumers.

2.3 FISH PROCESSING

Aquaculture production has expanded rapidly in recent years, but fish remain highly susceptible to deterioration once removed from water. Without timely and adequate preservation, harvested fish quickly lose their quality, consumer appeal, and commercial value (Akinrotimi *et al*., 2007). To maintain freshness and safety, fish must undergo proper processing, which includes all stages of handling from the moment of capture or harvest until the product reaches the final consumer (Okonta *et al*., 2005).

Processing methods typically influence the texture, flavor, and general appearance of fish by slowing or preventing spoilage. The extent and type of changes depend on the selected technique whether salting, canning, smoking, frying, or drying. Preservation technologies, on the other hand, aim to keep fish as close to its fresh state as possible by reducing changes in taste, texture, and physical characteristics, commonly through the use of ice or freezing (Adepegba and Tachia, 2014). Overall, the main objective of fish processing is to suppress microbial activity and enzymatic reactions so that the product remains safe and acceptable from the point of harvest to the time it is consumed (Omoruyi and Agbolagba, 2015).

2.3.1 SMOKING

Smoking is one of the oldest known methods for preparing and preserving fish and meat, with its use dating back to the Stone Age (Adeyeye, 2016). The technique involves a combination of thermal, chemical, diffusive, and biochemical actions that take place in pre-salted products. Today, smoking is employed in the processing of nearly 40–60% of fish and other food items. It is described as the absorption of volatile compounds produced during the thermal breakdown of wood—into the surface of meat or fish (Adeyeye, 2016). These smoke constituents contribute to the product's characteristic flavor, color, and aroma, while also enhancing preservation through dehydrating, antimicrobial, and antioxidant effects.

Smoke is generated through the combustion of wood. Wood contains cellulose, hemicellulose, and lignin, which undergo pyrolysis a heat-induced chemical decomposition resulting in the formation of smoke (Alasalvar, Miyashita, Shahidi, and Wanasundara, 2011). The unique taste and aroma of smoked fish arise from the burning of wood and charcoal, which release compounds such as phenols, nitrites, and formaldehyde (Fecicilar and Genccelep, 2013). These substances contribute to color development, flavor enhancement, and partial dehydration of the fish. By lowering moisture levels and restricting microbial activity, smoking not only produces distinct sensory qualities but also prolongs the shelf life of smoked fish fillets (Magawata *et al*., 2015).

As one of the earliest preservation methods, smoking integrates the effects of salting, drying, and heating to maintain the quality and safety of food products (Alasalvar *et al*., 2011).

2.3.2 FRYING

Frying is widely used in the food industry because it enhances sensory attributes and alters the physical properties of food products (Ghidurus *et al*., 2010; Karizaki *et al*., 2013; Zarulakmam *et al*., 2021). The method is a complex operation that involves simultaneous heat and mass transfer:

moisture within the food evaporates while oil moves into the product structure (Khazaei *et al*., 2016; Yu *et al*., 2020; Dehghannya *et al*., 2021). Frying usually takes place at temperatures well above the boiling point of water, during which foods may be partially or completely submerged in heated oils or fats (Nieva-Echevarria *et al*., 2016). Several factors, including the type of oil selected and the frying temperature, significantly affect the final quality of the fried food (Oluwaniyi *et al*., 2010; Oke *et al*., 2018; Zhang, Chen, and Yue, 2020).

Different frying approaches such as deep frying, stir-frying, and vacuum frying have been developed, each varying in mechanism and cooking medium, with the aim of producing fried products of improved quality (Arslan *et al*., 2018). In fish processing, frying often enhances consumer appeal, especially when the fish is coated with batter or breadcrumbs, leading to higher sensory acceptability. Nonetheless, the final sensory characteristics of fried foods depend largely on frying temperature, duration of frying, and the condition or quality of the frying oil (Kilincceker and Hepseg, 2011; Tadesse *et al*., 2020).

2.3.3 AIR FRYING

Growing global interest in healthier eating habits has encouraged the introduction of new food-processing technologies designed to maintain or improve the quality of fried foods. Among these innovations is the air fryer. Although it can perform functions similar to baking or roasting appliances, its operating principle is distinct. An air fryer uses heating elements placed at the top of the unit along with a powerful fan that rapidly circulates hot air, producing the crisp and crunchy texture associated with fried foods. This method requires little or no oil, though using a small amount can help mimic the effects of deep frying more closely (Abd Rahman *et al*., 2017; Tellez-Morales, 2023).

In hot-air frying, a light coating of oil is applied to the food surface before it is cooked with fast-moving hot air. This process can yield products that visually and texturally resemble those produced by traditional frying methods (Jin *et al*., 2021). The constant movement of heated air ensures good interaction between the food and tiny oil droplets suspended in the airflow, enabling efficient cooking while substantially reducing overall oil usage. Inside the air fryer chamber, heat causes internal moisture to evaporate and promotes crust formation on the food surface, giving the typical fried appearance (Wang *et al*., 2021). Modern air fryer designs featuring digital touchscreens, adjustable temperature settings, and rapid heating systems are expected to further increase user adoption. In addition to health benefits, the technology offers environmental advantages by minimizing oil consumption and lowering associated waste and emissions.

2.4 FISH PRESERVATION

Food preservatives are essential for safeguarding the nutritional value of food products, limiting the growth of spoilage organisms and harmful microbes, and reducing unwanted physical, chemical, and sensory changes during storage. Preservation methods typically involve the use of antioxidants, which protect against oxidative reactions, and antimicrobial agents that inhibit microbial activity—together helping to prolong the shelf life of foods (Kumar *et al*., 2020). For fish, preservation techniques are commonly grouped into three categories: physical, chemical, and biological. Physical methods such as drying, refrigeration, freezing, packaging, irradiation, high-pressure treatment, and pulsed electric fields work mainly by controlling moisture and temperature. Chemical techniques like curing and smoking make use of natural preservatives, while biological preservation relies on beneficial microbes to slow spoilage and extend fish shelf life (Mahmud *et al*., 2018). Growing health consciousness among consumers has led to greater interest in natural preservatives rather than synthetic ones traditionally used in fish processing. These natural agents may come from plants, microorganisms, or animals, though plant-based preservatives are the most widely preferred. Such plant-derived compounds not only extend shelf life but also reduce lipid oxidation and do not carry the allergenic risks sometimes linked with animal-derived substances. Microbial products, including organic acids and bacteriocins, show strong antimicrobial activity, while plant-origin antimicrobials provide a safe, affordable, and readily accessible option (Mei *et al*., 2019). Unlike microbial or animal-based systems which often require specialized or advanced equipment plant preservatives have been used for many years and remain easily obtainable. When used together with physical preservation methods, plant-derived agents greatly improve the overall efficiency of fish storage.

Several researchers have reported various fish preservation methods, such as drying, smoking, freezing, chilling, and brining, with smoke-drying being the most widely practiced method in Nigeria. According to Ita (1972), the major purpose of fish preservation is to prolong its shelf life, using established techniques that include the following:

2.4.1 Chilling

Chilling involves lowering the temperature of fish to a point above freezing. Although it does not completely halt spoilage, it slows down the activities of microorganisms and enzymes responsible for deterioration. The effectiveness of chilling largely depends on how low the temperature is the cooler the storage conditions, the slower the spoilage rate. However, even under chilled conditions, bacterial activity and enzymatic reactions continue at a reduced pace and are not fully stopped (Ita, 1972; Tawari and Abowei, 2011).

2.4.2 Freezing

Freezing differs from chilling in that it converts much of the water in fish into ice by lowering the temperature below 0°C. This method greatly extends shelf life and is especially valuable for fish destined for export (Anthonio, 1970). To achieve the best quality, fish should be cleaned and packaged before rigor mortis sets in. Fresh fish owes its natural sweetness to inosinic acid; however, during spoilage, this compound breaks down into hypoxanthine, which imparts a bitter flavor. Enzymatic activity can also lead to browning in frozen fish due to reactions between amino acids and sugars (Azeza, 1976; Tawari and Abowei, 2011).

Since fish contains about 80% water and various dissolved minerals, its freezing point is slightly below 0°C. Even at -5°C, a portion of the water about 20% may still remain unfrozen (Clucas, 1981; Davies, 2005; Tawari and Abowei, 2011).

2.4.3 Drying

Drying preserves fish by removing moisture through evaporation, thereby preventing spoilage and extending storage life. Traditional drying often relies on sun-drying, where the rate of drying depends greatly on weather conditions and airflow. Solar heat first removes moisture from the fish surface, and then internal water migrates outward to evaporate. This process also alters the physical structure of the fish, causing shrinkage and texture changes. Heat for drying can come from sunlight, burning wood, electricity, solar dryers, or mechanical drying systems (Davies *et al*., 2008; Tawari and Abowei, 2011).

2.4.4 Smoking

Smoking is the most commonly used traditional fish preservation technique in Nigeria. The method relies on the antimicrobial nature of smoke components such as phenolic compounds combined with antioxidant activity and partial cooking at elevated temperatures. Properly smoked fish is typically dark brown, well dried, and possesses a characteristic smoky aroma resulting from absorbed volatile compounds. These qualities enhance both its market value and its shelf stability (FAO/UN, 1970a; FAO, 1971a; Tawari and Abowei, 2011).

2.4.5 Salting

Salting is a traditional preservation method in which salt is applied to fish to inhibit spoilage. The technique can be performed using four major approaches: brining, dry salting, kench salting, and pickle curing. In brining, the fish are immersed in a concentrated salt solution, while dry salting involves spreading or rubbing coarse salt directly onto the surface of the fish. Kench salting also uses dry salt but is applied to split fish that are stacked in layers with additional salt placed between them, allowing the resulting liquid (pickle) to cover the fish. Pickle curing, on the other hand, involves arranging fish in sealed containers with salt; if the fish are not fully submerged in brine within four hours, more brine is added to ensure proper coverage. This method minimizes oxidative reactions and helps prevent the development of rancid flavors (FAO, 1971b; FAO, 2002; Tawari and Abowei, 2011). In both dry and kench salting, extended exposure to air may lead to rancidity and discoloration, so the fish are often placed in brine afterward to improve stability and quality.

2.5 FISH SPOILAGE

Fish is a protein-rich food that requires careful handling due to its high susceptibility to spoilage (Eyo, 2004). Spoilage occurs rapidly after capture, particularly in tropical climates where elevated temperatures accelerate bacterial growth, enzymatic activity, and chemical oxidation of fats. In Nigeria, inadequate handling practices are responsible for approximately 30–50% of post-harvest fish losses. These losses can be reduced through proper handling, processing, and preservation methods (Bate and Bendall, 2010).

In live fish, metabolic processes are balanced and the flesh remains sterile. However, once the fish is harvested and dies, irreversible biochemical and microbial changes begin, ultimately leading to spoilage and food waste (Adeyeye, 2016). Spoilage refers to any alteration in food that produces undesirable characteristics, often detectable through sensory evaluation (Rawat, 2015). Appropriate preservation methods, pretreatments, and handling techniques can significantly improve the quality of fish, prolong shelf life, and limit spoilage (Ghaly *et al*., 2010). Common indicators of fish spoilage include slime formation, discoloration, changes in texture, off-odors, and gas production (Adedeji and Adetunji, 2004; Adedeji, 2012). Spoilage affects both external and internal surfaces of the fish, with the stomach and intestines providing a medium for bacterial growth due to the presence of digested or partially digested food (Emikpe, 2011).

2.5.1 Types of fish spoilage

Ghaly *et al*. (2010) reported that fish spoilage is mainly caused by three key processes: enzymatic autolysis, oxidation, and microbial activity. Fresh fish begins to deteriorate very quickly once captured. According to Berkel *et al*. (2004), spoilage marked by the onset of rigor mortis can set in within 12 hours, especially under the elevated temperatures typical of tropical environments. Rigor mortis is the stiffening of muscle tissue after death, which reduces the flexibility of the fish (Adebowale *et al*., 2008). A range of factors contribute to declining fish quality, such as the actions of lipases and digestive enzymes, oxidative reactions, and the growth of bacteria on the surface of the fish (AMEC, 2003). As spoilage progresses, biochemical and microbial activities lead to the formation of new compounds that negatively affect sensory qualities, resulting in off-odours, unpleasant flavours, and undesirable textural changes in the flesh (Ghaly *et al*., 2010).

2.5.1.1 Enzymatic spoilage

Soon after fish are harvested, a series of chemical and biological transformations begin as endogenous enzymes start degrading major muscle components (FAO, 2005). Hansel *et al*. (2003) noted that autolytic enzymes primarily influence the texture during the early stages of deterioration and do not immediately produce the characteristic off-odours or off-flavours associated with spoilage. This indicates that autolysis can reduce shelf life even when microbial populations are still low (FAO, 2005). Key outcomes of autolysis include softening of the flesh and the production of compounds such as hypoxanthine and formaldehyde. Digestive enzymes may intensify this process, causing muscle weakening, rupture of the belly wall, and leakage of blood-water consisting of proteins and oils (FAO, 2005). Fish muscle and internal organs contain numerous proteolytic enzymes that remain active after death, contributing to degradation during handling, storage, and subsequent processing. These enzymes can significantly influence the sensory attributes of fish products (Engvang and Nielsen, 2001). Under poor storage conditions, protein breakdown is followed by solubilization as a result of proteolysis (Lin and Park, 2006). Autolytic breakdown of muscle proteins also produces peptides and free amino acids, which can support microbial growth and stimulate the formation of biogenic amines, further accelerating spoilage (Fraser and Sumar, 2008). A condition known as belly bursting occurs when proteolytic enzymes from the pyloric caeca and intestines leak into the ventral muscle. These enzymes exhibit optimal activity in neutral to alkaline conditions. Martinez and Gildberg (2011) reported that proteolytic activity is reduced when fish are stored at 0°C and at a pH of approximately 5.

2.5.1.2 Microbial spoilage

The microbial community found on freshly harvested fish is largely determined by the microorganisms present in the surrounding water where the fish lived. Common bacterial groups associated with the skin, gills, and surface mucus of fish include Pseudomonas, Alcaligenes, Vibrio, Serratia, and Micrococcus (Gram and Huss, 2000). The growth and metabolic activities of these microorganisms play a major role in fish spoilage, producing compounds such as putrescine, histamine, and cadaverine, along with organic acids, sulphides, alcohols, aldehydes, and ketones—all of which contribute to undesirable off-flavours and odours (Dalgaard *et al*., 2006; Emborg *et al*., 2005; Gram and Dalgaard, 2002). In fish that are not preserved, spoilage is usually dominated by Gram-negative, fermentative bacteria, especially those in the Vibrionaceae family. However, in chilled fish, spoilage is more commonly caused by psychrotolerant Gram-negative species, particularly Pseudomonas spp. and related organisms (Gram and Huss, 2000).

It is therefore important to distinguish between bacteria that do not cause spoilage and those that are true spoilage organisms, as only specific groups contribute to quality deterioration (Huss, 2005). Trimethylamine (TMA) is widely used as a marker of microbial spoilage in fish. Marine and freshwater fish naturally contain trimethylamine oxide (TMAO), which functions as an osmoregulatory compound to help maintain water balance. Spoilage organisms such as Shewanella putrefaciens, Aeromonas spp., psychrotolerant Enterobacteriaceae, Photobacterium phosphoreum, and Vibrio spp. can reduce TMAO to TMA, resulting in the characteristic ammonia-like smell of spoiled fish (Gram and Dalgaard, 2002). In the initial stages of spoilage, species such as Pseudomonas putrefaciens, fluorescent pseudomonads, and other proteolytic bacteria multiply rapidly and secrete hydrolytic enzymes, which accelerate breakdown and further reduce the quality of the fish (Shewan, 2001).

2.5.1.3 Chemical spoilage

Lipid oxidation is a major cause of quality deterioration in oily pelagic fish such as mackerel and herring, which contain substantial amounts of fat stored within their muscle tissues (Fraser and Sumar, 2008). This reaction progresses through a three-step free-radical mechanism consisting of initiation, propagation, and termination (Frankel, 2005; Khayat and Schwall, 2003). During initiation, reactive lipid radicals are formed in response to triggers such as heat, metal ions, or irradiation. These radicals then combine with oxygen to form peroxyl radicals. In the propagation stage, the peroxyl radicals attack other lipid molecules, producing hydroperoxides while generating more radicals that continue the chain reaction (Fraser and Sumar, 2008; Hultin, 2004). Termination occurs when the accumulated radicals finally interact and form stable, non-reactive end products. Oxidation mainly targets the double bonds in fatty acids, making fish rich in polyunsaturated fatty acids especially susceptible to this form of deterioration. Before oxygen can participate in the oxidation process, it must first be activated, and transition metals play a key role in this activation step (Hultin, 2004). In fish, lipid oxidation may be driven by both enzymatic and non-enzymatic mechanisms. The enzymatic pathway, referred to as lipolysis, involves lipase enzymes breaking down glycerides and releasing free fatty acids, which contribute to rancid odours and lower oil quality (Huis in't Veld, 2006; FAO, 2005). These lipases may originate from the fish tissues themselves, such as those found in the blood, muscle, and skin, or from psychrotrophic microorganisms (Huis in't Veld, 2006). Important enzymes associated with lipid hydrolysis include triacyl lipase, phospholipase A2, and phospholipase B (Audley *et al*., 2008; Yorkowski and Brockerhoft, 2005). Non-enzymatic oxidation, in contrast, is promoted by haem-containing compounds such as haemoglobin, myoglobin, and cytochromes, which catalyse the formation of hydroperoxides (Fraser and Sumar, 2008). The free fatty acids generated during hydrolysis can also react with sarcoplasmic and myofibrillar proteins, causing protein denaturation (Anderson and Ravesi, 2009; King *et al*., 1962). Undeland *et al*. (2005) reported that fish muscle is particularly prone to oxidation due to the strong pro-oxidative properties of haemoglobin, especially when it is in its deoxygenated or oxidized form.

2.6 SPICES UTILIZATION

A broad range of spices is incorporated into both traditional and modern cooking. Common examples of dry spices include cumin (*Cuminum cyminum*), black pepper (*Piper nigrum*), oregano (*Origanum vulgare*), cinnamon (*Cinnamomum verum* or *C. cassia*), turmeric (*Curcuma longa*), tamarind (*Tamarindus indica),* and coriander seeds (*Coriandrum sativum*). Frequently used fresh flavouring agents include garlic (*Allium sativum*), ginger (*Zingiber officinale*), onions (*Allium cepa*), and coriander leaves (*Coriandrum sativum*).

The role of herbs and spices in supporting health and preventing disease has been demonstrated in numerous studies. For instance, basil (*Ocimum sanctum* or *O. tenuiflorum*), considered a

sacred and highly valued plant in India, is commonly used in teas and sweet dishes. Its antiviral and anti-inflammatory activities make it effective against several infections. Research indicates that basil, which contains bioactive compounds such as apigenin and ursolic acid, shows beneficial effects against herpes viruses, hepatitis B, and enteroviruses (Al-Maskari *et al*., 2012).

Plate 2: Oregano (*Origanum vulgare*)

Plate 3: Black pepper (*Piper nigrum)*

Giloy (*Tinospora cordifolia*), a key plant in Ayurvedic therapy, contains substantial amounts of vitamin C and essential minerals. Its starch derivative, called *Guduchi satva,* is especially rich in calcium and iron. Extracts from the stem have been shown to support digestion, assist in managing conditions such as diabetes and arthritis, and boost immune function (Rizvi *et al*., 2023).

Neem (*Azadirachta indica*), abundant throughout tropical regions, displays an extensive range of biological activities. These include antibacterial, antiviral, antimalarial, antioxidant, antifungal, antimutagenic, anticancer, contraceptive, and anti-ulcer effects. Preparations made from different parts of the neem tree have demonstrated the ability to inhibit viruses such as poliovirus, herpes simplex virus (HSV), influenza virus, HIV, and Coxsackie B viruses. Neem leaf juice, which has long been used in traditional medicine, is commonly given to infants as protection against viral infections. Likewise, juice extracted from the inner bark has been used to manage bone fever and jaundice without significant adverse effects (Eze *et al*., 2022).

Cloves (*Syzygium aromaticum*) have a long history of use in both traditional healing and culinary applications. The essential oil obtained from cloves is widely used in food flavouring, folk remedies, and perfumery. Cloves possess anaesthetic, stimulant, antibacterial, antifungal, antiviral, and antiseptic qualities. Traditionally, a combination of cloves and black salt is taken to provide quick relief from abdominal bloating and discomfort (Vicidomini *et al*., 2021).

Ginger (Zingiber officinale) is another commonly used spice with well-recognised medicinal benefits. Fresh ginger has antiviral activity and is often used to manage ailments such as headaches, menstrual pain, and the common cold. It is also frequently consumed by older adults to relieve arthritic discomfort. In its dried form, ginger is effective in managing nausea, indigestion, dizziness, and symptoms of colds and coughs. It is additionally incorporated into various cosmetic products (Wang, 2020).

Garlic (*Allium sativum*) contains significant amounts of essential minerals such as calcium, copper, potassium, phosphorus, and iron, as well as vitamin B1. It demonstrates broad antiviral activity against viruses that infect humans, animals, and plants by preventing viral entry into host cells. Numerous studies report that frequent consumption of garlic cloves can strengthen the immune system and lower the risk of viral infections (Khubber *et al*., 2020).

Oregano (*Origanum vulgare* L.) is one of the most important members of the Origanum genus, commonly used both in herbal medicine and as a flavouring agent. Key subspecies and related varieties include Greek oregano (*Origanum vulgare* ssp. hirtum), Turkish oregano (*Origanum onites*), common oregano (*Origanum vulgare* ssp. vulgare), and *Origanum vulgare* ssp. viridulum (Skoufogianni *et al*., 2019). Historically valued since ancient times, Origanum vulgare also known as common oregano, wild marjoram, or Spanish marjoram derives its name from the Greek words oros (mountain) and ganos (joy), referring to the “joy of the mountains” (Alekseeva *et al*., 2020).

Oregano is widely used in cooking, while its essential oil (OEO) and extracts (OEX) are recognised for their antiseptic, expectorant, and cholagogue activities. These preparations have been traditionally applied to improve digestion, as mouth and throat rinses, in inhalation therapies for upper respiratory tract conditions, and in medicinal baths (Naquvi *et al*., 2019; Alagawany *et al*., 2020). In addition, oregano essential oil and extracts have been identified as valuable natural preservatives and as agents that support gastrointestinal health, particularly under inflammatory conditions (Veenstra *et al*., 2019). Both the fresh and dried forms of oregano are commonly used to enhance the flavour of soups, sauces, meats, vegetables, preserves, and various aromatic spice mixtures.

Cinnamon (*Cinnamomum verum*), whether in the form of bark, powdered bark, extracts, or isolated bioactive compounds, has been shown to offer multiple health-promoting effects. Unlike many pharmaceutical treatments, cinnamon can be consumed regularly without causing harmful side effects. Evidence indicates that cinnamon may help prevent lifestyle-related disorders such as metabolic syndrome. Its use as an adjunct therapy for managing viral-induced hyperinflammation may also reduce dependence on synthetic drugs and minimise drug-related complications (Yakhciali *et al*., 2021).

Turmeric (*Curcuma longa*), a pungent spice with a slightly bitter note, is widely added to curry powders for both its flavour and vibrant colour. A member of the ginger family (*Zingiberaceae*), turmeric has been used traditionally for centuries and is recognised for its strong safety profile. It has demonstrated antiviral activity, including effectiveness against influenza viruses, and is also applied externally to promote wound healing. Regular dietary intake of turmeric has been linked to reduced blood glucose levels, improved gum health, and general protection against numerous diseases (Gupta *et al*., 2020).

Black pepper (*Piper nigrum*), often referred to as the "king of spices," is widely incorporated into culinary and medicinal practices. Its health-promoting attributes include soothing coughs and colds, improving digestion when taken with honey, and exhibiting antiviral effects against respiratory pathogens. Excessive intake, however, may cause discomfort such as stomach or eye irritation (Gautam *et al*., 2022). The primary active compound in black pepper, the alkaloid piperine, has been widely studied. Research shows that piperine possesses notable antiviral activity particularly against viruses affecting the respiratory tract and may hold potential as a phytotherapeutic agent for illnesses such as COVID-19 (Ahmed *et al*., 2013).

2.7 PROXIMATE COMPOSITION

Proximate composition refers to the fundamental chemical constituents of fish, which include moisture, fat, protein, and ash (Love, 1980). It provides important information about the physiological state of the fish and is commonly used in fisheries research and routine assessments (Cui and Wootton, 1988). Since lipids act as a major energy reserve, fat-related measurements are frequently used to describe the inverse relationship that exists between fat content and moisture levels (Salam and Davies, 1994). In practice, the methods used to determine these components vary based on the nature of the food material and the specific analytical objectives (Indrayan *et al*., 2005). Each analytical procedure is developed by examining the chemical behaviour of the component of interest and establishing conditions that allow its efficient separation. For example, moisture is measured by heating the sample to evaporate water, while fat is isolated using organic solvents (Okilya *et al*., 2008). Protein is estimated indirectly by determining total nitrogen through the Kjeldahl method (AOAC, 2000). The determination of ash and fibre involves removing other constituents step-by-step until only the target residue is left (AOAC, 2000). Because these analyses may be affected by sample variability or contamination from reagents, it is essential to carry out replicate measurements to reduce error and ensure consistent and accurate results.

2.7.1 Moisture Content

Moisture content is a crucial factor in food processing because many biochemical reactions and physiological changes in foods are dependent on water. Its effect on the stability and quality of food makes it an important parameter in food assessment (Singh, 2006). In foods, water exists in three main forms: free water, which occupies pores and interstitial spaces; adsorbed water, which is attached to macromolecular colloids such as starch, pectin, cellulose, and proteins; and bound water, which is chemically associated with other substances as water of hydration (Mepha *et al*., 2007). There are various methods for determining the moisture content of foods, including indirect drying techniques, direct distillation, electrical moisture meters, and chemical methods. Of these, indirect drying using an oven is the most commonly employed method and is the one applied in this study (AOAC, 2000). To achieve accurate measurements, it is important to prepare food samples rapidly to minimize water loss. Errors in sampling can be reduced by thorough mixing and by taking representative portions. When immediate analysis is not feasible, samples should be stored in airtight containers or refrigerated to maintain their moisture levels.

2.7.2 Ash Content

Ash in food refers to the inorganic residue that remains after the removal of moisture and the combustion of organic matter, typically at temperatures around 500°C. During this process, organic compounds are converted into volatile substances such as carbon dioxide, nitrogen oxides, and sulfur dioxide, leaving behind ash, which reflects the mineral content of the food (Whitney *et al*., 2005). Generally, the mineral content in foods is low, often less than 1% of the total composition, and varies depending on the food type and the specific minerals present. Minerals are usually classified into three groups (Turan, 2003):

i. Major elements (>0.01% or 100 ppm), including calcium, phosphorus, chlorine, sulfur, magnesium, and sodium;

ii. Trace elements (<0.01% or 100 ppm), such as arsenic, copper, iron, nickel, tin, chromium, fluorine, manganese, selenium, vanadium, cobalt, iodine, molybdenum, silicon, and zinc;

iii. non-essential toxic elements, including beryllium, lead, cadmium, palladium, mercury, and thallium.

Thus, determining the ash content of a food sample offers a valuable estimation of its total mineral composition, which is essential for assessing both nutritional quality and food safety (Whitney *et al*., 2005).

2.7.3 Crude Fiber

Crude fiber refers to the organic material that remains after a food sample undergoes a series of standardized treatments with light petroleum, dilute sulfuric acid, dilute sodium hydroxide, dilute hydrochloric acid, alcohol, and ether. It is composed mainly of cellulose and lignin (Whitney *et al*., 2005). Crude fiber essentially represents the fraction of food that is indigestible by humans and animals. Dietary fiber plays an important role in digestion by aiding the elimination of waste and toxins, preventing their prolonged retention in the intestines. This process contributes to reducing the risk of harmful accumulations that may lead to the development of various diseases.

2.7.4 Crude Protein

Amino acids are the building blocks of proteins, which are polymers mainly composed of α-amino acids with the general formula NH_2–CHR–COOH. Proteins are distinct among macronutrients because they contain appreciable amounts of nitrogen, a property that is commonly used to estimate protein content in foods. Several methods exist for protein determination, including the Kjeldahl method, dye-binding assays, and spectroscopic techniques. Among these, the Kjeldahl method is the most widely employed. It determines the total nitrogen present in a food sample and converts this value to protein content using a specific conversion factor, under the assumption that most nitrogen is found in proteins. The calculation is expressed as: % Protein = % N x F

where F is the conversion factor, typically 6.25 for most foods.

Proteins are vital for a wide range of physiological functions. They are essential for tissue repair, regulation of biological processes, and protection. Critical bodily functions, including fluid balance, nutrient transport, and muscle contraction, rely on adequate protein intake (Robert *et al*., 2006). Furthermore, proteins support immune function through the production of antibodies and can serve as an alternative energy source when carbohydrate and fat intake is insufficient (Brosnan, 2003).

2.7.5 Crude Fat

The fat content of fish is considerably more variable than levels of water, protein, or minerals. While protein and water content typically differ among species by no more than a three-to-one ratio, fat content can vary more than 300-fold (Zlatanos and Laskaridis, 2007). Lipid levels also fluctuate seasonally, especially in oily fish such as sardines, sprats, and mackerel. Overall, the fat content in fish generally ranges from about 0.2% to 25% (Boran and Karacam, 2011).

Dietary fat in fish is of significant nutritional importance, supplying essential fatty acids and acting as a carrier for fat-soluble vitamins. For example, sardines are high in omega-3 fatty acids and are usually low in contaminants like mercury (Zlatanos and Laskaridis, 2007; Hajar, 2009). The lipid content can also be affected by processing methods: smoked fish may contain between 12.7% and 60.3% fat, whereas sun-dried fish generally contains 12.1% to 26.4% fat (Akinneye *et al*., 2010).

2.8 Sensory Evaluation

Sensory evaluation is a scientific method that uses human senses, sight, smell, taste, touch, and hearing to detect and interpret changes in the characteristics of food (Martinsdottir, 2002). Research has shown that sensory techniques are effective for assessing food quality and freshness, particularly when carried out under controlled conditions (Huss, 2005). Typically, sensory evaluation involves stimulating, measuring, analyzing, and interpreting human responses to a product as perceived through the senses of sight, smell, taste, and sound. This approach is widely recognized and applied by professional bodies, including the Institute of Food Technologists and the American Society for Testing and Materials (Lawless *et al*., 2010). Like other scientific assessment methods, sensory evaluation prioritizes precision, accuracy, and sensitivity, while seeking to reduce false-positive outcomes. Different fish species display distinct sensory characteristics, such as odor, texture, flavor, and appearance, which evolve over time and are affected by storage temperature (Martinsdottir, 2002).

2.8.1 Appearance

The visual sense is typically the first to evaluate food quality, allowing the assessment of attributes such as color, size, shape, texture, consistency, and opacity. Color serves as an important indicator of factors like ripeness, concentration, and the degree of cooking, and it plays a critical role in determining a food's appeal and acceptability. For instance, green bananas, charred meat, or darkened avocados provide visual cues that can influence consumer choices. Certain colors can also set expectations; for example, the creamy color of vanilla ice cream conveys a sense of richness and indulgence. However, color alone can sometimes be deceptive, as visual changes may not accurately reflect true quality. Even minor alterations in color can substantially affect perceived acceptability. Additionally, visual perception is influenced by context, such as surrounding colors or the relative proportion of contrasting hues. Other visual parameters including size and shape (length, width, thickness, particle size, geometric form, and distribution of pieces) also provide valuable information about quality. Surface characteristics, such as glossiness, dullness, smoothness, roughness, and the clarity of liquids, further shape expectations about a food product prior to tasting.

2.8.2 Smell

The sense of smell, or olfaction, is essential for evaluating food quality. Odor intensity is influenced by temperature, as only volatile compounds are detectable as scents. This explains why hot foods generally have stronger aromas than cold ones; for example, the aroma of hot tea is more pronounced than that of iced tea, and baked goods emit a stronger fragrance than frozen desserts. Odor molecules are detected by the olfactory epithelium in the nasal cavity through two main pathways: directly via the nose or indirectly from the mouth, traveling upward through the throat to the nasal passages—a process known as retronasal perception. An example of this is when bubbles from a carbonated drink reach the nasal cavity during laughter, demonstrating the connection between oral and nasal airflow. Sensitivity to odors varies between individuals and can be influenced by factors such as hunger, satiety, emotional state, attention, respiratory infections, and gender. Women who are pregnant or menstruating may experience changes in their sense of smell. Because responses to the same odor differ among people, reliable evaluation of a new food aroma typically requires a large panel of assessors.

2.8.3 Taste

Taste, or gustatory perception, is an important determinant of food choice. For a substance to be detected as having taste, it must first dissolve in water, oil, or saliva. Taste sensations are primarily perceived by taste buds on the surface of the tongue, though they are also found on the mucous membranes of the palate and in certain regions of the throat. Anatomical variations, particularly in the anterior region of the tongue, contribute to individual differences in taste sensitivity. For instance, PROP tasters possess a higher density of fungiform papillae (FP), which affects their perception of certain tastes (Tepper *et al*., 1997; Bartoshuk *et al*., 1994).

In addition to genetic factors, individual taste perception is influenced by sensitivity to sweet, fatty, and bitter components in foods and beverages. Personal preferences are further shaped by factors such as the perceived health benefits of foods and the convenience of consumption (Duffy *et al*., 2003).

2.8.4 Texture

The sense of touch provides essential information about a food’s texture, either through oral sensations or by handling the food with the hands. Texture is perceived in multiple stages: initially through visual cues, followed by tactile feedback from directly handling the food or using utensils, and finally through mouthfeel, which is sensed by the teeth and tactile nerve endings on the tongue and palate. Texture reflects the internal structure and composition of a food and is apparent in its response to applied forces. These mechanical properties include characteristics such as hardness or firmness, adhesiveness, cohesiveness, gumminess, springiness or resilience, and viscosity, which are detected through kinesthetic perception in the hands, fingers, tongue, jaw, and lips (Meilgaard *et al*., 2007). Beyond mechanical attributes, texture also encompasses tactile qualities, which may be described in terms of geometric features (e.g., grainy, gritty, flaky, crystalline) or moisture-related sensations (e.g., wetness, oiliness, dryness, moistness). These are perceived through tactile nerves located on the hands, lips, and tongue (Meilgaard *et al*., 2007). Highly sensitive areas, including the lips, tongue, face, and hands, can detect subtle differences in particle size, as well as variations in temperature and chemical composition of foods.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted at the processing unit at the experimental farm of the Department of Aquaculture and Fisheries Management, University of Benin, located in Ugbowo, Benin City, Edo State, Nigeria. The site is situated at approximately 6.4°N latitude and 5.6°E longitude, with an average ambient temperature of 27.6°C (NAA, 2014; Google Earth, 2023).

3.2 Experimental Design

This study was carried out using a Completely Randomized Design (CRD). Each treatment had three replicates. The spice treatment was labelled as,

(Tl): Control: No spice treatment

(T2): Treated with oregano

(T3): Treated with black pepper

(T4): Treated with a mixture of oregano and black pepper (50% each).

The study employed a 4 x 3 factorial experiment that was used to examine the influence of processing methods and spices treatment of the *Merluccius Merluccius* (Hake). The experimental setup included three main independent variables: the processing methods (smoking, deep frying, and air frying) and the spice treatments (oregano, black pepper and mixture of the two spices).

3.2.1 Treatment Combinations

The combination of processing methods and spice treatments formed a total of 12 treatment combinations.

Spices (4) x processing method (3) = 12 treatments

The 12 treatments were replicated 3 times (12 x 3 =36 samples).

3.3 Sample Collection and Preparation

The primary material for this study was fresh frozen *Merluccius Merluccius* with an average weight of 100-120g, which was bought from a cold room at a major market in Benin City. The spices were also gotten from the market and was finely grounded. The fish gotten from the market at the laboratory was gutted, with the removal of internal organs, and washed using clean, uncontaminated water. A total of 6 apparently uniformly sized *Merluccius Merluccius* fish randomly distributed to the four treatments: Tl, T2, T3, T4. The already finely grounded spices (oregano and black pepper) were applied on the wet surface of the freshly prepared fish at concentration level of 5% w/w based on the treatments, and allowed to marinate for 5-7 minutes before being assigned to the processing methods (Williams, 2012). The proximate composition and organoleptic analysis of this research were conducted over a period of 3 months. At every month intervals, the treated samples were taken to the laboratory for the proximate composition while the organoleptic analysis was done amongst educated panelists.

3.4 Processing Apparatus

3.4.1 Cabinet smoker: is a type of smoking kiln used primarily in fish processing through the application of smoke and heat. It is made of cabinets that is a vertical, box-like structure made of metal and this were where the trays are placed. The smoking trays were arranged in layers inside the cabinet to hold the fish. The furnace is located at the base of the kiln or just below the cabinet, it held the firewood or sawdust used to generate smoke and heat. Chimney allowed smoke to escape while controlling airflow and temperature inside the kiln and the drip tray caught the oil and moisture that dripped from the fish to prevent flare-ups and maintain cleanliness.

3.4.2 Deep Frying: A frying pot which is usually a deep, heavy-duty pan made of aluminum or steel. The depth allowed enough oil to submerge the fish completely for even frying. Gas cooker, this was the heat source which provided quick and adjustable heat. A slotted spoon which had a metal or heat-resistant plastic with holes was used to turn the fish while frying and to remove fried fish from the hot oil, allowing excess oil to drain off.

3.4.3 Air Fryer: The removable basket inside held the fish and had small mesh at the bottom to allow air circulation and excess oil or moisture from the fish drips through the basket holes into the drip tray that was below it. When plugged in, an electric heating element (located above the basket) heated up. A powerful built-in fan which blew the hot air downward and around the fish at high speed. It had a cooking timer and also a temperature control button to set the desired temperature and cooking time.

3.5 Processing Methods

The study investigated the impact of three processing methods on the quality characteristics of spiced *Merluccius merluccius* commonly available in Nigeria.

3.5.1 Cabinet Smoking Kiln: The fish was placed evenly on the smoking trays, ensuring good spacing to allow smoke and heat circulation. The trays were inserted into the cabinet smoking chamber in layers. The fire was ignited in the firebox using charcoal. The airflow was controlled by adjusting the chimney. The fish was monitored regularly to prevent overcooking or burning. When the fish was well-smoked, the trays were removed and the fish was allowed to cool in a clean area to avoid condensation and spoilage.

3.5.2 Deep Fryer: The oil was poured into a deep pot enough to cover the fish fully and was heated on medium-high heat using a gas cooker. The temperature of the heated oil was checked and this was checked by dropping a small piece of onion, when it sizzled and floated, it indicated that the oil was ready. The fish was gently placed in the hot oil using tongs and fried in batches to avoid overcrowding. Each side was fried for at least 3-5 minutes and the fish was turned halfway through for even browning. The fish was said to be ready when it turned golden brown and the skin became crispy. The fish was removed using a slotted spoon and placed on paper towels to drain the excess oil.

3.5.3 Air Fryer: Air-frying was carried out using a digital air fryer. Each fish sample was placed in the air fryer basket in a single layer to ensure even heat circulation. The fish was air-fried, depending on the size and thickness, the samples were turned halfway occasionally during the processing to promote uniform cooking. After air-frying, the sample was removed from the fryer and was allowed to cool at room temperature before subsequent analyses.

3.6 Proximate Composition

Proximate composition analysis is a fundamental procedure used in food science and nutrition to determine the basic nutritional components of a food sample namely; moisture, ash, crude protein, crude fat, crude fiber, and nitrogen-free extract (NFE). Each component was analyzed using standardized laboratory methods, according to Association of Official Analytical Chemists AOAC, (2000).

3.6.1 Moisture Content

Apparatus: Moisture can (silica dish or crucible), hot air-drying oven, desiccator.

The empty moisture can was weighed first and recorded as W_0. A few grams of the different processed fish samples (*Merluccius merluccius*) were placed into the moisture can and weighed as W_1. The samples were then dried in a hot air oven at the desired temperature for some hours and cooled in a desiccator. After cooling, the crucible and the dried sample were weighed again and recorded as W_2. To ensure complete drying, the sample was returned to the oven for a few more hours, followed by cooling in the desiccator and re-weighing. This process was repeated until a constant weight (W_2) was obtained. The percentage moisture content was calculated using the formula:

Moisture (%) = x 100

Where:

W_0 = weight of empty moisture can

W_1 = weight of moisture can + fish sample before drying

W_2 = weight of moisture can + dry sample

3.6.2 Ash Content

Apparatus: Crucible, weighing balance, muffle furnace, spatula, desiccator.

The empty crucible was weighed first and recorded as W_0. A few grams of each processed fish sample were placed into the crucible, and the weight was noted as W_1. The crucible containing the samples was then transferred to a muffle furnace and incinerated for some time at the desired temperature. After ashing, the crucible was removed, cooled in a desiccator, and weighed again to obtain W_2. The percentage ash content was calculated using the formula:

Ash (%) = x 100

Where:

W_0 = weight of empty crucible

W_1= weight of crucible + sample before ashing

W_2= weight of crucible + ash (after ashing)

3.6.3 Crude Protein: This was determined using the Kjeldahl method, which involved estimating total nitrogen and multiplying by a factor of 6.25. A few grams of the different processed fish samples were weighed into a digestion flask. Kjeldahl catalyst tablets and concentrated tetraoxosulphate (VI) acid were added, and the mixture was digested at the desired temperature for some minutes or hours. After cooling, the digest was diluted to the desired volume with distilled water. Then, some volume of 4% boric acid and a drop of methyl red indicator were added. The digest was made alkaline with the desired volume of NaOH solution and then distilled. The distillate was titrated with 0.1 N HCl until a color change from green to pink occurred.

Crude protein (%) was calculated by:

Crude Protein (%) = X 6.25

Where:

Na = Normality of HCl used (0.1N)

Va = Volume of HCl used for titration

V1 = Total volume of digest used

V2 = Volume of digest used for distillation

W = Weight of sample

14 = Atomic number of nitrogen

1000 = Constant

3.6.4 Crude Fat: The extraction flask was initially dried in the oven at the desired temperature, cooled in the desiccator, and weighed (W_0). A few grams of the different fish samples were weighed into a dry porous thimble (W_1) and covered with clean white cotton wool. Then, a volume of petroleum ether was poured into the extraction flask, and the thimble was placed in the Soxhlet extractor above the solvent. The apparatus was assembled and placed in a water bath. Extraction was carried out for some hours. Once the process was complete, the thimble was carefully removed for reuse. The extraction flask was also removed and gently heated to remove any remaining petroleum ether. The flask was dried in the oven, cooled in the desiccator, and reweighed (W_2).

The percentage crude fat was calculated by:

Crude Fat (%) = X 100

Where:

W_0 = weight of empty extraction flask;

W_1 = weight of sample used

W^2 = Weight of empty extraction flask + oil after extraction

3.6.5 Crude fiber: A few grams of each fish sample was weighed into a conical flask. *1.25%* H_2S04 was added and boiled for some minutes, and the volume of H_2SO_4 added was maintained. This was allowed to cool, filtered, and washed to neutrality. The residue was washed back into the same conical flask containing 1.25% NaOH and made up to reach the volume marked. It was boiled for some minutes, maintaining the same volume, then filtered after cooling and washed to neutrality. The residue was washed into a crucible with ethanol and then oven-dried to constant weight. The washed residue was dried in a hot air oven at the desired temperature until a constant weight was obtained. After cooling in a desiccator, the dry weight was recorded as W_1. The residue was then placed in a pre-weighed crucible and incinerated in a muffle furnace at a desired temperature for some minutes or hours. Upon completion of ashing, the crucible was cooled in a desiccator and weighed again to obtain the ash weight (W2). The crude fiber content was calculated using:

$$\textbf{Crude fibre (\%)} = \frac{W1-W2}{w} \times 100$$

Where:

W_1= Weight of dried residue after acid and alkali digestion

W_2= weight of ash after incineration

W= weight of the original sample used

3.6.6 Nitrogen-Free Extract (NFE): The nitrogen free extract which is referred to as soluble carbohydrate was not determined directly but obtained as a difference between the crude protein, ash, moisture, crude fiber and fat. It represented the carbohydrate portion of the food that is readily available like sugars and starches.

N.F.E = 100 - (% ash + % moisture + % crude fiber +% crude fat + % crude protein)

These values were typically expressed as percentages of the original sample and are important for assessing the nutritional value, quality and suitability of food for consumption or further processing.

3.7 Organoleptic Evaluation

Organoleptic characteristics analysis, as outlined by Olaniyi *et al.* (2016), this employed a subjective analysis approach. Seven panelists were recruited for the tests and trained for each attribute like smell, texture, taste, appearance and overall acceptance aspects of organoleptic characteristics and how to allocate mark for each parameter (Adebowale *et al.,* 2008). Fish samples were served in clean plates alongside questionnaires to the panelists. Panelists were instructed to assess the fish by feeling and tasting it, assigning scores based on parameters listed above. The questionnaires were returned and analyzed for each parameter. They were instructed to mask their mouth with the clean water that was provided after tasting each sample to avoid bias in their evaluation and this analysis was carried out in a clean environment. Panelists rated each attribute using a 9-point hedonic scale rating score card as shown in Appendix 1 (Lim, 2011). The ratings provided a comprehensive understanding of how each treatment affected the sensory quality of *Merluccius Merluccius* over the storage period.

3.8 Data Analysis

Data was analyzed using two-way ANOVA to test for significant differences at 5% probability level among treatments. Duncan's Multiple Range Test (DMRT) was used to separate means. Analysis was done using SPSS version 25.0, and the results were expressed as means ± standard deviation.

CHAPTER FOUR

4.0 RESULTS

4.1 Proximate Composition of *Merluccius Merluccius* on Different Processing Methods and Spice Types

The proximate composition of *Merluccius Merluccius* as affected by different processing methods and spice treatments (black pepper, oregano, black pepper + oregano, and control).

4.1.1 Carbohydrate

For the black pepper (BP) treatment, at Week 0, carbohydrate values ranged from 13.79 ± 0.92% in air-fried samples to 18.33 ± 0.45% in smoked samples, and no significant differences ($p > 0.05$) were observed among the processing methods. At Week 6, carbohydrate increased notably in deep-fried (19.83 ± 0.27%) and smoked samples (17.51 ± 1.00%), while air-fried samples remained lowest (9.45 ± 2.62%), and significant differences ($p < 0.05$) were observed. By Week 12, carbohydrate values ranged between 17.99 ± 1.61% and 20.99 ± 0.24%, and no significant differences ($p > 0.05$) were observed.

For the oregano (ORG) treatment, at Week 0, carbohydrate values ranged between 17.40 ± 0.95% and 20.23 ± 2.52%, and no significant differences ($p > 0.05$) were observed. At Week 6, carbohydrate ranged from 17.20 ± 1.60% in smoked to 21.06 ± 0.58% in deep-fried samples, and although deep-fried samples appeared higher, the differences were not statistically significant ($p > 0.05$). However, at Week 12, carbohydrate increased significantly in deep-fried (21.29 ± 0.54%) and smoked samples (20.90 ± 1.62%) compared to air-fried samples (10.30 ± 3.67%), showing significant differences ($p < 0.05$).

Oregano + Black Pepper (ORGBP) treatment, at Week 0, carbohydrate values ranged from 15.90 ± 1.72% to 18.03 ± 2.56%, and there were no significant differences ($p > 0.05$). At Week 6,

Table 4.1.1: Carbohydrate Analysis Based on the Different Processing Methods and Spice Treatment

Weeks	Treatment	Air-fried	Deep Fried	Smoked	F-value	p-value
0	Black Pepper	13.79 ± 0.92^{a}	15.09 ± 1.87^{ab}	18.33 ± 0.45^{b}	7.233	0.071
	Black Pepper + Oregano	17.58 ± 0.93^{a}	18.03 ± 2.56^{a}	15.90 ± 1.72^{a}	0.732	0.551
	Oregano Only	18.46 ± 1.63^{a}	20.23 ± 2.52^{a}	17.40 ± 0.95^{a}	1.235	0.406
	Control	10.92 ± 1.07	–	–	–	–
6	Black Pepper	9.45 ± 2.62^{a}	19.83 ± 0.27^{b}	17.51 ± 1.00^{b}	22.471	0.016*
	Black Pepper + Oregano	16.39 ± 0.44^{a}	21.59 ± 3.39^{a}	15.03 ± 4.50^{a}	2.252	0.253
	Oregano Only	18.56 ± 0.10^{ab}	21.06 ± 0.58^{b}	17.20 ± 1.60^{a}	7.931	0.063
	Control	7.10 ± 2.31	–	–	–	–
12	Black Pepper	20.99 ± 0.24^{a}	17.99 ± 1.61^{a}	18.57 ± 4.91^{a}	0.57	0.617
	Black Pepper + Oregano	18.28 ± 0.07^{a}	22.78 ± 2.15^{b}	27.93 ± 0.56^{c}	28.301	0.011*
	Oregano Only	10.30 ± 3.67^{a}	21.29 ± 0.54^{b}	20.90 ± 1.62^{b}	14.25	0.029*
	Control	17.01 ± 0.78	–	–	–	–

Note: Means with different superscripts across row are significantly different (p<0.05)

carbohydrate values ranged from 15.03 ± 4.50% to 21.59 ± 3.39% across processing methods, and the differences were not significant ($p > 0.05$). By Week 12, carbohydrate content increased to 27.93 ± 0.56% in smoked samples, followed by 22.78 ± 2.15% in deep-fried and 18.28 ± 0.07% in air-fried samples, with significant differences ($p < 0.05$) observed.

For the Control (no spice) treatment, carbohydrate values at Week 0 (10.92 ± 1.07%), Week 6 (7.10 ± 2.31%), and Week 12 (17.01 ± 0.78%) were reported without differences among the processing methods, indicating no significant differences ($p > 0.05$).

4.1.2 Ash Content

For the Black Pepper (BP) treatment, at Week 0, ash values ranged from 0.53 ± 0.09% in air-fried to 1.01 ± 0.17% in smoked samples, and no significant differences ($p > 0.05$) were observed among the processing methods. At Week 6, ash content increased to 1.67 ± 0.08% in deep-fried and 1.69 ± 0.18% in smoked samples, while air-fried samples remained lower at 0.75 ± 0.00%, and significant differences ($p < 0.05$) were observed. However, by Week 12, ash values ranged from 2.00 ± 0.25% to 2.95 ± 0.13%, and no significant difference ($p > 0.05$).

For the Oregano (ORG) treatment, at Week 0, ash ranged from 0.54 ± 0.06% in air-fried to 1.31 ± 0.05% in deep-fried samples, and significant differences ($p < 0.05$) were observed, with deep-fried samples having the highest ash content. At Week 6, ash values ranged between 0.61 ± 0.03% and 1.64 ± 0.63%, and although the means differed numerically, the differences were not statistically significant ($p > 0.05$). At Week 12, ash values ranged from 1.99 ± 0.42% to 2.96 ± 0.17%, and again no significant differences ($p > 0.05$).

For the Oregano + Black Pepper (ORGBP) treatment, at Week 0, ash content ranged between 1.06 ± 0.21% and 1.33 ± 0.40%, and no significant differences ($p > 0.05$) were observed. At Week 6, ash increased to 1.89 ± 0.10% in deep-fried and 1.92 ± 0.13% in smoked samples, compared to

Table 4.1.2: Ash Analysis Based on the Different Processing Methods and Spice Treatment

Weeks	Treatment	Air-fried	Deep Fried	Smoked	F-value	p-value
0	Black Pepper	0.53 ± 0.09^{a}	0.88 ± 0.30^{a}	1.01 ± 0.17^{a}	3.014	0.192
	Black Pepper + Oregano	1.06 ± 0.21^{a}	1.33 ± 0.40^{a}	1.20 ± 0.37^{a}	0.303	0.759
	Oregano Only	0.54 ± 0.06^{a}	1.31 ± 0.05^{c}	0.98 ± 0.02^{b}	128.835	0.001**
	Control	1.08 ± 0.05	–	–	–	–
6	Black Pepper	0.75 ± 0.00^{a}	1.67 ± 0.08^{b}	1.69 ± 0.18^{b}	44.756	0.006**
	Black Pepper + Oregano	1.23 ± 0.17^{a}	1.89 ± 0.10^{b}	1.92 ± 0.13^{b}	16.653	0.024*
	Oregano Only	0.61 ± 0.03^{a}	1.64 ± 0.63^{a}	1.30 ± 0.06^{a}	4.097	0.139
	Control	1.99 ± 0.18	–	–	–	
12	Black Pepper	2.00 ± 0.25^{a}	2.95 ± 0.13^{a}	2.35 ± 0.57^{a}	3.454	0.167
	Black Pepper + Oregano	2.84 ± 0.24^{a}	2.15 ± 0.11^{a}	2.24 ± 0.54^{a}	2.345	0.244
	Oregano Only	2.96 ± 0.17^{b}	2.00 ± 0.18^{ab}	1.99 ± 0.42^{ab}	8.039	0.062
	Control	2.16 ± 0.02	–	–	–	–

Note: Means with different superscripts across row are significantly different (p<0.05)

1.23 ± 0.17% in air-fried, and significant differences ($p < 0.05$) were observed. At Week 12, ash values ranged from 2.15 ± 0.11% to 2.84 ± 0.24%, and no significant differences ($p > 0.05$) were observed.

For the Control (no spice) treatment, ash values at Week 0 (1.08 ± 0.05%), Week 6 (1.99 ± 0.18%), and Week 12 (2.16 ± 0.02%) were recorded without processing differences, indicating no significant differences ($p > 0.05$) across air-frying, deep-frying, and smoking.

4.1.3 Fat Content

For the Black Pepper (BP) treatment, at Week 0, fat values ranged from 5.56 ± 0.60% in air-fried to 8.66 ± 0.78% in smoked samples, and there were significant differences ($p < 0.05$), with smoked and deep-fried samples having higher fat content than air-fried samples. At Week 6, fat values ranged between 5.49 ± 0.29% and 7.21 ± 0.26%, and there were no significant differences ($p > 0.05$). However, by Week 12, fat decreased to 1.76 ± 0.28% in deep-fried samples compared to 3.70 ± 0.13% in air-fried and 3.71 ± 0.42% in smoked samples, and significant differences ($p < 0.05$) were observed.

For the Oregano (ORG) treatment, at Week 0, fat levels ranged between 7.65 ± 0.45% and 8.42 ± 0.52%, and no significant differences ($p > 0.05$) were observed among processing methods. At Week 6, fat values were 7.83 ± 0.30% in air-fried, 6.60 ± 0.09% in deep-fried, and 6.47 ± 0.41% in smoked samples, and significant differences ($p < 0.05$) were observed, with air-fried samples having significantly higher fat content. By Week 12, fat values decreased further to 3.52 ± 0.06% in air-fried, 3.18 ± 0.02% in deep-fried, and 3.15 ± 0.05% in smoked samples, and significant differences were observed ($p < 0.05$), with air-fried remaining higher.

Weeks	Treatment	Air-fried	Deep Fried	Smoked	F-value	p-value
0	Black Pepper	5.56 ± 0.60^{a}	8.16 ± 0.46^{b}	8.66 ± 0.78^{b}	14.145	0.030*
	Black Pepper + Oregano	7.69 ± 0.60^{a}	7.97 ± 0.41^{a}	7.47 ± 0.81^{a}	0.323	0.746
	Oregano Only	8.39 ± 0.21^{a}	8.42 ± 0.52^{a}	7.65 ± 0.45^{a}	2.235	0.255
	Control	5.77 ± 0.23	–	–	–	–
6	Black Pepper	5.49 ± 0.29^{a}	6.07 ± 1.00^{a}	7.21 ± 0.26^{a}	4.007	0.142
	Black Pepper + Oregano	5.81 ± 0.06^{a}	7.47 ± 0.91^{ab}	7.82 ± 0.47^{b}	6.586	0.08
	Oregano Only	7.83 ± 0.30^{b}	6.60 ± 0.09^{ab}	6.47 ± 0.41^{a}	12.801	0.034*
	Control	3.63 ± 4.68	–	–	–	–
12	Black Pepper	3.70 ± 0.13^{b}	1.76 ± 0.28^{a}	3.71 ± 0.42^{b}	27.394	0.012*
	Black Pepper + Oregano	2.75 ± 0.11^{a}	2.43 ± 0.02^{a}	3.43 ± 0.62^{a}	3.965	0.144
	Oregano Only	3.52 ± 0.06^{b}	3.18 ± 0.02^{ab}	3.15 ± 0.05^{a}	42.713	0.006**
	Control	3.64 ± 0.32	–	–	–	

Table 4.1.3: Fat Analysis Based on the Different Processing Methods and Spice Treatment

Note: Means with different superscripts across row are significantly different (p<0.05)

For the Oregano + Black Pepper (ORGBP) treatment, at Week 0, fat values ranged from 7.47 ± 0.81% to 7.97 ± 0.41%, and no significant differences ($p > 0.05$) were observed. At Week 6, fat increased slightly to 7.82 ± 0.47% in smoked and 7.47 ± 0.91% in deep-fried, compared to 5.81 ± 0.06% in air-fried, but the difference was not statistically significant ($p > 0.05$). By Week 12, fat values reduced to 2.75 ± 0.11% in air-fried, 2.43 ± 0.02% in deep-fried, and 3.43 ± 0.62% in smoked, and no significant differences ($p > 0.05$) were observed.

For the Control (no spice) treatment, fat content was 5.77 ± 0.23% at Week 0, 3.63 ± 4.68% at Week 6, and 3.64 ± 0.32% at Week 12, with no significant differences ($p > 0.05$) reported among processing methods.

4.1.4 Fibre Content

For the Black Pepper (BP) treatment, at Week 0, fibre content ranged from 2.97 ± 0.13% in deep-fried to 5.04 ± 0.25% and 4.87 ± 0.25% in air-fried and smoked samples, respectively, and significant differences ($p < 0.05$) were observed, with deep-fried samples having significantly lower fibre content. At Week 6, fibre values ranged from 4.54 ± 0.41% to 5.92 ± 1.28%, and no significant differences ($p > 0.05$) were observed among processing methods. By Week 12, fibre values increased to 6.55 ± 0.62% in air-fried, 5.92 ± 0.16% in deep-fried, and 6.96 ± 0.12% in smoked samples, and no significant differences ($p > 0.05$) were observed.

For the Oregano (ORG) treatment, at Week 0, fibre values ranged from 3.44 ± 0.11% in deep-fried to 3.99 ± 0.04% and 4.28 ± 0.15% in air-fried and smoked samples, respectively, and significant differences ($p < 0.05$) were observed, with deep-fried samples showing significantly lower fibre content. At Week 6, fibre values ranged from 3.94 ± 0.11% to 5.08 ± 0.78%, and no significant differences were observed ($p > 0.05$). At Week 12, fibre increased slightly to between

5.87 ± 0.26% and 6.56 ± 0.15%, and no significant differences (p > 0.05) were observed among methods.

Table 4.1.4: Crude Fibre Analysis Based on the Different Processing Methods and Spice Treatment

Weeks	Treatment	Air-fried	Deep Fried	Smoked	F-value	p-value
0	Black Pepper	5.04 ± 0.25^{b}	2.97 ± 0.13^{a}	4.87 ± 0.25^{b}	56.377	0.004**
	Black Pepper + Oregano	3.30 ± 0.19^{a}	4.57 ± 0.78^{ab}	5.28 ± 0.08^{b}	9.193	0.053
	Oregano Only	3.99 ± 0.04^{b}	3.44 ± 0.11^{a}	4.28 ± 0.15^{b}	29.494	0.011*
	Control	5.00 ± 0.24	–	–	–	–
6	Black Pepper	4.80 ± 0.33^{a}	5.92 ± 1.28^{a}	4.54 ± 0.41^{a}	1.675	0.325
	Black Pepper + Oregano	4.74 ± 0.15^{b}	3.91 ± 0.02^{a}	5.78 ± 0.21^{c}	81.602	0.002**
	Oregano Only	4.02 ± 0.13^{a}	3.94 ± 0.11^{a}	5.08 ± 0.78^{a}	3.765	0.152
	Control	3.47 ± 0.08	–	–	–	–
12	Black Pepper	6.55 ± 0.62^{a}	5.92 ± 0.16^{a}	6.96 ± 0.12^{a}	3.927	0.145
	Black Pepper + Oregano	6.10 ± 0.01^{a}	6.20 ± 0.04^{a}	5.97 ± 0.21^{a}	1.894	0.294
	Oregano Only	6.56 ± 0.15^{a}	5.87 ± 0.26^{a}	5.87 ± 0.34^{a}	4.596	0.122
	Control	6.45 ± 0.47	–	–	–	–

Note: Means with different superscripts across row are significantly different (p<0.05)

For the Oregano + Black Pepper (ORGBP) treatment, at Week 0, fibre ranged from 3.30 ± 0.19% in air-fried to 5.28 ± 0.08% in smoked samples, though the difference was not statistically significant ($p > 0.05$). At Week 6, fibre ranged from 3.91 ± 0.02% in deep-fried to 4.74 ± 0.15% in air-fried and 5.78 ± 0.21% in smoked, and highly significant differences ($p < 0.05$) were observed, with smoked samples having the highest fibre and deep-fried the lowest. By Week 12, fibre values ranged narrowly from 5.97 ± 0.21% to 6.20 ± 0.04%, and no significant differences ($p > 0.05$) were observed.

For the Control (no spice) treatment, fibre values were 5.00 ± 0.24% at Week 0, 3.47 ± 0.08% at Week 6, and 6.45 ± 0.47% at Week 12, with no significant differences ($p > 0.05$) reported.

4.1.5 Moisture Content

For the Black Pepper (BP) treatment, at Week 0, moisture values ranged from 47.50 ± 1.32% in smoked samples to 60.65 ± 4.77% in air-fried samples, and significant differences ($p < 0.05$) were observed, with air-fried samples retaining higher moisture while smoked samples showed the lowest due to dehydration. At Week 6, moisture values ranged from 46.73 ± 1.23% in smoked to 57.46 ± 3.39% in air-fried, and significant differences ($p < 0.05$) were observed, confirming that smoking consistently reduced moisture while air frying maintained higher moisture content. By Week 12, moisture values ranged from 41.65 ± 1.47% in smoked to 55.16 ± 2.81% in air-fried, and there were significant differences ($p < 0.05$).

For the Oregano (ORG) treatment, at Week 0, moisture values ranged between 45.76 ± 0.52% in smoked and 60.37 ± 4.36% in air-fried, and significant differences ($p < 0.05$) were observed.

Table 4.1.5: Moisture Content Analysis Based on the Different Processing Methods and Spice Treatment

Weeks	Treatment	Air-fried	Deep Fried	Smoked	F-value	p-value
0	Black Pepper	15.05 ± 0.08^{b}	15.10 ± 0.18^{b}	14.22 ± 0.32^{a}	10.58	0.044*
	Black Pepper + Oregano	15.68 ± 0.80^{a}	13.95 ± 1.38^{a}	13.85 ± 0.32^{a}	2.405	0.238
	Oregano Only	15.97 ± 0.33^{a}	14.21 ± 1.55^{a}	14.69 ± 0.18^{a}	1.955	0.286
	Control	15.28 ± 0.74	–	–	–	–
6	Black Pepper	18.07 ± 0.11^{a}	15.52 ± 2.31^{a}	16.54 ± 0.86^{a}	1.626	0.332
	Black Pepper + Oregano	15.62 ± 0.43^{a}	15.85 ± 0.96^{a}	18.06 ± 0.57^{b}	7.555	0.067
	Oregano Only	16.54 ± 0.30^{ab}	15.70 ± 0.74^{a}	18.56 ± 0.49^{b}	14.835	0.028*
	Control	41.81 ± 1.84	–	–	–	–
12	Black Pepper	18.34 ± 0.16^{a}	23.22 ± 1.07^{a}	24.84 ± 5.41^{a}	2.257	0.252
	Black Pepper + Oregano	19.43 ± 0.08^{a}	17.38 ± 0.47^{a}	18.23 ± 2.24^{a}	1.211	0.412
	Oregano Only	17.97 ± 3.10^{a}	18.39 ± 0.03^{a}	17.55 ± 0.42^{a}	0.11	0.9
	Control	19.92 ± 0.36	–	–	–	–

Note: Means with different superscripts across row are significantly different (p<0.05)

At Week 6, moisture ranged from 48.07 ± 1.23% to 58.19 ± 3.17%, and again significant differences ($p < 0.05$) were observed, with air-fried retaining the highest moisture. By Week 12, moisture values ranged between 45.67 ± 0.12% in smoked and 54.18 ± 3.06% in air-fried, and significant differences ($p < 0.05$) were observed.

For the Oregano + Black Pepper (ORGBP) treatment, at Week 0, moisture ranged from 46.37 ± 0.97% in smoked to 59.51 ± 3.11% in air-fried, and significant differences ($p < 0.05$) were observed. At Week 6, moisture ranged between 47.32 ± 0.08% and 57.43 ± 1.18%, and significant differences ($p < 0.05$) were observed, with deep-fried and smoked samples showing lower moisture levels due to oil penetration and heat-induced dehydration. By Week 12, moisture remained lowest in smoked (45.92 ± 0.37%), moderate in deep-fried, and highest in air-fried (54.41 ± 2.10%), and significant differences ($p < 0.05$) persisted.

For the Control (no spice) treatment, moisture values were 59.33 ± 2.86% at Week 0, 56.15 ± 3.98% at Week 6, and 53.02 ± 2.11% at Week 12, with significant differences ($p < 0.05$) among processing methods.

4.1.6 Protein Content

For the Black Pepper (BP) treatment, at Week 0, protein content ranged from 52.92 ± 1.13% in smoked samples to 60.06 ± 0.39% in air-fried samples, and significant differences ($p < 0.05$) were observed, indicating that air-frying preserved protein more effectively, while smoking resulted in greater protein loss due to heat denaturation. At Week 6, protein values ranged narrowly between 52.01 ± 1.08% and 52.50 ± 2.28%, and no significant differences ($p > 0.05$) were observed among processing methods. By Week 12, protein values ranged from 48.43 ± 0.30% in air-fried to 72.29 ± 30.65% in smoked samples, and no significant differences ($p >0.05$)

were recorded, although the numerical increase in smoked samples reflects concentration effects resulting from moisture loss rather than actual protein gain.

Table 4.1.6: Crude protein Analysis Based on the Different Processing Methods and Spice Treatment

Weeks	Treatment	Air-fried	Deep Fried	Smoked	F-value	p-value
0	Black Pepper	60.06 ± 0.39^{b}	57.82 ± 2.58^{ab}	52.92 ± 1.13^{a}	9.872	0.048*
	Black Pepper + Oregano	54.77 ± 1.61^{a}	56.16 ± 1.69^{a}	56.32 ± 3.14^{a}	0.286	0.769
	Oregano Only	52.67 ± 1.39^{a}	52.42 ± 1.36^{a}	55.03 ± 1.35^{a}	2.214	0.257
	Control	57.16 ± 6.97	–	–	–	–
6	Black Pepper	52.11 ± 1.42^{a}	52.50 ± 2.28^{a}	52.01 ± 1.08^{a}	0.049	0.953
	Black Pepper + Oregano	56.22 ± 0.09^{a}	51.29 ± 1.60^{a}	61.39 ± 13.80^{a}	0.793	0.529
	Oregano Only	52.15 ± 0.05^{a}	51.23 ± 0.56^{a}	51.35 ± 1.70^{a}	0.466	0.666
	Control	35.14 ± 5.12	–	–	–	–
12	Black Pepper	48.43 ± 0.30^{a}	48.87 ± 2.83^{a}	72.29 ± 30.65^{a}	1.179	0.419
	Black Pepper + Oregano	50.70 ± 0.03^{a}	48.53 ± 2.33^{a}	46.10 ± 4.00^{a}	1.483	0.357
	Oregano Only	51.87 ± 2.64^{a}	48.78 ± 0.08^{a}	50.31 ± 0.04^{a}	2.052	0.274
	Control	40.60 ± 14.13	–	–	–	–

Note: Means with different superscripts across row are significantly different (p<0.05)

For the Oregano (ORG) treatment, at Week 0, protein values ranged from 52.42 ± 1.36% in deep-fried to 55.03 ± 1.35% in smoked samples, and no significant differences were observed ($p > 0.05$). At Week 6, protein ranged from 51.23 ± 0.56% to 52.15 ± 0.05%, and again no significant differences were observed ($p > 0.05$). By Week 12, protein values ranged between 48.78 ± 2.33% in deep-fried and 51.87 ± 2.64% in air-fried samples, and no significant differences were recorded ($p > 0.05$).

For the Oregano + Black Pepper (ORGBP) treatment, at Week 0, protein values ranged from 53.06 ± 4.49% in deep-fried to 59.07 ± 17.13% in smoked samples, and no significant differences ($p > 0.05$) were observed. At Week 6, protein ranged from 51.99 ± 3.76% in deep-fried to 54.60 ± 9.58% in smoked samples, and no significant differences ($p > 0.05$) were observed. By Week 12, protein values ranged from 50.81 ± 1.79% in deep-fried to 52.23 ± 2.42% in smoked and air-fried samples, and no significant differences ($p > 0.05$) were recorded.

For the Control (no spice) treatment, protein values were 57.16 ± 6.97% at Week 0, decreased to 35.14 ± 5.12% at Week 6, and increased again to 40.60 ± 14.13% at Week 12, with no significant differences ($p > 0.05$) observed.

4.2 General Mean of Proximate Composition of *Merluccius Merluccius* based on the processing methods and spices.

The proximate composition of *Merluccius Merluccius* was influenced by both spice treatment and processing method, although most differences were not statistically significant ($p > 0.05$). The results for each proximate parameter are presented below.

4.2.1 Carbohydrate

Carbohydrate content varied across both spice treatments and processing methods. For the Black Pepper (BP) treatment, CHO was lowest in air-fried samples (14.74 ± 5.36%), slightly higher in

Table 4.2.1: Proximate Composition of *Merluccius merluccius* by Processing Methods and Spice Types

Nutrient	Treatment	Air-fried	Deep-fried	Smoked	F-value	p-value
CHO	Black Pepper	14.74 ± 5.36[a]	17.64 ± 2.41[a]	18.14 ± 2.30[a]	1.516	0.251
	Black Pepper + Oregano	17.42 ± 0.97[a]	20.80 ± 3.07[a]	19.62 ± 6.80[a]	0.937	0.413
	Oregano Only	15.77 ± 4.61[a]	20.86 ± 1.28[b]	18.50 ± 2.16[ab]	4.233	0.035*
	Control (No Spice)	11.68 ± 4.63[a]	11.68 ± 4.63[a]	11.68 ± 4.63[a]	0.000	1.000
Ash	Black Pepper	1.09 ± 0.72[a]	1.83 ± 0.95[a]	1.68 ± 0.66[a]	1.503	0.254
	Black Pepper + Oregano	1.71 ± 0.89[a]	1.79 ± 0.42[a]	1.78 ± 0.56[a]	0.026	0.974
	Oregano Only	1.37 ± 1.24[a]	1.65 ± 0.43[a]	1.42 ± 0.50[a]	0.199	0.822
	Control (No Spice)	1.74 ± 0.53[a]	1.74 ± 0.53[a]	1.74 ± 0.53[a]	0.000	1.000
Fat	Black Pepper	4.91 ± 0.99[a]	5.33 ± 2.96[a]	6.53 ± 2.31[a]	0.836	0.453
	Black Pepper + Oregano	5.41 ± 2.25[a]	5.96 ± 2.78[a]	6.24 ± 2.24[a]	0.177	0.839
	Oregano Only	6.58 ± 2.39[a]	6.06 ± 2.39[a]	5.75 ± 2.11[a]	0.197	0.823
	Control (No Spice)	4.35 ± 2.37[a]	4.35 ± 2.37[a]	4.35 ± 2.37[a]	0.000	1.000
Fibre	Black Pepper	5.46 ± 0.91[a]	4.93 ± 1.63[a]	5.45 ± 1.19[a]	0.336	0.720
	Black Pepper + Oregano	4.71 ± 1.26[a]	4.89 ± 1.11[a]	5.67 ± 0.34[a]	1.604	0.234
	Oregano Only	4.85 ± 1.32[a]	4.41 ± 1.15[a]	5.07 ± 0.81[a]	0.544	0.591
	Control (No Spice)	4.97 ± 1.35[a]	4.97 ± 1.35[a]	4.97 ± 1.35[a]	0.000	1.000
Moisture	Black Pepper	17.15 ± 1.64[a]	17.95 ± 4.25[a]	18.53 ± 5.56[a]	0.167	0.848
	Black Pepper + Oregano	16.91 ± 1.99[a]	15.72 ± 1.72[a]	16.71 ± 2.45[a]	0.557	0.585
	Oregano Only	16.83 ± 1.68[a]	16.10 ± 2.05[a]	16.93 ± 1.82[a]	0.358	0.705
	Control (No Spice)	25.67 ± 12.71[a]	25.67 ± 12.71[a]	25.67 ± 12.71[a]	0.000	1.000
Protein	Black Pepper	53.53 ± 5.36[a]	53.06 ± 4.49[a]	59.07 ± 17.13[a]	0.587	0.568
	Black Pepper + Oregano	53.89 ± 2.66[a]	51.99 ± 3.76[a]	54.60 ± 9.58[a]	0.291	0.752
	Oregano Only	52.23 ± 1.38[a]	50.81 ± 1.79[a]	52.23 ± 2.42[a]	1.103	0.357
	Control (No Spice)	44.30 ± 12.65[a]	44.30 ± 12.65[a]	44.30 ± 12.65[a]	0.000	1.000

Note: Means with different superscripts across row are significantly different (p<0.05)

deep-fried samples (17.64 ± 2.41%), and highest in smoked samples (18.14 ± 2.30%), with no significant differences ($p > 0.05$).

In the Black Pepper + Oregano treatment, CHO was highest in deep-fried samples (20.80 ± 3.07%), moderate in smoked samples (19.62 ± 6.80%), and lowest in air-fried samples (17.42 ± 0.97%), with no significant differences ($p > 0.05$).

For the Oregano-only treatment, significant differences were observed ($p < 0.05$), with deep-fried samples having the highest carbohydrate content (20.86 ± 1.28%), smoked samples moderate (18.50 ± 2.16%), and air-fried samples the lowest (15.77 ± 4.61%).

Control samples without spices showed relatively uniform carbohydrate content across all processing methods (11.68 ± 4.63%), with no significant differences ($p > 0.05$).

4.2.2 Crude Protein

Protein content was generally high across treatments. In the Black Pepper treatment, smoked samples had the highest protein content (59.07 ± 17.13%), while air-fried (53.53 ± 5.36%) and deep-fried (53.06 ± 4.49%) samples were slightly lower, with no significant differences ($p > 0.05$).

In the Black Pepper + Oregano treatment, protein was highest in smoked samples (54.60 ± 9.58%), moderate in air-fried (53.89 ± 2.66%), and lowest in deep-fried (51.99 ± 3.76%), with no significant differences ($p > 0.05$).

For the Oregano-only treatment, smoked and air-fried samples had slightly higher protein (52.23 ± 2.42% and 52.23 ± 1.38%, respectively) compared to deep-fried samples (50.81 ± 1.79%), with no significant differences ($p > 0.05$).

Control samples were uniform at 44.30 ± 12.65% across all processing methods, with no significant differences ($p > 0.05$).

4.2.3 Crude Fat

Fat content showed small variations across treatments. In the Black Pepper treatment, smoked samples had the highest fat (6.53 ± 2.31%), deep-fried were moderate (5.33 ± 2.96%), and air-fried the lowest (4.91 ± 0.99%), with no significant differences ($p > 0.05$).

For the Black Pepper + Oregano treatment, fat was slightly higher in smoked samples (6.24 ± 2.24%) compared to deep-fried (5.96 ± 2.78%) and air-fried (5.41 ± 2.25%), with no significant differences ($p > 0.05$).

In the Oregano-only treatment, air-fried samples had the highest fat content (6.58 ± 2.39%), deep-fried were moderate (6.06 ± 2.39%), and smoked samples were lowest (5.75 ± 2.11%), with no significant differences ($p > 0.05$).

Control samples remained uniform at 4.35 ± 2.37% across all processing methods, with no significant differences ($p > 0.05$).

4.2.4 Ash Content

Ash content, representing mineral content, was slightly influenced by processing methods. In the Black Pepper treatment, deep-fried samples had the highest ash (1.83 ± 0.95%), smoked samples moderate (1.68 ± 0.66%), and air-fried the lowest (1.09 ± 0.72%), with no significant differences ($p > 0.05$).

For the Black Pepper + Oregano treatment, ash content was fairly uniform with deep-fried (1.79 ± 0.42%), smoked (1.78 ± 0.56%), and air-fried (1.71 ± 0.89%), with no significant differences ($p > 0.05$).

In the Oregano-only treatment, deep-fried samples were slightly higher (1.65 ± 0.43%), smoked moderate (1.42 ± 0.50%), and air-fried the lowest (1.37 ± 1.24%), with no significant differences ($p > 0.05$).

Control samples were uniform at 1.74 ± 0.53% across all processing methods, with no significant differences ($p > 0.05$).

4.2.5 Crude Fibre

Fibre content showed minor differences across treatments. In the Black Pepper treatment, air-fried samples had the highest fibre (5.46 ± 0.91%), smoked samples were moderate (5.45 ± 1.19%), and deep-fried the lowest (4.93 ± 1.63%), with no significant differences ($p > 0.05$).

For the Black Pepper + Oregano treatment, fibre was highest in smoked samples (5.67 ± 0.34%), moderate in deep-fried (4.89 ± 1.11%), and lowest in air-fried (4.71 ± 1.26%), with no significant differences ($p > 0.05$).

In the Oregano-only treatment, smoked samples were highest (5.07 ± 0.81%), air-fried moderate (4.85 ± 1.32%), and deep-fried lowest (4.41 ± 1.15%), with no significant differences ($p > 0.05$).

Control samples were uniform across all processing methods (4.97 ± 1.35%), with no significant differences ($p > 0.05$).

4.2.6 Moisture Content

Moisture content varied across both processing methods and spice treatments. In the Black Pepper treatment, air-fried samples had the lowest moisture (17.15 ± 1.64%), deep-fried moderate (17.95 ± 4.25%), and smoked samples the highest (18.53 ± 5.56%), with no significant differences ($p > 0.05$).

For the Black Pepper + Oregano treatment, deep-fried samples had slightly lower moisture (15.72 ± 1.72%) compared to air-fried (16.91 ± 1.99%) and smoked (16.71 ± 2.45%), with no significant differences ($p > 0.05$).

In the Oregano-only treatment, deep-fried samples had the lowest moisture (16.10 ± 2.05%), air-fried moderate (16.83 ± 1.68%), and smoked samples the highest (16.93 ± 1.82%), with no significant differences ($p > 0.05$).

Control samples were uniform across all processing methods (25.67 ± 12.71%), with no significant differences ($p > 0.05$). Overall, smoked samples tended to retain slightly more moisture, while deep-frying reduced moisture.

4.3 Sensory Evaluation of Processed *Merluccius merluccius* Based on the Different Processing Methods and Spices Treatment

4.3.1 Flavour

For the Black Pepper (BP) treatment, in June, flavour values ranged from 5.29 ± 2.50 in air-fried to 6.86 ± 1.95 in deep-fried and 5.86 ± 1.57 in smoked samples, and no significant differences ($p > 0.05$) were observed among the processing methods, though deep-fried samples had slightly higher flavour scores. In July, flavour ranged from 6.14 ± 2.27 in air-fried to 6.86 ± 1.34 in deep-fried and 6.71 ± 1.80 in smoked samples, and no significant differences ($p > 0.05$) were observed. In August, flavour values ranged from 5.43 ± 1.62 in air-fried to 7.14 ± 1.95 in deep-fried and 6.14 ± 1.77 in smoked samples, and again no significant differences ($p > 0.05$) were observed.

For the Oregano (ORG) treatment, in June, flavour scores ranged from 4.71 ± 1.98 in air-fried to 6.86 ± 1.68 in deep-fried and 4.14 ± 2.48 in smoked samples, and no significant differences ($p > 0.05$) were observed, even though deep-fried samples had higher scores. In July, flavour values ranged from 5.71 ± 1.70 in air-fried to 7.14 ± 1.77 in deep-fried and 6.86 ± 1.57 in smoked, with no significant differences ($p > 0.05$). By August, flavour ranged from 5.00 ± 1.73 in air-fried to

7.29 ± 1.80 in deep-fried and 5.57 ± 2.30 in smoked samples, and no significant differences ($p > 0.05$) were observed.

For the Oregano + Black Pepper (ORGBP) treatment, in June, flavour values were 5.71 ± 2.43 in air-fried, 7.29 ± 1.70 in deep-fried, and 5.14 ± 2.73 in smoked fish, with no significant differences ($p > 0.05$) among methods. In July, flavour ranged from 6.00 ± 2.16 in air-fried to 6.71 ± 2.21 in deep-fried and 6.86 ± 1.77 in smoked fish, and no significant differences ($p > 0.05$) were observed.

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black Pepper	June	5.29 ± 2.50^{a}	6.86 ± 1.95^{a}	5.86 ± 1.57^{a}	1.061	0.367
	July	6.14 ± 2.27^{a}	6.86 ± 1.34^{a}	6.71 ± 1.80^{a}	0.294	0.749
	August	5.43 ± 1.62^{a}	7.14 ± 1.95^{a}	6.14 ± 1.77^{a}	1.627	0.224
Control	June	7.00 ± 1.53^{a}	7.00 ± 2.16^{a}	7.71 ± 1.11^{a}	0.434	0.655
	July	6.57 ± 1.13^{a}	6.43 ± 1.90^{a}	6.86 ± 2.41^{a}	0.093	0.911
	August	7.00 ± 1.53^{a}	7.43 ± 2.23^{a}	8.29 ± 0.95^{a}	1.099	0.355
Oregano	June	4.71 ± 1.98^{ab}	6.86 ± 1.68^{b}	4.14 ± 2.48^{a}	3.344	0.058
	July	5.71 ± 1.70^{a}	7.14 ± 1.77^{a}	6.86 ± 1.57^{a}	1.408	0.27
	August	5.00 ± 1.73^{a}	7.29 ± 1.80^{a}	5.57 ± 2.30^{a}	2.579	0.104
Oregano + Black pepper	June	5.71 ± 2.43^{a}	7.29 ± 1.70^{a}	5.14 ± 2.73^{a}	1.588	0.232
	July	6.00 ± 2.16^{a}	6.71 ± 2.21^{a}	6.86 ± 1.77^{a}	0.348	0.711
	August	6.43 ± 2.44^{a}	8.14 ± 0.90^{a}	6.86 ± 1.46^{a}	1.877	0.182

Table 4.3.1: Flavour Analysis based on the various Processing Methods and Spices

Note: Means with different superscripts across row are significantly different ($p<0.05$)

In August, flavour scores were 6.43 ± 2.44 in air-fried, 8.14 ± 0.90 in deep-fried, and 6.86 ± 1.46 in smoked fish, and no significant differences ($p > 0.05$) were recorded

For the Control (CT) treatment, in June, flavour values were 7.00 ± 1.53 in air-fried, 7.00 ± 2.16 in deep-fried, and 7.71 ± 1.11 in smoked fish, and no significant differences ($p > 0.05$) were observed. In July, flavour ranged from 6.57 ± 1.13 in air-fried to 6.43 ± 1.90 in deep-fried and 6.86 ± 2.41 in smoked samples, and no significant differences ($p > 0.05$) were observed. By August, flavour increased slightly to 7.00 ± 1.53 in air-fried, 7.43 ± 2.23 in deep-fried, and 8.29 ± 0.95 in smoked samples, but no significant differences ($p > 0.05$) were observed.

4.3.2 Aroma

For the Black Pepper (BP) treatment, in June, aroma values ranged from 6.00 ± 1.53 in air-fried to 7.71 ± 0.76 in deep-fried and 6.29 ± 1.38 in smoked samples, and there were significant differences ($p < 0.05$) among the processing methods. The deep-fried fish had the highest aroma score, indicating that deep-frying enhanced the aromatic appeal of black-pepper-seasoned fish. In July, aroma ranged from 5.71 ± 2.69 to 6.71 ± 1.38 and 6.43 ± 1.90, with no significant differences ($p > 0.05$) observed. By August, aroma ranged from 6.57 ± 0.79 in air-fried to 7.71 ± 0.76 in deep-fried and 6.71 ± 1.38 in smoked fish, and no significant differences ($p > 0.05$) were observed.

For the Oregano (ORG) treatment, in June, aroma scores ranged from 6.43 ± 1.51 in air-fried to 7.43 ± 0.79 in deep-fried and 5.43 ± 2.44 in smoked samples, and no significant differences ($p > 0.05$) were observed among processing methods. In July, aroma ranged between 5.71 ± 2.29 in air-fried, 6.71 ± 1.70 in deep-fried, and 6.29 ± 1.50 in smoked fish, and no significant differences ($p > 0.05$) were recorded. By August, aroma increased to 7.00 ± 1.16 in air-fried, 7.71 ± 0.76 in deep-fried, and 6.29 ± 1.98 in smoked fish, with no significant differences ($p > 0.05$) observed.

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black pepper	June	6.00 ± 1.53^{a}	7.71 ± 0.76^{b}	6.29 ± 1.38^{a}	3.683	0.046
	July	5.71 ± 2.69^{a}	6.71 ± 1.38^{a}	6.43 ± 1.90^{a}	0.437	0.653
	August	6.57 ± 0.79^{a}	7.71 ± 0.76^{a}	6.71 ± 1.38^{a}	2.631	0.099
Control	June	6.14 ± 1.86^{a}	7.00 ± 1.53^{a}	7.29 ± 0.76^{a}	1.164	0.335
	July	6.43 ± 1.90^{a}	6.00 ± 2.08^{a}	6.71 ± 2.14^{a}	0.217	0.807
	August	6.57 ± 1.51^{a}	7.43 ± 1.62^{a}	7.43 ± 0.79^{a}	0.931	0.412
Oregano	June	6.43 ± 1.51^{a}	7.43 ± 0.79^{a}	5.43 ± 2.44^{a}	2.371	0.122
	July	5.71 ± 2.29^{a}	6.71 ± 1.70^{a}	6.29 ± 1.50^{a}	0.509	0.609
	August	7.00 ± 1.16^{a}	7.71 ± 0.76^{a}	6.29 ± 1.98^{a}	1.844	0.187
Oregano + Black pepper	June	5.43 ± 1.90^{a}	6.57 ± 1.27^{a}	6.00 ± 2.16^{a}	0.692	0.513
	July	6.00 ± 2.08^{a}	6.14 ± 2.04^{a}	6.14 ± 1.34^{a}	0.014	0.986
	August	6.00 ± 1.16^{a}	7.00 ± 1.41^{a}	6.71 ± 2.14^{a}	0.705	0.507

Table 4.3.2: **Aroma Analysis Based on the Various Processing Methods and Spices**

Note: Means with different superscripts across row are significantly different ($p<0.05$)

For the Oregano + Black Pepper (ORGBP) treatment, in June, aroma values were 5.43 ± 1.90 in air-fried, 6.57 ± 1.27 in deep-fried, and 6.00 ± 2.16 in smoked fish, and no significant differences ($p > 0.05$) were observed. In July, aroma ranged from 6.00 ± 2.08 to 6.14 ± 2.04 and 6.14 ± 1.34 in air-fried, deep-fried, and smoked samples respectively, and no significant differences ($p > 0.05$) were observed. In August, aroma ranged from 6.00 ± 1.16 in air-fried to 7.00 ± 1.41 in deep-fried and 6.71 ± 2.14 in smoked fish, and no significant differences ($p > 0.05$) were observed.

For the Control (CT) treatment, in June, aroma scores were 6.14 ± 1.86 in air-fried, 7.00 ± 1.53 in deep-fried, and 7.29 ± 0.76 in smoked fish, with no significant differences ($p > 0.05$) observed. In July, aroma ranged between 6.43 ± 1.90, 6.00 ± 2.08, and 6.71 ± 2.14 for air-fried, deep-fried, and smoked samples respectively, and no significant differences ($p > 0.05$) were observed. By August, aroma ranged from 6.57 ± 1.51 in air-fried to 7.43 ± 1.62 in deep-fried and 7.43 ± 0.79 in smoked fish, and no significant differences ($p > 0.05$) were observed.

4.3.3 Texture

For the Black Pepper (BP) treatment, in June, texture values ranged from 6.00 ± 1.16 in air-fried to 7.14 ± 1.46 in deep-fried and 5.86 ± 1.46 in smoked samples, and no significant differences ($p > 0.05$) were observed. In July, texture ranged between 6.57 ± 1.81, 6.71 ± 1.38, and 7.86 ± 1.22 for air-fried, deep-fried, and smoked samples respectively, and no significant differences ($p > 0.05$) were observed. In August, texture ranged from 6.57 ± 0.79 in air-fried to 7.29 ± 1.50 in deep-fried and 6.71 ± 0.95 in smoked samples, and again no significant differences ($p > 0.05$) were recorded.

For the Oregano (ORG) treatment, in June, texture ranged from 6.14 ± 1.95 in air-fried to 7.14 ±

Treatment	Month	Air Fried	Deep Fried	SM (Smoked)	F-value	p-value
Black pepper	June	6.00 ± 1.16[a]	7.14 ± 1.46[a]	5.86 ± 1.46[a]	1.856	0.185
	July	6.57 ± 1.81[a]	6.71 ± 1.38[a]	7.86 ± 1.22[a]	1.564	0.236
	August	6.57 ± 0.79[a]	7.29 ± 1.50[a]	6.71 ± 0.95[a]	0.797	0.466
Control	June	6.29 ± 1.70[a]	7.00 ± 1.16[a]	7.00 ± 0.82[a]	0.728	0.496
	July	6.57 ± 1.40[a]	6.43 ± 1.99[a]	7.00 ± 1.92[a]	0.194	0.825
	August	6.86 ± 1.07[a]	7.57 ± 1.13[a]	7.43 ± 0.79[a]	0.984	0.393
Oregano	June	6.14 ± 1.95[a]	7.14 ± 1.07[a]	5.57 ± 2.57[a]	1.148	0.339
	July	6.00 ± 2.00[a]	7.00 ± 1.83[a]	6.86 ± 1.34[a]	0.672	0.523
	August	7.00 ± 1.53[a]	7.57 ± 1.13[a]	6.29 ± 1.60[a]	1.408	0.27
Oregano + Black pepper	June	6.71 ± 1.50[a]	6.29 ± 1.38[a]	5.57 ± 1.90[a]	0.902	0.423
	July	6.43 ± 2.15[a]	6.29 ± 2.14[a]	6.00 ± 2.08[a]	0.074	0.929
	August	6.86 ± 1.57[a]	7.00 ± 1.53[a]	6.43 ± 1.72[a]	0.239	0.79

1.07 in deep-fried and 5.57 ± 2.57 in smoked fish, and no significant differences ($p > 0.05$) were observed. and no significant differences ($p > 0.05$) were observed.

Table 4.3.3: **Texture Analysis based on the various Processing Methods and Spices**

Note: Means with different superscripts across row are significantly different (p<0.05)

In July, texture ranged from 6.00 ± 2.00 in air-fried to 7.00 ± 1.83 in deep-fried and 6.86 ± 1.34 in smoked fish, and no significant differences ($p > 0.05$) were observed. By August, texture ranged between 7.00 ± 1.53 in air-fried, 7.57 ± 1.13 in deep-fried, and 6.29 ± 1.60 in smoked fish, For the Oregano + Black Pepper (ORGBP) treatment, in June, texture scores were 6.71 ± 1.50 for air-fried, 6.29 ± 1.38 for deep-fried, and 5.57 ± 1.90 for smoked fish, and no significant differences ($p > 0.05$) were observed. In July, texture ranged from 6.43 ± 2.15 in air-fried to 6.29 ± 2.14 in deep-fried and 6.00 ± 2.08 in smoked fish, and no significant differences ($p > 0.05$) were observed. In August, texture ranged between 6.86 ± 1.57 in air-fried, 7.00 ± 1.53 in deep-fried, and 6.43 ± 1.72 in smoked fish, and no significant differences ($p > 0.05$) were recorded.

For the Control (CT) treatment, in June, texture values were 6.29 ± 1.70 for air-fried, 7.00 ± 1.16 for deep-fried, and 7.00 ± 0.82 for smoked fish, and no significant differences ($p > 0.05$) were observed. In July, texture ranged from 6.57 ± 1.40 in air-fried to 6.43 ± 1.99 in deep-fried and 7.00 ± 1.92 in smoked fish, with no significant differences ($p > 0.05$). By August, texture scores increased slightly, ranging from 6.86 ± 1.07 in air-fried to 7.57 ± 1.13 in deep-fried and 7.43 ± 0.79 in smoked fish, and no significant differences ($p > 0.05$) were observed.

4.3.4 Appearance

For the Black Pepper (BP) treatment, in June, appearance scores ranged from 6.43 ± 1.27 in air-fried to 6.86 ± 0.90 in deep-fried and 6.43 ± 1.90 in smoked samples, and no significant differences ($p > 0.05$) were observed. In July, appearance ranged between 6.14 ± 1.77, 6.71 ± 1.98, and 6.86 ± 1.57 for air-fried, deep-fried, and smoked samples respectively, with no significant differences ($p > 0.05$). In August, appearance ranged from 6.71 ± 1.38 in air-fried to 6.86 ± 0.90 in deep-fried and 7.00 ± 1.16 in smoked samples, and again no significant differences ($p > 0.05$) were recorded.

For the Oregano (ORG) treatment, in June, appearance scores ranged from 5.00 ± 2.16 in air-fried to 7.29 ± 1.11 in deep-fried and 6.14 ± 2.34 in smoked fish, and no significant differences (p >

Table 4.3.4 Appearance Analysis based on the various Processing Methods and Spices

Treatment	Month	AF (Air Fried)	DF (Deep Fried)	SM (Smoked)	F-value	p-value
Black pepper	June	6.43 ± 1.27^a	6.86 ± 0.90^a	6.43 ± 1.90^a	0.213	0.81
	July	6.14 ± 1.77^a	6.71 ± 1.98^a	6.86 ± 1.57^a	0.315	0.734
	August	6.71 ± 1.38^a	6.86 ± 0.90^a	7.00 ± 1.16^a	0.106	0.9
Control	June	7.29 ± 0.76^a	7.43 ± 0.79^a	7.14 ± 1.86^a	0.092	0.913
	July	6.57 ± 1.51^a	6.71 ± 2.21^a	6.43 ± 1.72^a	0.042	0.959
	August	7.57 ± 0.54^a	7.57 ± 0.79^a	7.00 ± 1.73^a	0.585	0.567
Oregano	June	5.00 ± 2.16^a	7.29 ± 1.11^a	6.14 ± 2.34^a	2.41	0.118
	July	5.86 ± 2.19^a	7.00 ± 1.41^a	6.71 ± 1.25^a	0.886	0.429
	August	5.86 ± 1.86^a	7.43 ± 0.98^a	6.71 ± 1.50^a	1.95	0.171
Oregano + Black pepper	June	6.00 ± 2.31^a	6.71 ± 1.25^a	5.86 ± 1.95^a	0.413	0.668
	July	6.57 ± 1.72^a	6.29 ± 2.14^a	6.57 ± 1.90^a	0.051	0.95
	August	6.14 ± 2.34^a	7.43 ± 1.13^a	6.71 ± 0.95^a	1.137	0.343

Note: Means with different superscripts across row are significantly different (p<0.05)

0.05) were observed. In July, values ranged from 5.86 ± 2.19 in air-fried to 7.00 ± 1.41 in deep-fried and 6.71 ± 1.25 in smoked samples, and no significant differences ($p > 0.05$) were observed. In August, appearance ranged from 5.86 ± 1.86 in air-fried to 7.43 ± 0.98 in deep-fried and 6.71 ± 1.50 in smoked fish, and no significant differences ($p > 0.05$) were observed.

For the Oregano + Black Pepper (ORGBP) treatment, in June, appearance scores were 6.00 ± 2.31 for air-fried, 6.71 ± 1.25 for deep-fried, and 5.86 ± 1.95 for smoked fish, with no significant differences ($p > 0.05$) among methods. In July, appearance values were 6.57 ± 1.72, 6.29 ± 2.14, and 6.57 ± 1.90 for air-fried, deep-fried, and smoked fish respectively, and no significant differences ($p > 0.05$) were recorded. By August, appearance ranged from 6.14 ± 2.34 in air-fried to 7.43 ± 1.13 in deep-fried and 6.71 ± 0.95 in smoked samples, with no significant differences ($p > 0.05$) observed.

For the Control (CT) treatment, in June, appearance values ranged from 7.29 ± 0.76 in air-fried to 7.43 ± 0.79 in deep-fried and 7.14 ± 1.86 in smoked samples, and no significant differences ($p > 0.05$) were observed. In July, appearance ranged between 6.57 ± 1.51, 6.71 ± 2.21, and 6.43 ± 1.72 for air-fried, deep-fried, and smoked fish respectively, and no significant differences ($p > 0.05$) were observed. In August, appearance ranged from 7.57 ± 0.54 in air-fried to 7.57 ± 0.79 in deep-fried and 7.00 ± 1.73 in smoked samples, and no significant differences ($p > 0.05$) were observed.

4.3.5 Overall Acceptability

For the Black Pepper (BP) treatment, in June, overall acceptability values ranged from 5.57 ± 1.90 in air-fried to 7.71 ± 0.95 in deep-fried and 6.29 ± 1.60 in smoked samples, showing no significant differences ($p > 0.05$) among methods, although deep-fried fish was slightly more preferred. In July, scores ranged from 6.00 ± 2.08 to 6.71 ± 1.98 and 6.86 ± 1.46, and no significant differences

Table 4.3.5: Overall Acceptability Analysis based on the various Processing Methods and Spices

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black pepper	June	5.57 ± 1.90^{a}	7.71 ± 0.95^{b}	6.29 ± 1.60^{ab}	3.523	0.051
	July	6.00 ± 2.08^{a}	6.71 ± 1.98^{a}	6.86 ± 1.46^{a}	0.427	0.659
	August	6.00 ± 0.82^{a}	7.86 ± 0.90^{b}	6.86 ± 1.34^{ab}	5.522	0.013
Control	June	6.86 ± 1.68^{a}	7.14 ± 1.77^{a}	7.71 ± 1.11^{a}	0.556	0.583
	July	6.57 ± 1.27^{a}	6.43 ± 2.15^{a}	7.00 ± 1.92^{a}	0.188	0.831
	August	6.86 ± 1.68^{a}	7.57 ± 1.81^{a}	7.86 ± 1.07^{a}	0.77	0.478
Oregano	June	5.57 ± 2.37^{a}	7.00 ± 1.29^{a}	4.86 ± 3.08^{a}	1.491	0.252
	July	5.57 ± 2.15^{a}	6.86 ± 1.57^{a}	6.86 ± 0.90^{a}	1.464	0.258
	August	6.57 ± 1.99^{a}	7.43 ± 1.40^{a}	6.57 ± 2.15^{a}	0.489	0.621
Oregano + Black pepper	June	6.29 ± 1.38^{a}	7.14 ± 1.57^{a}	5.57 ± 2.82^{a}	1.054	0.369
	July	6.14 ± 1.68^{a}	6.57 ± 1.62^{a}	6.43 ± 1.90^{a}	0.111	0.896
	August	6.71 ± 1.38^{a}	8.00 ± 0.82^{a}	7.29 ± 1.50^{a}	1.812	0.19

Note: Means with different superscripts across row are significantly different (p<0.05)

($p > 0.05$) were observed. By August, overall acceptability ranged from 6.00 ± 0.82 in air-fried to 7.86 ± 0.90 in deep-fried and 6.86 ± 1.34 in smoked samples, with significant differences ($p < 0.05$) observed, indicating that deep-fried fish seasoned with black pepper was most preferred by panelists.

For the Oregano (ORG) treatment, in June, overall acceptability ranged from 5.57 ± 2.37 in air-fried to 7.00 ± 1.29 in deep-fried and 4.86 ± 3.08 in smoked fish, and no significant differences ($p > 0.05$) were observed. In July, values ranged from 5.57 ± 2.15 to 6.86 ± 1.57 and 6.86 ± 0.90 for air-fried, deep-fried, and smoked samples respectively, and no significant differences ($p > 0.05$) were observed. By August, overall acceptability values were 6.57 ± 1.99 in air-fried, 7.43 ± 1.40 in deep-fried, and 6.57 ± 2.15 in smoked fish, and no significant differences ($p > 0.05$) were observed.

For the Oregano + Black Pepper (ORGBP) treatment, in June, overall scores ranged from 6.29 ± 1.38 in air-fried to 7.14 ± 1.57 in deep-fried and 5.57 ± 2.82 in smoked fish, with no significant differences ($p > 0.05$) among processing methods. In July, values ranged from 6.14 ± 1.68 to 6.57 ± 1.62 and 6.43 ± 1.90, and no significant differences ($p > 0.05$) were observed. By August, overall acceptability ranged from 6.71 ± 1.38 in air-fried to 8.00 ± 0.82 in deep-fried and 7.29 ± 1.50 in smoked fish, and no significant differences ($p > 0.05$) were observed.

For the Control (CT) treatment, in June, overall values ranged from 6.86 ± 1.68 in air-fried to 7.14 ± 1.77 in deep-fried and 7.71 ± 1.11 in smoked fish, and no significant differences ($p > 0.05$) were observed. In July, scores ranged between 6.57 ± 1.27, 6.43 ± 2.15, and 7.00 ± 1.92 for air-fried, deep-fried, and smoked fish respectively, and no significant differences ($p > 0.05$) were observed. By August, overall acceptability ranged from 6.86 ± 1.68 in air-fried to 7.57 ± 1.81 in deep-fried and 7.86 ± 1.07 in smoked samples, and no significant differences ($p > 0.05$) were observed.

4.4 General Mean of Sensory Evaluation of *Merluccius merluccius* based on the different processing methods and spices.

The sensory evaluation of *Merluccius Merluccius* was conducted to determine the effect of different spice treatments and processing methods (air-fried, deep-fried, and smoked) on the organoleptic qualities of the samples. Attributes assessed included flavour, texture, aroma, appearance, and overall acceptability.

4.4.1 Flavour

The flavour scores of the samples varied across the different spice treatments and processing methods. For the Black Pepper (BP) treatment, deep-fried samples recorded the highest flavour score (6.95 ± 1.69), followed by smoked samples (6.24 ± 1.67), and air-fried samples (5.62 ± 2.09), with no significant differences ($p > 0.05$).

In the Control (CT) treatment (without spices), flavour scores were generally high and similar across processing methods: smoked (7.62 ± 1.66), deep-fried (6.95 ± 2.04), and air-fried (6.86 ± 1.35), with no significant differences ($p > 0.05$).

For the Oregano (ORG) treatment, significant differences were observed ($p < 0.05$). Deep-fried samples had the highest flavour score (7.10 ± 1.67), followed by smoked (5.52 ± 2.34), while air-fried samples recorded the lowest (5.14 ± 1.77).

In the Oregano + Black Pepper (ORGBP) treatment, deep-fried samples again had the highest flavour score (7.38 ± 1.72), smoked samples were moderate (6.29 ± 2.13), and air-fried samples the lowest (6.05 ± 2.25), with no significant differences ($p > 0.05$).

4.4.2 Texture

For the Black Pepper treatment, deep-fried samples had the highest score (7.05 ± 1.40), followed by smoked (6.81 ± 1.44) and air-fried (6.38 ± 1.28), with no significant differences (p > 0.05).

Table 4.4: General Mean of the Organoleptic Evaluation of *Merluccius merluccius* by Processing Methods and Spice Types

Attribute	Treatment	Air-fried	Deep-fried	Smoked	F-value	p-value
Flavour	Black Pepper	5.62 ± 2.09^{a}	6.95 ± 1.69^{b}	6.24 ± 1.67^{ab}	2.809	0.068
	Black Pepper + Oregano	6.05 ± 2.25^{a}	7.38 ± 1.72^{b}	6.29 ± 2.13^{ab}	2.547	0.087
	Oregano Only	5.14 ± 1.77^{a}	7.10 ± 1.67^{b}	5.52 ± 2.34^{a}	5.929	0.004**
	Control (No Spice)	6.86 ± 1.35^{a}	6.95 ± 2.04^{a}	7.62 ± 1.66^{a}	1.245	0.295
Texture	Black Pepper	6.38 ± 1.28^{a}	7.05 ± 1.40^{a}	6.81 ± 1.44^{a}	1.271	0.288
	Black Pepper + Oregano	6.67 ± 1.68^{a}	6.52 ± 1.66^{a}	6.00 ± 1.84^{a}	0.863	0.427
	Oregano Only	6.38 ± 1.80^{a}	7.24 ± 1.34^{a}	6.24 ± 1.90^{a}	2.136	0.127
	Control (No Spice)	6.57 ± 1.36^{a}	7.00 ± 1.48^{a}	7.14 ± 1.24^{a}	0.997	0.375
Aroma	Black Pepper	6.10 ± 1.79^{a}	7.38 ± 1.07^{b}	6.48 ± 1.50^{ab}	4.163	0.020*
	Black Pepper + Oregano	5.81 ± 1.69^{a}	6.57 ± 1.57^{a}	6.29 ± 1.85^{a}	1.069	0.350
	Oregano Only	6.38 ± 1.72^{ab}	7.29 ± 1.19^{b}	6.00 ± 1.95^{a}	3.366	0.041*
	Control (No Spice)	6.38 ± 1.69^{a}	6.81 ± 1.78^{a}	7.14 ± 1.35^{a}	1.173	0.317
Appearance	Black Pepper	6.43 ± 1.43^{a}	6.81 ± 1.29^{a}	6.76 ± 1.51^{a}	0.452	0.639
	Black Pepper + Oregano	6.24 ± 2.05^{a}	6.81 ± 1.57^{a}	6.38 ± 1.63^{a}	0.599	0.553
	Oregano Only	5.57 ± 2.01^{a}	7.24 ± 1.14^{b}	6.52 ± 1.69^{ab}	5.365	0.007**
	Control (No Spice)	7.14 ± 1.06^{a}	7.24 ± 1.41^{a}	6.86 ± 1.71^{a}	0.409	0.666
Overall acceptability	Black Pepper	5.86 ± 1.62^{a}	7.43 ± 1.40^{b}	6.67 ± 1.43^{ab}	5.878	0.005**
	Black Pepper + Oregano	6.38 ± 1.43^{a}	7.24 ± 1.45^{a}	6.43 ± 2.16^{a}	1.662	0.198
	Oregano Only	5.90 ± 2.12^{a}	7.10 ± 1.38^{a}	6.10 ± 2.30^{a}	2.207	0.119
	Control (No Spice)	6.76 ± 1.48^{a}	7.05 ± 1.88^{a}	7.52 ± 1.40^{a}	1.212	0.305

Note: Means with different superscripts across row are significantly different (p<0.05)

In the Control samples, texture scores were similarly uniform (6.57 ± 1.36 to 7.14 ± 1.24), with no significant differences ($p > 0.05$).

For the Oregano treatment, deep-fried samples had the highest texture score (7.24 ± 1.34), smoked samples the lowest (6.24 ± 1.90), and air-fried samples scored moderately (6.38 ± 1.80), with no significant differences ($p > 0.05$).

In the Oregano + Black Pepper treatment, air-fried samples recorded the highest texture score (6.67 ± 1.68), while smoked samples had the lowest (6.00 ± 1.84), with no significant differences ($p > 0.05$).

4.4.3 Aroma

Aroma was significantly affected in some treatments. For the Black Pepper treatment, deep-fried samples had the highest aroma score (7.38 ± 1.07), followed by smoked (6.48 ± 1.50) and air-fried (6.10 ± 1.79), with significant differences ($p < 0.05$).

In the Control samples, aroma scores were generally uniform across processing methods (6.38 ± 1.69 to 7.14 ± 1.35), with no significant differences ($p > 0.05$).

For the Oregano treatment, aroma scores varied significantly ($p < 0.05$), with deep-fried samples recording the highest value (7.29 ± 1.19), air-fried samples moderate (6.38 ± 1.72), and smoked samples the lowest (6.00 ± 1.95).

In the Oregano + Black Pepper treatment, aroma scores ranged from 5.81 ± 1.69 (air-fried) to 6.57 ± 1.57 (deep-fried), with no significant differences ($p > 0.05$).

4.4.4 Appearance

Appearance scores reflected how visually appealing the samples were after processing. For the Black Pepper treatment, the scores were similar across methods: deep-fried (6.81 ± 1.29), smoked (6.76 ± 1.51), and air-fried (6.43 ± 1.43), with no significant differences ($p > 0.05$).

In the Control, the appearance was also similar, ranging from 6.86 ± 1.71 (smoked) to 7.24 ± 1.41 (deep-fried), with no significant differences ($p > 0.05$).

In the Oregano treatment, significant differences were observed ($p < 0.05$), with deep-fried samples rated the most attractive (7.24 ± 1.14), followed by smoked (6.52 ± 1.69), and air-fried the least (5.57 ± 2.01).

For the Oregano + Black Pepper treatment, scores ranged from 6.24 ± 2.05 (air-fried) to 6.81 ± 1.57 (deep-fried), with no significant differences ($p > 0.05$).

4.4.5 Overall Acceptability

For the Black Pepper treatment, deep-fried samples were rated most acceptable (7.43 ± 1.40), followed by smoked (6.67 ± 1.43) and air-fried (5.86 ± 1.62), with significant differences ($p < 0.05$).

In the Control samples, overall scores ranged from 6.76 ± 1.48 to 7.52 ± 1.40, with no significant differences ($p > 0.05$).

For the Oregano treatment, deep-fried samples again had the highest acceptability (7.10 ± 1.38), while smoked (6.10 ± 2.30) and air-fried (5.90 ± 2.12) samples were lower, with no significant differences ($p > 0.05$).

In the Oregano + Black Pepper treatment, deep-fried samples (7.24 ± 1.45) were slightly preferred over smoked (6.43 ± 2.16) and air-fried (6.38 ± 1.43) samples, with no significant differences ($p > 0.05$).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Proximate Composition of *Merluccius merluccius* based on the processing methods and spices.

5.1.1 Carbohydrate

At week 0, for the black pepper treatment, there was no significant difference in carbohydrate content among the air-fried, deep-fried, and smoked samples. This shows that the initial processing methods did not greatly affect the carbohydrate level since carbohydrates are quite stable when exposed to short heat.

At week 6, the deep-fried and smoked samples had higher carbohydrate contents, while the air-fried samples were lower. This increase in deep-fried and smoked fish was likely caused by loss of moisture, which makes the nutrients more concentrated (Adeyeye, 2016). In the air-fried samples, the lower carbohydrate content observed may be linked to higher heat and air circulation, which can cause more oxidation and nutrient loss. According to Joshy *et al*. (2020), air-frying exposes fish to continuous hot air flow, which can accelerate oxidative changes and reduce certain nutrient components compared to other processing methods.

At week 12, the carbohydrate content became more stable across all the processing methods, probably because the nutrient changes had reduced over time. In the oregano-treated samples, carbohydrate content remained almost the same across all processing methods at the first and second analyses. This may be because oregano has antioxidant compounds that help protect nutrients from breaking down (Burt, 2004).

At the end of the research, deep-fried and smoked samples showed higher carbohydrate levels than air-fried ones. The antioxidants in oregano, along with the moisture loss during processing, may have helped preserve the carbohydrates better in the deep-fried and smoked samples.

For the combined spice treatment, carbohydrate content increased gradually across the analyses. Smoked samples had the highest values, followed by deep-fried and air-fried. The mix of oregano and black pepper likely provided stronger antioxidant protection, reducing nutrient loss during processing (Nazzaro *et al*., 2013). The high carbohydrate content in smoked samples may also be linked to dehydration and the preservative effect of smoke compounds. In the control samples, carbohydrate content changed slightly but showed no major difference among the processing methods. Since no spice was added, there was no antioxidant protection, so any changes may have come from heat and moisture loss rather than nutrient preservation. The slight increase later could be from moisture reduction, which made the nutrients more concentrated.

The mean of the carbohydrate content of the fish sample varied slightly across spice treatments and processing methods, although most differences were not statistically significant ($p > 0.05$). This suggests that both the addition of spices and processing method affected carbohydrate composition to some extent.

Control samples without spices showed the lowest and most consistent carbohydrate levels, indicating that in the absence of spices, carbohydrate levels depend mainly on the fish's natural composition. Similar observations were reported by Adeyemi *et al*. (2021) in non-spiced fish subjected to different processing methods.

Spiced samples, particularly those with oregano, showed higher carbohydrate contents, likely due to the polysaccharides and phenolic compounds present in the spice that promote carbohydrate retention during heating (Abu-Bakar *et al*., 2020). Deep-fried samples generally recorded higher values, possibly from caramelization and starch gelatinization during frying (Onwuka and Nwosu, 2022).

For black pepper treatments, slight increases were also observed, possibly due to piperine and volatile oils participating in browning reactions during heat processing (Adegoke and Falade, 2019). Smoked samples tended to show higher carbohydrate concentration as moisture loss during smoking concentrates dry matter (Maqsood *et al*., 2021). In contrast, air-fried samples recorded lower carbohydrate levels, likely because air frying involves shorter heating time and reduced browning intensity (Kwon *et al*., 2020; Téllez-Morales *et al*., 2024).

5.1.2 Crude Protein

At Week 0, the air-fried samples, particularly those treated with black pepper, had the highest protein values, while the smoked ones showed lower levels. This suggests that air-frying, which uses less oil and a shorter heating time, helped preserve the protein in the fish muscle better than smoking. Smoking, on the other hand, exposes the fish to higher heat for a longer period, which can cause protein denaturation and loss of solubility (NurSyahirah and Rozzamri, 2022).

By Week 6, the protein content across all treatments became quite similar, with no major differences between processing methods. This shows that after the processing, storage had a greater impact on protein levels than the processing method itself. Previous studies have shown that during storage, natural biochemical changes such as proteolysis and gradual moisture loss can reduce the measurable protein in fish (Malik *et al*., 2021). By Week 12, although most samples did not show significant differences, the smoked samples under the black pepper treatment had higher protein percentages. However, this increase is more likely due to moisture loss rather than a real gain in protein. As the fish loses water, the remaining nutrients become more concentrated, which makes the protein percentage appear higher (Akintola, 2013). In the oregano and oregano + black pepper samples, protein levels stayed fairly stable throughout weeks. This stability could be linked to the antioxidant properties of the spices, which may have helped protect the proteins from oxidation and breakdown. Tenyang *et al*. (2022) also reported that spices with antioxidant activity can help maintain protein quality in processed fish. For the control (no spice) samples, protein content dropped noticeably by Week 6 but rose again slightly by Week 12. The initial drop could be due to protein breakdown from oxidation and enzyme activity, while the later increase is most likely from moisture loss rather than any real improvement in protein quality.

Protein content was generally high in all the samples, showing that the fish sample is a good source of protein. The mean across the spice treatments, black pepper produced the highest protein values, especially in the smoked samples. This suggests that black pepper may help protect proteins during processing, possibly because of its antioxidant compound, piperine, which helps prevent heat-related protein damage (Yashin and Karelina, 2017). The samples treated with both black pepper and oregano also showed fairly high protein levels, while oregano alone had moderate values. The slightly lower protein content in oregano-only samples could be due to the loss of some of its volatile antioxidant compounds during heating (Dangal *et al*., 2024). In contrast, the control samples without spices had the lowest protein levels, showing that adding spices may help preserve nutrients during processing.

The smoked samples generally showed higher protein content than the deep fried and air-fried samples. This increase is mainly because smoking reduces the fish's moisture, which concentrates the remaining nutrients, including protein (Tenyang *et al*., 2022; Ogunyebi, 2022).

On the other hand, deep frying can cause some protein denaturation due to high temperature, which may slightly reduce protein quality even though the percentage appears high because of water loss (Zhang *et al*., 2023). Therefore, the results shows that smoking improves protein concentration through dehydration, while spices especially black pepper may help protect the protein from heat damage. Frying, however, tends to break down some of the protein despite the increase in measured protein percentage.

5.1.3 Crude Fat

At Week 0, the black pepper treated samples showed clear differences among the processing methods. The smoked and deep-fried samples had higher fat levels compared to the air-fried ones. This was expected, as frying and smoking often result in higher oil absorption, while air-frying uses little or no oil, leading to lower fat retention. Related findings reported by Téllez-Morales *et al*. (2024), who observed that traditional frying methods increase lipid uptake, whereas air-frying minimizes it due to reduced contact between the product and the oil. In contrast, the oregano and the combined oregano + black pepper treatments showed no significant differences at the start of the analysis, suggesting that the addition of spices did not immediately influence the fat composition of the fish. By Week 6, a gradual decline in fat content was observed in most samples. The decrease was more noticeable in the black pepper treatment, where differences among the processing methods became insignificant. This reduction could be due to lipid breakdown during storage, as fish lipids are highly susceptible to oxidation and hydrolysis (Erickson *et al*, 2023). Interestingly, in the oregano-treated samples, the air-fried fish maintained slightly higher fat content compared to the other methods. Similarly, the combined spice (ORGBP) samples showed minor, non-significant differences in fat levels, suggesting that the combination of both spices might have helped stabilize the lipids during storage (Fitri *et al*., 2023). At Week 12, the fat content dropped further in all treatments. The decline was more pronounced in deep-fried samples, likely due to prolonged oxidative degradation and the breakdown of absorbed oils. Deep-fried products generally undergo more oxidation and polymerization of fatty acids during storage, resulting in lower fat content and quality. In the black pepper–treated fish, significant differences reappeared at this stage, showing that deep-fried samples were more prone to fat loss compared to smoked and air-fried ones. The oregano-treated samples still retained slightly higher fat levels, further confirming the protective role of oregano's antioxidants in slowing down lipid oxidation. The combined spice treatment also showed moderate fat stability, implying that oregano and black pepper may have acted together to reduce oxidation and preserve fat quality (Gao *et al*., 2022). The control samples, which contained no spice, showed a steady reduction in fat content throughout the storage period. This trend is typical of unspiced fish products that lack antioxidant protection. Okerreke *et al*. (2014) similarly reported that unspiced or unsalted smoked fish tends to deteriorate faster due to unprotected lipid oxidation.

The average of the crude fat content showed minor variations among the different processing methods and spice treatments. Smoked samples generally contained slightly higher fat levels in the Black Pepper and Black Pepper + Oregano treatments, possibly due to water loss during smoking, which concentrates residual lipids. Similar observations were reported by Tiwo *et al*. (2019), who found increased fat content in smoked *Clarias gariepinus* and *Cyprinus carpio* resulting from dehydration rather than fat synthesis.

Deep-fried samples showed moderate fat values, which may be attributed to oil absorption during frying, a known effect in high-temperature lipid processing (de Oliveira *et al*., 2024). Conversely, air-fried samples exhibited lower fat content, suggesting limited oil uptake and some degree of lipid oxidation caused by circulating hot air (Paul *et al*., 2022). In the Oregano-only treatment, air-fried samples retained slightly higher fat content compared to smoked and deep-fried samples. This could be linked to the antioxidant properties of oregano, which may reduce lipid oxidation and promote fat stability during heating (Gouvêa *et al*., 2023). The combined action of spices such as black pepper and oregano, both rich in phenolic compounds, can help protect lipids against oxidative breakdown during processing, thereby maintaining better fat integrity.

The control samples, which showed relatively uniform fat levels across all processing methods, reinforce that spice incorporation and processing conditions both contribute to lipid retention.

5.1.4 Ash Content

In this study, the initial analysis of ash content showed that the way the fish was processed, whether air-fried, deep-fried, or smoked had only a small effect on its mineral content. For the sample treated with black pepper ash content tended to be a little higher in smoked samples compared to the air-fried and deep-fried ones, but these differences were not statistically significant. This suggests that right from the beginning, the method of processing does not drastically alter the mineral levels in the fish. In the sample treated with oregano, there were slight but noticeable differences at the start, with deep-fried samples showing somewhat higher mineral content. This is likely due to moisture loss during frying, which can concentrate the minerals in the fish. On the other hand, fish treated with both black pepper and oregano, as well as the control fish without any spices, showed no meaningful differences in mineral content between processing methods. This indicates that the addition of spices has little influence on mineral retention at this initial stage. While smoking and deep-frying may slightly concentrate minerals due to water loss, air-frying appears to preserve mineral content effectively. These observations align with previous studies, which have shown that minerals in fish are quite resilient and do not degrade easily under moderate heat (Ersoy *et al*., 2009).

Ash content indicates the total mineral composition of food. The general mean shows that the deep-fried samples generally had higher ash levels, while air-fried samples was the lowest. This pattern suggests that the mineral content of the fish was largely stable despite the different processing conditions.

This observation agrees with Paul, Nwakuba, and Simonyan (2022), who reported minimal differences in ash content among smoked fish samples, attributing this to the relative thermal stability of minerals during processing. Similarly, Idah, Musa, and Olaleye (2010) noted that drying and heating processes primarily reduce moisture but have limited effects on mineral content since most inorganic compounds remain unchanged at moderate processing temperatures. The consistent ash levels across spice treatments also indicate that the inclusion of black pepper and oregano did not significantly influence mineral retention, as these spices primarily affect antioxidant stability rather than mineral balance (Sharma, Mishra, and Singh, 2023).Overall, the minor fluctuations observed in this study suggest that both the processing methods and spice treatments maintained the mineral integrity of the fish sample, showing its inorganic constituents remained stable under typical thermal conditions.

5.1.5 Crude Fibre

At Week 0, deep-fried samples generally had lower fibre than smoked and air-fried ones. This is likely because direct oil contact during frying softens the fish tissue and causes some nutrient loss. Similar observations were made by Famurewa *et al*. (2017), who found that smoked *Clarias gariepinus* retained more fibre than other storage methods. By Week 6, fibre values became more stable across treatments, with no major differences. At Week 12, all samples showed a slight increase in fibre, which can be linked to continuous moisture loss that concentrates dry matter. Oregano-treated and combined oregano + black pepper samples maintained relatively stable fibre throughout storage, probably due to the antioxidant properties of the spices that slowed down deterioration. The control samples, however, fluctuated more, confirming that unspiced fish deteriorates faster during storage.

The mean crude fibre content showed slight variations across the different spice treatments and processing methods, though differences were not statistically significant ($p > 0.05$). Smoked samples generally contained marginally higher fibre than fried samples, which may be linked to the gradual drying and mild thermal exposure during smoking that preserves structural components of the fish tissue (Umar *et al*., 2024). In contrast, deep-fried samples exhibited lower fibre levels, likely due to the intense heat and oil exposure that can soften and partially degrade fibrous tissue within the muscle (Eze *et al*., 2024). The inclusion of spices such as black pepper and oregano appeared to have a minimal effect on fibre concentration, though their antioxidant properties may help stabilize the tissue matrix during processing, indirectly supporting fibre retention. Similar observations were made by Paul *et al*. (2022), who reported that smoked fish retained slightly higher fibre values than other thermally processed samples. Overall, the consistency in fibre levels across treatments suggests that both processing type and spice addition exerted only mild effects on the structural carbohydrate components of the fish.

5.1.6 Moisture Content

At week 0, air-fried samples generally retained more moisture, while smoked ones had the least. This remained consistent through the 12 weeks, as smoking naturally promotes dehydration, while air-frying traps more internal moisture. At week 6, there was a gradual decline in moisture which was observed in all samples, reflecting normal storage dehydration. The air-fried fish, however, still held slightly higher moisture than smoked and deep-fried ones, likely because of its gentler drying process. At Week 12, moisture dropped further across all treatments, with the smoked samples remaining the most dried (Fernandes *et al.,* 2016) Generally, air-fried samples maintained higher moisture stability during storage, while smoked samples showed the lowest, confirming the strong influence of processing methods on water retention in fish.

Moisture content average varied slightly across both spice treatments and processing methods, suggesting that thermal exposure and spice interactions had an influence on water retention. Smoked samples generally retained more moisture than air-fried and deep-fried ones, likely due to the gradual dehydration characteristic of smoking, which limits rapid water loss and helps maintain bound water within muscle fibers (Msusa *et al*., 2016).

Conversely, deep-fried samples showed lower moisture levels, consistent with the intense heat of frying, which promotes evaporation and denaturation of muscle proteins that normally hold water (Adeparusi and Olowojuni, 2023). Air-fried samples followed a similar trend, though the controlled hot-air circulation may have moderated the extent of moisture loss compared to deep-frying.

The inclusion of spices such as black pepper and oregano appeared to slightly enhance moisture retention, possibly because their essential oils and antioxidant components reduce oxidative damage and surface dehydration during processing (Ndife *et al*., 2022). Overall, the significant differences ($p > 0.05$) observed indicated that while processing and seasoning influenced the fish moisture profile, their combined effects did not significantly alter its proximate composition.

5.2 Sensory Evaluation of *Merluccius merluccius* based on the different processing methods and spices.

5.2.1 Flavour

Across all spice treatments, flavour scores did not differ significantly ($p > 0.05$) among the processing methods, although deep-fried samples generally had slightly higher values. For the Black Pepper (BP) treatment, the deep-fried fish consistently produced more acceptable flavour compared to air-fried and smoked samples. This could be attributed to oil absorption and the release of volatile oils such as piperine and caryophyllene from black pepper during frying, which enhances taste and aroma (Goyal *et al*., 2020).

In the Oregano treatment, deep-fried fish also recorded higher flavour ratings, likely due to the release of oregano's phenolic compounds such as thymol and carvacrol, which intensify flavour during oil-based heating (Singh *et al*., 2021). Smoked samples, however, often had slightly lower flavour scores, possibly because the smoke aroma masked oregano's herbal scent. This agrees with the findings of Kasele *et al*. (2023), who noted that smoke compounds can dominate delicate spice flavours in fish.

For the combined Oregano + Black Pepper (ORGBP) treatment, deep-fried samples consistently had the highest flavour ratings, suggesting a synergistic effect between the two spices. The combination likely enhanced flavour complexity through the interaction of terpenes from oregano and piperine from black pepper, compounds known to produce desirable aroma and taste notes when exposed to high frying temperatures (Abubakar *et al*., 2022).

The Control (CT) samples without added spice also exhibited relatively high flavour scores, especially for smoked fish. This can be explained by the natural flavour development during smoking, which contributes phenolic and carbonyl compounds that enhance palatability

(Olatunde and Benjakul, 2018). Overall, the observed pattern (deep-fried > smoked > air-fried) across treatments indicates that both processing method and spice type influenced flavour perception, even though not significantly. The results align with prior studies demonstrating that spices improve sensory quality, and that oil-based processes like deep-frying better retain and release volatile flavour compounds compared to air-frying or smoking (Joshy *et al*., 2020)

Flavour determines the consumer acceptance of processed fish. In this study, the mean of flavour intensity differed across spice treatments and processing methods. Deep-fried samples were generally preferred for their stronger, richer flavour, likely due to oil absorption, lipid oxidation, and Maillard reactions that create desirable aroma compounds during frying (Negara *et al*., 2021). In contrast, air-fried samples had milder notes, probably because of reduced oil interaction and fewer volatile compounds responsible for aroma (Ramírez-Flores *et al*., 2024).

Even without spices, smoked control samples showed pleasant flavour, as smoking introduces phenolic and carbonyl compounds that adds the smoky characteristic (Goulas and Kontominas, 2005). Among the spiced samples, those with oregano and black pepper stood out, especially when deep-fried. The release of compounds like piperine, thymol, and carvacrol under heat likely enhanced the herbal and spicy notes (Fan *et al*., 2025).

Overall, deep frying produced the most desirable flavour and aroma, while air frying yielded a lighter but cleaner profile consistent with earlier findings that oil-based methods enhance flavour more than dry-heat processing (Fitri *et al*., 2022; Ramírez-Flores *et al*., 2024).

5.2.2 Texture

In this analysis, texture scores across all treatments, did not show significant differences ($p > 0.05$). However, some patterns were noticeable. Deep-fried samples generally had slightly higher texture scores than air-fried and smoked fish across all spice treatments. This shows that deep-frying helped maintain a firmer, more pleasant mouthfeel. Heat and oil during frying likely caused quicker protein coagulation and better moisture retention, which consumers perceive as ideal texture (Hyldig and Nielsen, 2013). Air-fried and smoked samples had slightly lower texture scores. Air-frying, which uses less oil, may lead to more moisture loss and a slightly drier texture, while smoking combines heat and drying that can make fish feel slightly tougher if not carefully controlled (Coppes *et al*., 2002).

Spice type appeared to have minimal influence on the texture compared to the processing methods. Although spices like black pepper and oregano can enhance flavour and aroma, their effect on the physical structure of the fish muscle is limited under the processing conditions used (Fitri *et al*., 2022). There were no significant differences in the mean texture scores among the various spice treatments and processing methods, indicating that both factors had little influence on the firmness or tenderness of the fish. This suggests that the structure remained relatively stable despite the differences in heat application and seasoning.

Deep-fried samples generally appeared slightly firmer and more appealing in texture, which is typical since frying causes rapid surface dehydration and the formation of a crisp outer layer. According to Fang *et al*. (2023), frying promotes moisture loss and protein denaturation at the surface, creating a desirable crust that enhances perceived texture. In contrast, air-fried and smoked samples tended to be softer, possibly because of reduced oil absorption or the gentler heat transfer involved in those methods.

The use of spices such as black pepper and oregano did not significantly alter the textural quality. Their main influence is likely flavour enhancement rather than structural modification of the fish muscle. Similar findings were noted by Abraha *et al*. (2018), who reported that moderate processing conditions, such as smoking and drying, generally preserve texture when moisture removal is controlled.

5.2.3 Aroma

For the Black Pepper (BP) treatment, deep-fried samples consistently produced the strongest aroma, with significant differences observed in June. This can be attributed to the release of volatile oils such as β-caryophyllene, limonene, and piperine from black pepper during high-temperature frying, which intensifies the aromatic profile of the fish (Fan *et al*., 2025). Oil-based frying promotes solubilization of these compounds into the fish matrix, leading to higher aroma intensity compared to air-fried or smoked samples (Chen *et al*., 2024).

In the Oregano (ORG) treatment, deep-fried fish also had slightly higher aroma scores than other methods. This may be due to the volatilization of oregano's essential oils, primarily thymol and carvacrol, which release more effectively under frying temperatures to produce pleasant herbal notes (Li *et al*., 2023). However, smoked fish showed reduced aroma intensity, likely due to masking of oregano volatiles by smoke phenols and carbonyl compounds.

For the Oregano + Black Pepper (ORGBP) combination, deep-fried fish again yielded the best aroma ratings, indicating a synergistic effect between the two spices. The combination of pepper-derived terpenes and oregano phenolics may have created a more complex and balanced aroma, consistent with reports that mixed spice applications enhance the aromatic complexity of processed fish (Fan *et al*., 2025). In the Control (CT) samples, smoked fish exhibited naturally higher aroma acceptability, even without spices.

In this study, the mean of the aroma scores did not vary significantly among the different spice treatments and processing methods, indicating that both the spices and processing conditions helped to preserve the natural odour of the fish. The consistently pleasant aroma across treatments suggests that the spices complemented the samples inherent flavour rather than masking it. Smoked samples tended to have slightly stronger aroma intensity, which is expected since smoking generates various volatile compounds, such as phenols and carbonyls, that contribute to a rich, smoky scent. This observation agrees with the findings of Fan *et al*. (2025), who explained that smoke-derived phenolic compounds play a major role in developing the characteristic aroma of smoked aquatic products. Likewise, Liu *et al*. (2022) reported that frying encourages lipid oxidation and Maillard reactions, producing aldehydes, ketones, and pyrazines which are the. key contributors to the appealing aroma of fried fish.

The mild enhancement in aroma noted in spice-treated samples, especially those containing black pepper and oregano, can be linked to the essential oils and terpenes naturally present in these spices. These compounds add aromatic depth and may interact with heat-generated volatiles during processing. According to Parmar *et al*. (2024), herbs and spices improve the flavour and aroma stability of fish by releasing volatile oils and antioxidants that work synergistically with compounds formed during heating. The absence of significant differences in aroma scores ($p > 0.05$) suggests that the spice concentrations and processing temperatures used were well balanced, providing a pleasant, natural aroma without overpowering the fish's intrinsic scent.

5.2.4 Appearance

For the Black Pepper treatment, deep-fried samples were slightly more appealing than air-fried and smoked fish. This is likely due to the even browning and glossy surface produced by frying in oil, which enhances the golden color and overall visual appeal (Chen *et al*., 2024). Air-frying and smoking did not produce strong visual effects, although they still maintained acceptable appearance scores.

The Oregano treatment showed a similar pattern, with deep-fried fish appearing slightly better than other methods. Smoked samples occasionally had a darker or uneven color, likely from smoke absorption, but this did not reduce overall acceptability.

In the Oregano + Black Pepper combination, appearance was generally consistent across methods. The mixture of spices may have contributed to the subtle color variations, but they were not visually significant to the panelists. This suggests that the visual quality of fish is more influenced by processing method than by spice type. Finally, the Control (CT) samples had consistently good appearance across all methods. This confirms that even without spices, standard processing methods such as deep-frying, air-frying, and smoking can maintain visual quality, supporting consumer expectations.

Appearance is a key sensory factor influencing consumer perception of food quality, as it forms the first impression before aroma or taste are even evaluated. In this study, the mean appearance scores were largely consistent across most spice treatments and processing methods, suggesting that both the spices and thermal processes maintained the visual quality of *Meluza* fish. However, for the oregano treatment, deep-fried samples were rated more attractive than air-fried or smoked ones, indicating that the method of heat application had a noticeable influence on product colour and surface appeal.

Deep-frying is known to enhance the visual appeal of fish through the formation of a golden-brown crust, resulting from Maillard browning and lipid interactions at high temperatures. This agrees with findings by Dong *et al*. (2023), who explained that frying produces desirable surface pigments and uniform coloration that improve the perceived freshness and palatability of fish products. In contrast, air-frying operates with lower oil content and milder heat transfer, often leading to lighter or uneven surface colouring. Smoked samples, while visually distinct, may display darker or patchy pigmentation due to deposition of smoke compounds, a pattern similarly reported by Fitri *et al*. (2022) in their review of dried and smoked fish products.

The minimal differences observed among other treatments suggest that the spice additions black pepper, oregano, or their combination did not significantly alter the surface characteristics of the fish. This outcome aligns with Abraha *et al*. (2018), who observed that spices generally have a limited direct effect on the external appearance of fish unless applied in high concentrations or during prolonged marination.

5.2.5 Overall Acceptability

The deep-fried fish achieved the highest overall acceptability scores, particularly in the Black Pepper treatment by the final month, indicating that the combination of frying and spices enhances the sensory appeal of fish. The Oregano and Oregano + Black Pepper treatments also followed with deep-fried samples being slightly more preferred, although the differences were not statistically significant, suggesting that the spices contribute positively to the overall acceptability but are secondary to processing method. The control samples without added spices maintained good acceptability across all methods, this shows that proper processing alone can yield products that meet consumer expectations.

Overall acceptability reflects how well consumers perceive the product as a whole, combining impressions from flavour, aroma, texture, and appearance. In this study, the average of the samples treated with black pepper and deep-fried were generally rated as the most acceptable, while smoked and air-fried samples were slightly less preferred. This pattern suggests that the frying process may have enhanced the sensory qualities of the fish, giving it a more appealing flavour and texture profile.

The higher acceptability of the deep-fried samples aligns with reports that frying enhances sensory perception by improving taste, aroma, and surface crispness through Maillard and lipid oxidation reactions (Nur Syahirah and Rozzamri, 2022). These reactions generate appealing volatile compounds that tend to boost consumer liking of fried fish products. Similarly, Okorie-Humphrey *et al*. (2022) noted that the inclusion of spices such as *Ocimum gratissimum* in smoked fish significantly improved flavour, colour, and overall acceptability, showing how spice-derived bioactive compounds interact positively with processing methods to enhance sensory appeal.

CHAPTER SIX

6.0 CONCLUSION

This study evaluated the influence of different processing methods and spice treatments on the proximate composition and sensory quality of *Merluccius merluccius.*

The processing methods and spices influenced the nutritional composition and sensory acceptability of the fish. Among the methods, deep frying produced the best overall results, with the samples showing the highest scores for flavour, aroma, texture, and visual appeal. This could be because of the oil absorption and the Maillard reaction, which enhanced the colour and taste. The smoked samples ranked next, because of their elevated protein levels and distinctive smoky aroma, while air-fried fish, though lower in fat and healthier, was less preferred due to its lighter texture and mild flavour. Nutritionally, the smoked fish recorded the highest protein and fat levels, primarily as a result of moisture reduction, which concentrated the nutrients. Deep fried samples also retained the nutrient levels, though slight fat oxidation occurred during the research. Air-fried fish, on the other hand, maintained good moisture stability and lower lipid content.

Among the spices, black pepper enhanced nutrient stability through the antioxidant effect of piperine, while oregano maintained nutrient quality due to its phenolic compounds. The combination of black pepper and oregano (ORGBP) yielded the best performance overall, providing balanced flavour, improved oxidative stability, and high sensory scores. Overall, deep-fried fish treated with black pepper and oregano was the most preferred and nutritionally stable product, followed by smoked fish seasoned with black pepper.

6.2 Recommendations

1. Deep-frying is recommended as the most effective processing method for producing fish because of the flavour, aroma, and overall consumer acceptability. Smoking may be adopted where longer

storage is needed, especially when combined with antioxidant-rich spices.

2. The combination of black pepper and oregano should be encouraged for fish processing, as their synergistic antioxidant and flavour-enhancing properties help maintain nutrient quality and improve sensory attributes.
3. To minimize nutrient loss, especially protein and fat oxidation during storage, processors should incorporate antioxidant-rich spices like oregano and black pepper into fish marinades before heat treatment.
4. Though air-frying yielded lower flavour intensity, it produced the lowest fat content, making it suitable for consumers seeking healthier, low-oil processed fish.
5. Further research should examine the microbiological stability, lipid oxidation indices, and consumer preference across different storage conditions to optimize spice concentration and processing parameters for commercial use.

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APPENDIX 1:

Instructions; taste the samples and rate how much you like or dislike each of the characteristics.

Panelist code: Sample code: Table fl: 9-point Hedonic scale questionnaire

Rating Scale	Overall Acceptability	Texture	Smell/ Aroma	Taste/ Flavour	Appearance
Dislike extremely					
Dislike very much					
Dislike moderately					
Dislike slightly					
Neither like nor dislike					
Like slightly					
Like moderately					
Like very much					
Like extremely					

APPENDIX 2

Deep Fried, Spiced Fish

Smoked Spiced Fish

Organoleptic samples

Oregano-Spiced Fish

APPENDIX 3
RESEARCH QUESTIONNAIRE
DEPARTMENT OF AQUACULTURE AND FISHERIES MANAGEMENT
FACULTY OF AGRICULTURE
UNIVERSITY OF BENIN

I am a final year student of the above named Department carrying out a research on "Effect of Different Processing Methods on the Quality Characteristics of Spiced *Merluccius merluccius*"

Please evaluate the fish samples presented to you based on the sensory characteristics listed below. Use the 9-point hedonic scale to indicate how much you like or dislike each sample. Rinse your mouth with water before and after tasting each sample.

INSTRUCTIONS: Please rate each attribute on a scale of 1-9 where;

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

Panellist code:_________________
Date:________________

Sample ORG-SM

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample BP -SM

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORGBP-SM

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORGBPC-SM

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample CT-SM

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORG-DF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample BP-DF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORGBP-DF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORGBPC-DF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample CT-DF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORG-AF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample BP-AF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORGBP-AF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample ORGBPC-AF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									

Sample CT-AF

	Like extremely	Like very much	Like moderately	Like slightly	Neither like nor dislike	Dislike slightly	Dislike moderately	Dislike very much	Dislike extremely
Flavour/taste									
Texture									
Aroma/smell									
Appearance									
Overall acceptance									