EFFECTS OF DIFFERENT PROCESSING METHODS AND SPICES ON THE PROXIMATE COMPOSITION AND ORGANOLEPTIC ANALYSIS OF *Merluccius merluccius*

BY

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FACULTY OF AGRICULTURE
UNIVERSITY OF BENIN

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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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CERTIFICATION

This is to certify that this project titled "**EFFECTS OF DIFFERENT PROCESSING METHODS AND SPICES ON THE PROXIMATE COMPOSITION AND ORGANOLEPTIC ANALYSIS OF *Merluccius merluccius*"** was carried out by **Osaivbie Hope IYIRIARO** with matriculation number **AGR2004377** of the department of Aquaculture and Fisheries Management, Faculty of Agriculture, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

This project is dedicated to Almighty God, whose boundless grace, wisdom, and strength have guided me through every stage of this journey. I also lovingly dedicate it to my wonderful parents and dear siblings, whose unwavering love, prayers, and encouragement have been my greatest source of strength and inspiration.

Finally, I dedicate this work to all students and researchers in Aquaculture and Fisheries who continue to pursue innovation and sustainability for a brighter and more productive future in fish farming.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

ABSTRACT

This study investigated the effects of different processing methods and natural spices on the proximate composition and sensory characteristics of *Merluccius merluccius* (Meluza). The experiment employed a 4 × 3 factorial designs consisting of four spice treatments, control (no spice), black pepper, cinnamon, and a combination of black pepper + cinnamon across three processing methods: deep frying, air frying, and smoking. Proximate and organoleptic analyses were carried out over a three-month period following standard procedures. Results revealed that both processing method and spice type significantly influenced the nutritional and sensory quality of the fish. Deep frying generally increased lipid content and enhanced juiciness, while smoking reduced moisture and increased ash concentration, reflecting mineral concentration through dehydration. Spiced samples, especially those treated with black pepper + cinnamon, showed higher carbohydrate and protein retention than controls, indicating antioxidant and preservative effects of the spices. Sensory evaluation indicated that deep-fried and spiced samples were most preferred in terms of aroma, flavour, texture, and overall acceptability. The combination of black pepper and cinnamon proved particularly effective in improving taste and aroma without compromising nutritional value. The study concludes that integrating natural spices with suitable processing methods enhances both the nutritive and organoleptic quality of *M. merluccius*. It is therefore recommended that deep frying with black pepper + cinnamon is suitable for the production of high-quality and consumer-preferred fish products.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Fish is a valuable source of essential amino acids, making it a highly nutritious option that is more easily digestible than other types of meat (Rana *et al*., 2023). The World Health Organization (WHO) recommends including fish in the diet due to its high omega-3 fatty acid content, which helps lower the risk of coronary heart disease. The WHO suggests consuming fish 1–2 times per week to ensure an adequate intake of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (FAO/WHO, 2011). Fish is particularly vital in coastal and developing areas, where it serves as a major source of animal protein. On a global scale, fish contributes around 17% of total animal protein consumption, providing nutritional benefits to more than three billion people (FAO, 2020). Fish can be prepared in various ways, such as raw (sashimi), curing, marinating, pickling, smoking, frying, grilling, and steaming (Department of Fisheries, 2022). As the global population continues to rise, it is increasingly important to make efficient use of seafood resources.

Among the wide varieties of fish species, Meluza (*Merlucciuss merluccius*.), widely known as hake Internationally but in Nigeria, the nomenclature for *Merlucciuss merluccius* varies across regions. In Benin City, the fish is commonly referred to as Meluza, a name derived from its Spanish origin. In Lagos, it is often known as *Panla* or *Eja Osan* like in parts of Delta State. This species is highly valued due to its sweet taste and tender texture which makes it suitable for a wide range of culinary applications (Fernández *et al*., 2017). Meluza is primarily found in temperate waters and is particularly popular in European and African markets, where it is often consumed fresh or processed into various products (Kumolu-Johnson and Ndimele, 2011).

Fish typically contains about 70–84% water, 15–24% protein, 0.1–22% fat, and 1–2% minerals. Due to its high moisture content, fish is extremely perishable and prone to rapid quality decline if not properly preserved or processed. Immediately after death, fish begins to undergo various physiological and microbial changes that compromise its freshness and overall quality (Davies and Davies, 2009). In tropical countries like Nigeria, where the temperatures are generally high, fish can begin to spoil within 12 hours when kept at room temperature, depending on the species and size. This aligns with studies on fish species such as *Pseudotolithus elongatus* (Croaker) and *Oreochromis niloticus* (Tilapia), which have shown a shelf life of around 12 hours under similar ambient conditions in Nigeria (Akinmoladun *et al*., 2020; Olorunfemi *et al*., 2021). Hence, it is essential to retain key sensory properties like taste, texture, and appearance, while also safeguarding the nutritional value of the fish. To tackle these concerns, a variety of processing techniques have been introduced to extend shelf life and enhance quality attributes. Among these methods are;

Deep frying remains the most widely used method in both food industries and among consumers, primarily due to its ability to enhance the sensory qualities such as taste and texture of fried products. It involves submerging the fish in hot oil.

Smoking is one of the most commonly used fish preservation techniques in the country. Nearly all fish species found locally can undergo smoking, and estimates suggest that about 70–80% of both marine and freshwater fish caught are consumed in this form (FAO, 1992; 2001). It is a more traditional technique, involves exposing fish to smoke produced from burning wood or other organic materials. Smoking imparts a characteristic smoky flavour and helps preserve the fish by drying it and inhibiting microbial growth through the action of smoke compounds (Gurbuz *et al*., 2020). The effects of smoking can vary depending on factors such as temperature, smoke density, and duration of exposure, making it essential to optimize these variables for the desired outcome.

Air frying has gained popularity, particularly in home cooking, because it uses minimal oil and is highly convenient. During this process, heat is delivered to the food through a mist of fine oil droplets combined with circulating hot air, which significantly reduces oil absorption in the final product (Dehghannya and Ngadi, 2021).

Black pepper (*Piper nigrum*), one of the spices to be used in this study, is known for its rich content of beneficial enzymes such as glutathione peroxidase and glucose-6-phosphate dehydrogenase (Karthikeyan and Rani, 2003). It possesses strong antioxidant and free radical scavenging abilities (Gülcin, 2005). Additionally, studies by Khalaf *et al*. (2008) have shown that *piperine* the active compound in black pepper can enhance the bioavailability of nutrients like selenium, B-complex vitamins, beta-carotene, and curcumin. It also promotes lipid thermogenesis (Malini *et al*., 1999) and stimulates the secretion of digestive enzymes (Moorthy *et al*., 2009).

Cinnamon, known for its high *cinnamaldehyde* content, has been shown to possess potent antimicrobial and antioxidant properties, helping to prevent lipid oxidation and microbial spoilage in food products (Shan *et al*., 2007).

1.2 Justification of the Study

Fish is highly susceptible to rapid quality deterioration, making proper processing essential to minimize post-harvest losses, particularly as fish production increases (Bechtel, 2003). Doyle (2007) explains that deterioration in fish results in undesirable changes in nutritional and sensory attributes, making it unacceptable for consumption. In Nigeria, spoilage significantly limits fish availability due to inadequate preservation and poor storage practices. Factors such as temperature, handling, and the initial microbial load greatly influence fish quality.

To extend shelf life and preserve seafood quality, a variety of processing techniques such as drying, smoking, frying, freezing, chilling, salting, marinating, and canning have been widely employed yet they differ in how they affect nutritional and sensory quality of fish (Bluwey *et al*., 2018). Additionally, preservatives play a critical role in preventing microbial growth and delaying spoilage. As a result, there is growing interest in natural alternatives like herbs and spices, which are considered safer for consumers and offer additional health benefits (Krishnan *et al*., 2014).

This study aims to evaluate the impact of deep frying, smoking and air frying after the application of black pepper and cinnamon spices on the quality and acceptability of Meluza. The results are expected to contribute to safer, more appealing and nutritious fish products for consumption.

1.3 Aim and Objectives of the Study

The aim of this study was to investigate the effects of different processing methods and spices on the proximate composition and organoleptics analysis of *Merluccius merluccius*. While the specific objectives were to determine the:

1. proximate composition of *Merluccius merluccius* treated with the different processing methods (deep frying, smoking and air frying) and spices
2. effects of these processing methods on the sensory characteristics of spiced *Merluccius merluccius*

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview of European Hake (*M. merluccius*)

The European hake (*M. merluccius*, L. 1758) is one of the most heavily targeted demersal fish species in European waters as shown in figure 1.

However, recent assessments indicate a significant decline in exploitation, with the critical exploitation ratio decreasing by 39% since 2013 (General Fisheries Commission for Mediterranean, (GFCM) 2022). It plays a major role in Mediterranean fisheries, ranking as the second most abundant demersal species in terms of catch volume and importance (FAO, 2011; Sabatella *et al.,* 2017).

Italy is the leading country exploiting this species, particularly in the Northern and Central Adriatic Sea, where bottom trawl fisheries contribute about 75% of total Adriatic landings. Catch volumes in this region have varied over the years, peaking in 2006 and dropping to their lowest in 2019 (GFCM), 2021).

It is widely distributed in the Northeast Atlantic, the entire Mediterranean Sea, and the southern Black Sea (FishBase, 2021). It is commonly found at depths of 25 to 1000 meters, with the highest concentrations between 100 and 300 meters (Ungaro *et al.,* 2003). Size and maturity differ by region, influenced by environmental factors. Hake in colder Atlantic waters tend to grow larger and mature later than those in warmer areas like the Mediterranean. In the Mediterranean, their length usually does not exceed 80–90 cm. In the northern and central Adriatic, females start to dominate from 30–33 cm and make up nearly the whole population from 38–40 cm (Zorica *et al.,* 2021).

Plate 1: *Merluccius merluccius*

Source: International Press Telecommunication council

2.2 Scientific Classification of *M. merluccious*

Domain: Eukaryota

Kingdom: Animalia

Phylum: Chordata

Class: Actinopterygii

Order: Gardiformes

Family: Merlucciidae

Genus: Merlucciuss

Species: *M. merluccius*

M. merluccius is gonochoristic, meaning individuals are either male or female. It reproduces externally, with multiple spawning cycles and fractional, pelagic egg release. Although spawning occurs throughout the year, the peak periods and intensity vary by location (Recasens *et al.,* 2008; Domínguez-Petit and Saborido-Rey, 2010). These traits contribute to the species' adaptability and continued presence in commercial fisheries.

It is an opportunistic predator whose diet shifts as it matures. Juvenile hake primarily feed on small crustaceans such as euphausiids and mysids, which are abundant in coastal zones (Borme *et al.,* 2023). As they grow, their diet gradually includes small pelagic fish like anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*), along with decapods and cephalopods (Šantić *et al.,* 2018).

In adulthood, the species becomes largely piscivorous, targeting fish such as blue whiting (*Micromesistius poutassou*) and horse mackerel, while also feeding on squid and large crustaceans. Cannibalism is also observed among larger individuals, particularly in high-density areas such as the Adriatic Sea (Borme *et al.,* 2023).

Recent studies using DNA metabarcoding have confirmed that diet varies not only by life stage but also by habitat. Offshore individuals show a preference for cephalopods and demersal fish, while inshore populations consume more pelagic species and crustaceans. These feeding adaptations, influenced by depth, prey availability, and seasonality, reflect the ecological flexibility of hake and its important role in linking benthic and pelagic food chains (Milisenda *et al.,* 2021).

2.3 Evaluation of Fish Freshness

In the fish trade, freshness is predominantly evaluated through sensory perception, relying heavily on visual inspection, smell, and tactile feel of the fish (Karube *et al.,* 2001). These methods fall under organoleptic assessment, which involves the use of human senses to determine quality. Several physical and sensory attributes are used as indicators of freshness:

2.3.1 General physical condition of fish

This is a primary indicator of freshness, as clear, bright and slightly bulging eyes suggest good quality, while cloudy or sunken eyes indicate spoilage. The gills of fresh fish appear bright red or pink and moist, but as deterioration progresses, they turn brown or grey and lose their sheen. Skin and scales should be shiny with a metallic glow, and the surface slime should be thin and transparent; dull coloration, loose scales, and thick, milky slime signal spoilage. Fresh fish flesh is firm and elastic, springing back when pressed, whereas spoiled fish flesh is soft and leaves permanent dents (Herrera *et al.,* 2025; Gram and Dalgaard, 2002).

2.3.2. Odour

A fresh fish should emit a mild, seawater-like scent. Any unpleasant or sour smell, especially from the gills or the belly cavity, suggests spoilage. Trimethylamine (TMA) is the main cause of the strong fishy smell in fish (Hebard *et al.,* 1982). It is a gas with a rotting fish odour that develops at normal temperatures (Emmanuel *et al.,* 1984). People can detect very small amounts of TMA, even as low as 0.00021 ppm (Sawyer *et al.,* 2003). In freshwater fish, Trimethylamine Oxide (TMA-O) helps protect tissues from absorbing too much water

(Leonardos *et al.,* 1969). However, spoilage bacteria such as *Shewanella putrefaciens*, *Aeromonas* spp., *Enterobacteriaceae*, *Photobacterium phosphoreum*, and *Vibrio* spp. break down TMA-O into TMA, producing unpleasant odours and flavours (Gram and Dalgaard, 2002; Akharume *et al.,* 2021).

To reduce this smell, fish or fish products are often soaked in different solutions. For example, soaking salmon in soybean milk was found to be more effective in masking fishy odour than adding anchovy or spices (Heu *et al.,* 2008). Other common soaking agents include lime juice, lemon juice, milk, coconut water, and vinegar, which have been shown to reduce or remove fishy odours (Kouakou *et al.,* 2014; Keyimu and Abdullah, 2014; Herath *et al.,* 2019; Hidayat and Suprayitno, 2019).

2.3.3 Discolouration or bruising

Darkened or brown areas along the ventral side, belly flaps and backbone, often indicates reduced freshness or spoilage. In standardized sensory evaluation sheets used in seafood grading, features like "reddening along backbone" and "brown discolouration of the belly flaps" are listed as markers for lower freshness scores (Seafood Academy, 2011). Additionally, bruises or localized dark patches in the fillet often caused by ruptured blood vessels are recognized as spoilage indicators (FAO, 2019).

2.3.4. Post-mortem changes

After water (about 70–80% w/w), proteins comprise approximately 15–20% of fish flesh by weight. Muscle proteins can be categorized into sarcoplasmic proteins (water-soluble), myofibrillar proteins (myosin and actin), and stromal proteins such as collagen (Holwerda *et at*., 2025). During postmortem storage, sarcoplasmic proteins largely remain stable, but proteolysis affects structural proteins. Three proteolytic systems including calpains and cathepsins actively hydrolyze myofibrillar proteins, promoting softening while preserving the major contractile components (Li *et al.,* 2023). Structural integrity is further compromised by freezing-induced damage: variations in freezing rate and storage temperature significantly accelerate protein denaturation in fish muscle (Bao *et al.,* 2023).

Postmortem timing also plays a role: in Asian seabass, extending storage from 1 to 24 hours enhanced water-holding and tenderness via myofibril fragmentation and increased sarcoplasmic protein solubilization (Malila *et al.,* 2024). Visualization and measurement of these alterations are possible via microscopy and texture analysis, though whole-muscle assessment remains challenging. Currently, rapid industrial diagnostics are lacking, but understanding these proteolytic and structural changes lays the groundwork for potential future solutions.

2.3.5 Condition of the abdominal wall

Intact, firm belly walls reflect freshness, while ruptured or soft belly walls suggest the onset of spoilage (Bate and Bendall, 2010). The condition of a fish's abdominal (belly) wall is a critical sensory marker of freshness. In high-quality, fresh fish, the belly walls remain intact, firm, and resilient, retaining their shape even when handled. In contrast, fish with softened, ruptured, or protruding abdominal walls often show early signs of spoilage or poor handling. The Food and Agriculture Organization (FAO, 1998) specifically includes this attribute in its standard sensory quality checklist, noting that fresh fish typically exhibit intact belly walls, whereas spoilage is indicated by ruptured bellies and visible viscera protrusion.

This attribute is part of a broader checklist of freshness traits widely utilized in both commercial and regulatory inspection contexts. Key parameters include the firmness of the flesh, appearance of eyes and gills, and the degree of belly integrity making it an essential, quick, non-invasive assessment for quality control and consumer safety (FAO, 1998).

2.4 Major Causes of Fish Spoilage

Freshness and spoilage represent two ends of the post-harvest quality spectrum and must be clearly differentiated (Gram and Huss, 2000). A fresh fish retains all its original sensory, physical, and chemical characteristics. Spoilage, however, refers to the progressive deterioration that occurs after harvesting, eventually rendering the fish unacceptable for consumption (Hui, 2006). This deterioration is often marked by changes in colour, smell, texture, and the condition of eyes, gills, and muscles (Baird-Parker, 2000).

Spoilage results primarily from the activity of autolytic enzymes, microbial growth, and chemical reactions that begin shortly after death. These agents break down proteins, fats, and other cellular components, leading to undesirable odours, textural softening, and colour changes.

In addition, several intrinsic and extrinsic factors accelerate the spoilage of fish (Abbas and Saleh, 2009), including: High water content which supports microbial proliferation, elevated fat levels making the fish susceptible to rancidity through lipid oxidation, rich protein composition which provides an ideal substrate for bacterial degradation, delicate muscle structure which breaks down quickly post-harvest, exposure to ambient or elevated temperatures which speeds up enzymatic and microbial activity, poor hygiene practices during handling, transportation and storage which introduce or spread contaminants. Spoilage in fish is a complex phenomenon triggered by the activity of enzymes, bacteria, and internal chemical substances. This process begins almost immediately after the fish dies and generally occurs in three distinct phases (Amos, 2007):

1. Rigor mortis; the initial stiffening of muscles post-death.
2. Autolysis; the breakdown of tissues by the fish’s own enzymes.

3. Bacterial activity and putrefaction; microbial invasion leading to decay and foul odours.

2.4.1 Categories of Fish Spoilage

2.4.1.1 Enzymatic Spoilage

After the fish is harvested, various biochemical and physiological changes commence, mainly due to the action of endogenous enzymes breaking down key biomolecules in the tissues (FAO, 2005). According to Hansen *et al*. (2003), enzymes involved in autolysis primarily affect the texture of the fish in the early phases of spoilage, although they do not directly cause the characteristic odours and flavours typically associated with full spoilage. This means that significant texture deterioration and shelf-life reduction can occur even when microbial growth is minimal (FAO, 2005).

One major effect of enzymatic activity is the accumulation of compounds like hypoxanthine and formaldehyde. Digestive enzymes also contribute significantly to muscle softening, belly wall rupture, and leakage of a fluid that contains proteins and lipids (FAO, 2005).

A variety of proteolytic enzymes are present in both the muscle tissues and internal organs of fish post-harvest. These enzymes play a key role in post-mortem muscle degradation during storage and processing. Engvang and Nielsen (2001) noted that such enzymatic actions often result in noticeable changes in product quality and sensory attributes. If whole fish are not stored correctly, these proteases break down structural proteins, eventually leading to their solubilisation (Lin and Park, 2006).

Furthermore, the autolysis of muscle proteins can lead to the formation of peptides and free amino acids, which serve as substrates for microbial growth and the production of biogenic amines chemical compounds linked to fish spoilage (Fraser and Sumar, 2008). A notable outcome of enzymatic spoilage is belly bursting, which occurs when proteolytic enzymes from the intestinal region, especially the pyloric caeca, seep into the surrounding ventral muscles. These enzymes are most active at neutral to slightly alkaline pH levels. Martinez and Gildberg (2011) observed that reducing the temperature to around 0°C and maintaining a pH of 5 significantly slows down enzymatic degradation.

2.4.1.2 Microbial Spoilage

The types of microorganisms found on freshly caught fish are largely influenced by the microbial population in the surrounding water environment. Common bacterial genera that naturally inhabit fish surfaces include *Pseudomonas*, *Alcaligenes*, *Vibrio*, *Serratia*, and *Micrococcus* (Gram and Huss, 2000). Among the primary contributors to fish spoilage are microbes whose growth and metabolism result in the production of undesirable compounds such as biogenic amines (e.g., histamine, putrescine, cadaverine), volatile sulphur compounds, organic acids, alcohols, aldehydes, and ketones all of which lead to unpleasant odours and flavours (Dalgaard *et al.,* 2006; Emborg *et al.,* 2005; Gram and Dalgaard, 2002).

In fish that are not preserved, spoilage is typically driven by Gram-negative fermentative bacteria like members of the *Vibrionaceae* family. In contrast, during chilled storage, spoilage is mainly caused by psychrotolerant Gram-negative bacteria, such as *Pseudomonas* and *Shewanella* species (Gram and Huss, 2000). It is therefore essential to differentiate between harmless microflora and actual spoilage organisms, as not all bacteria present on fish contribute to spoilage (Huss, 2005).

An important indicator of microbial spoilage is the concentration of trimethylamine (TMA), which is formed through the bacterial reduction of trimethylamine oxide (TMAO). TMAO functions in live fish as an osmoregulatory compound, helping to balance water content in marine and freshwater environments. Bacteria such as *Shewanella putrefaciens*, P.

Phosphoreum, *Vibrio* spp., *Aeromonas* spp., and certain cold-tolerant Enterobacteriaceae are capable of reducing TMAO to TMA, which is associated with a strong, ammonia-like odour characteristic of spoiled fish (Gram and Dalgaard, 2002).

Spoilage bacteria like *Pseudomonas putrefaciens* and fluorescent *Pseudomonas* species proliferate quickly during early stages of spoilage and are known for producing extensive amounts of proteolytic and hydrolytic enzymes, which contribute further to tissue breakdown and quality loss (Yan *et al.,* 2020).

2.4.1.3 Chemical Spoilage

One of the leading forms of chemical spoilage in fish, particularly in oily or fatty pelagic species such as herring and mackerel, is lipid oxidation (Fraser and Sumar, 2008). This form of deterioration occurs through a free radical chai reaction consisting of three key phases: initiation, propagation, and termination (Frankel, 2005; Khayat and Schwall, 2003).

Initiation begins when free radicals are generated in lipids due to triggers like heat, exposure to light, metal ions, or irradiation. These radicals then react with oxygen to produce peroxyl radicals. During the propagation phase, the peroxyl radicals react with other lipid molecules to form hydroperoxides and new radicals, perpetuating the chain reaction (Fraser and Sumar, 2008; Hultin, 2004). Termination occurs when free radicals combine to form stable, non-radical end products, which signals the end of the oxidation process. Fish lipids, being rich in polyunsaturated fatty acids, are particularly vulnerable to oxidation due to the presence of multiple double bonds. The presence of transition metals helps activate molecular oxygen, making it reactive and accelerating oxidation (Hultin, 2004).

In fish, fat spoilage can occur through enzymatic or non-enzymatic pathways. The enzymatic degradation of fats known as lipolysis is carried out by lipases, which hydrolyse triglycerides into free fatty acids. These breakdown products contribute to the development of rancid flavours and lower the overall quality of fish oil (Huis in't Veld, 2006; FAO, 2005).

2.5 Fish Preservation and Processing

Berkel *et al*. (2004) described food preservation as the processing of food items in order to extend their storage life. Common preservation methods used globally for fish include freezing, canning, smoking, sun-drying, salting, and pickling (Mayer and Ward, 1991; Obodai *et al.,* 2011; Wilbur, 2002). In addition, the use of spices with antimicrobial properties has also been explored as a means of slowing spoilage and prolonging shelf life (Farag *et al.,* 1989; Shelef, 1983).

Processing and preservation of fresh fish are highly important because fish begins to spoil almost immediately after harvest, leading to potential economic losses if not properly managed (Okonta and Ekelemu, 2005). When fish cannot be sold in its fresh state, preservation methods such as freezing, smoking, drying, and heat treatments (including sterilization and pasteurization) are applied to prolong shelf life. Proper preparation and handling are also vital to ensure superior quality, maximum yield, and profitability.

Davies *et al*. (2008) observed that processed fishery products are still largely stored using traditional preservation techniques. Due to long distribution distances and the limited availability of refrigeration, processing and storage become necessary (Agbon *et al.,* 2002). However, inadequate handling, poor processing methods, and insufficient storage facilities continue to limit fish availability, particularly for rural populations that make up a large proportion of people in developing countries (Ayuba and Omeji, 2006). Moreover, Ayuba and

Omeji (2006) highlighted that insect infestation is one of the leading factors responsible for substantial losses in the quality and quantity of dried fish stored in Nigeria.

The advancement of fishing equipment and techniques for efficient handling, harvesting, processing, and storage of fish is crucial, particularly at a time when aquaculture is rapidly expanding in Nigeria (Akinneye *et al.,* 2007). Fish processing aims to produce forms that are appealing to consumers while also extending the storage life of the product. For processed fish intended for storage, certain qualities are essential, including assurance of food safety, maintenance of hygienic conditions, and prevention of harmful microorganisms and toxin formation (Ita, 1972).

2.5 Fish Preservation Methods

Fish is highly prone to spoilage due to its high-water content, which encourages the rapid growth of microorganisms and enzymatic degradation (Bujjamma *et al.,* 2015; FAO, 2022). In West Africa, smoking is one of the most widely adopted traditional fish preservation methods because it effectively reduces moisture and introduces antimicrobial compounds such as phenols and formaldehyde from wood smoke (Adenike, 2014; FAO, 2022). The main objectives of smoking include prolonging shelf life, improving flavour, and enhancing the visual appeal of the product.

Smoking also plays a vital role in mitigating post-harvest losses, which are reported to be as high as 25–30% in many low- and middle-income countries (WorldFish, 2021). These losses have a significant effect on the livelihood of fishing communities, particularly women, who are heavily involved in fish processing (Adeyeye *et al.,* 2016). In areas where refrigeration and transport facilities are limited, smoked fish serves as an important source of dietary protein all year round. It is frequently used to add flavour to local dishes, especially stews and sauces (Environmental Justice Foundation, (EJF) 2021).

Additionally, fish smoking contributes to food security by ensuring steady availability and allowing for the distribution of fish products across both rural and urban markets (FAO, 2022). Among the various preservation techniques, smoking remains the most prevalent due to its simplicity, cultural relevance, and reliance on locally sourced materials (Adenike, 2014).

2.5.1 Hot Smoking

The final quality of smoked fish depends on several critical factors, including the initial freshness of the raw fish, the strength and concentration of the brine used, the type of wood employed during smoking, the chemical composition of the smoke, the smoking method applied, and the conditions under which the smoked fish is stored (Huong, 2014; Adeyeye *et al.,* 2016). Recognizing the inefficiencies and product losses associated with traditional smoking techniques, improved technologies such as modern smoking kilns have been introduced. These advancements, often driven by projects like the West Africa Agricultural Productivity Program (WAAPP), aim to enhance drying efficiency and reduce post-harvest waste (FAO, 2016).

The hot smoking process generally involves several key stages: an initial drying phase to reduce surface moisture, the actual smoking and cooking process, followed by rapid cooling. After thermal treatment, it is crucial to reduce the temperature of the smoked fish to below 3.3°C (38°F) to limit microbial growth and reduce the likelihood of foodborne pathogens before the product is stored or consumed (Hilderbrand, 1992; Gram *et al.,* 2020).

Hot smoking is particularly popular for processing oily or semi-oily fish species such as mackerel, sardines, tuna, and halibut. This method not only helps prolong the shelf life of the fish but also contributes to flavour enhancement and nutrient retention, making it a widely accepted preservation technique in the seafood industry.

2.5.2 Effects of Smoking on Fish Quality

Fish deteriorates quickly after harvest due to its high moisture content, neutral pH, and rich nutritional profile, which together create favourable conditions for microbial growth and spoilage. In many African regions, especially in rural areas, fish handling, processing, and marketing are crucial to local livelihoods However, inadequate post-harvest facilities and poor hygienic practices during handling and storage often lead to product degradation and pose significant food safety concerns (FAO, 2022).

Proper handling under hygienic conditions can ensure fish remain safe for consumption. Unfortunately, artisanal fish processing operations frequently lack basic sanitary resources such as clean water, suitable storage systems, and well-maintained equipment. These limitations increase the chances of contamination by spoilage organisms and pathogens, potentially causing foodborne illnesses (Bujjamma *et al.,* 2015; FAO, 1992).

Although smoking helps extend shelf life and improve flavour, it cannot ensure food safety if contamination takes place during or after the process. Microorganisms present in smoked fish may include harmful species introduced through unhygienic handling, contaminated equipment, or unclean water sources (Atef *et al.,* 2011; Olaoye *et al.,* 2020). Yeasts and moulds, in particular, are indicators of poor sanitary conditions during harvesting, processing, or storage and may lead to the production of harmful mycotoxins (Olaoye *et al.,* 2020).

The public health risks associated with smoked fish are evident throughout the entire value chain from harvesting to retail especially when proper hygiene measures are lacking. However, the adoption of good fishing and processing practices, together with the use of modern equipment, can help retain the nutritional, sensory, and hygienic qualities of smoked fish (Degnon *et al.,* 2012; FAO, 2022).

Because refrigeration is often unavailable, smoked fish is frequently marketed without proper cooling, thereby increasing the chances of microbial contamination after processing (Akinwumi *et al.,* 2015). To mitigate these risks, Akinwumi *et al*. (2015) emphasize the need for fish to be processed, stored, and distributed under rigorous hygiene and safety protocols to protect public health.

2.5.3 Deep Frying

Frying is a widely adopted dry-heat cooking method used both at home and in industrial food processing. It involves immersing food such as fish in hot oil, triggering various heat and mass transfer processes that influence the final product's texture, appearance, and chemical makeup. The frying process generally occurs in four overlapping stages: heating, surface boiling, falling rate, and bubble endpoint (Pankaj and Keener, 2017).

During the heating stage, the food's surface temperature rapidly increases upon contact with the hot oil, causing surface moisture to evaporate instantly. This evaporation results in vigorous bubbling and begins the formation of a crispy crust (Gertz, 2014). As frying continues, heat is transferred to the food surface through both conduction and convection, and bubbling intensifies as the oil interacts with escaping steam. This marks the surface boiling stage, where the high heat transfer rate accelerates cooking but also increases the likelihood of oil oxidation (Pankaj and Keener, 2017; Gertz, 2014)

The falling rate stage is the longest phase and involves deeper heat penetration into the food. At this point, significant physical and chemical changes take place, including thickening of the crust, rapid internal moisture loss, and key thermal reactions such as protein denaturation and starch gelatinization (Oke *et al.,* 2018). Protein denaturation occurs when heat causes the shrinkage of collagen fibres and the breakdown of structural proteins, which reduces the food's water-holding capacity and alters its texture (Abraha *et al.,* 2018). Additionally, protein denaturation is intensified by the aggregation of sarcoplasmic proteins and the rupture of cell membranes (Alipour *et al.,* 2010).

The final phase, known as the bubble endpoint, signals that water loss is nearly complete. At this stage, heat transfer slows significantly due to the absence of moisture, and the frying process nears completion (Pankaj and Keener, 2017).

2.5.4 Effects of Deep Frying on Fish Quality

Several chemical reactions occur simultaneously during frying that affect fish quality. Apart from protein denaturation and starch changes, the Maillard reaction takes place, especially at high temperatures. This reaction between reducing sugars and amino acids is responsible for the characteristic browning of fried foods (Zhang, Zhang, and Adhikari, 2020). However, it also poses a risk of acrylamide formation, a compound recognized as potentially carcinogenic (Aiswarya and Baskar, 2018).

As moisture evaporates, it escapes through pores in the fish muscle, creating space that allows small amounts of oil to enter. This oil uptake depends largely on the fish's residual water content (Dueik and Bouchon, 2011; Marquez *et al.,* 2014).

The frying oil itself is subject to hydrolysis, oxidation, and polymerization, all of which degrade its quality. Hydrolysis occurs when water from the fish interacts with the oil's ester bonds, producing free fatty acids and other breakdown products (Oke *et al.,* 2018). Oxidation, intensified by heat and oxygen exposure, breaks down fatty acids and acylglycerols into unstable compounds such as hydroperoxides (Choe and Min, 2006). Factors like oil type, fatty acid composition, and frying temperature all affect the rate of oxidation. Under extremely high heat and limited oxygen, oxidation can shift to polymerization, forming triacylglycerol dimers and non-volatile polar compounds (Gertz *et al.,* 2000). These compounds may accumulate in the fish and pose health risks when consumed in excess (Jurid *et al.,* 2020).

Because of these risks, it is essential to control key frying parameters such as oil type, frying temperature, time and the number of frying cycles. Proper regulation of these factors ensures better product quality and minimizes the formation of harmful substances in both the oil and the fried fish.

2.5.5 Air Frying

Frying is one of the most widely practiced cooking methods in homes, restaurants, and the food industry, but increasing health concerns regarding high-fat foods have accelerated the adoption of hot-air frying as an alternative to deep frying (Pankaj and Keener, 2017; Zaghi *et al.,* 2019; Dehghafryera and Ngadi, 2021). In an air fryer, high-temperature air circulates rapidly around the food, functioning similarly to a convection oven and producing a crisp outer layer with considerably less oil compared to immersion frying (Priya *et al.,* 2017; Zaghi *et al.,* 2019). During the process, a steep temperature gradient develops within the fish muscle, leading to rapid heat transfer and moisture migration, followed by crust formation, which influences both texture and nutritional composition (Andrés *et al.,* 2012; Heredia *et al.,* 2014).

Unlike deep frying, small amounts of surface oil are sometimes sprayed onto fish before air frying to enhance flavour, browning, and texture, and this added oil should be included when considering fat balance (Abd Rahman *et al.,* 2016; Joshy *et al.,* 2019, 2020). However, even under comparable temperature settings, air frying typically involves slower heat and mass transfer than deep frying, thus requiring longer cooking times to achieve similar doneness. Deep frying, by contrast, tends to promote greater browning and thicker crust formation (Heredia *et al.,* 2014; Liu *et al.,* 2022).

2.5.6 Effects of Air Frying on Fish Quality

Several comparative studies have reported distinct outcomes for fish quality. Air-fried fish products generally exhibit lower oil uptake, reduced lipid oxidation, and modified volatile/flavour profiles compared with deep-fried counterparts (Cao *et al.,* 2020; Liberty *et al.,* 2019; Lumanlan *et al.,* 2020). Importantly, safety-related contaminants such as acrylamide and polycyclic aromatic hydrocarbons (PAHs) are often reduced in air-fried products, though their occurrence depends on fish species, processing temperature, and frying duration (Basuny and Oatibi, 2016; Lee *et al.,* 2020; Dehghannya and Ngadi, 2021).

Specifically in fish and seafood, research has highlighted the potential of air frying as a healthier alternative to deep frying. For example, optimized air-frying conditions have been developed for fish-based snacks, demonstrating feasibility as a "healthy fried" route (Joshy *et al.,* 2019, 2020). Comparative studies on sturgeon steaks and chub mackerel reveal significant differences in texture, moisture retention, lipid behaviour, and colour between deep-fried and air-fried samples (Liu *et al.,* 2022; Negara *et al.,* 2021). Microstructural changes in muscle fibres further explain variations in texture and storage stability (Ngamwonglumlert and Devahastin, 2018). From a sensory perspective, air-fried fish can achieve acceptable crispness and appearance, though deep-fried fish often receives higher scores for flavour intensity due to higher oil absorption (Ciccone *et al.,* 2020; Cao *et al.,* 2020).

2.5.7 Fish Canning

Fish canning is a preservation method that involves subjecting fish sealed in containers such as tinplate cans, aluminium cans, or glass jars to heat treatment until the product is fully sterilized (Idachaba, 2001). This thermal process must be adequate to eliminate heat-sensitive bacteria and spores, deactivate enzymes, and sufficiently cook the fish, ensuring that the final product remains safe and palatable for consumers even after long-term storage (FAO, 2005). The concept of commercial sterilization refers to a thermal processing technique aimed at destroying nearly all microorganisms and spores that could potentially grow in the canned product (FAO, 2008). To prevent recontamination, canned fish is sealed in virtually airtight containers, which helps block the entry of harmful pathogens. When processed correctly, canned fish can be safely stored for several years without refrigeration (Leistner and Gould, 2002).

Typically, traditional canned fish products are derived from small pelagic species such as herring (*Clupea* spp.), sardine (*Sardinella* spp.), mackerel (*Scomberomorus* spp.), anchovy (*Engraulis* spp.), tuna (*Thunnus* spp.), and bonga (*Ethmalosa* spp.) (Gopakumar, 2010). It is essential that fish intended for canning are of high quality and handled under hygienic conditions to minimize microbial contamination. The use of poor-quality raw materials can result in canned products with undesirable odour, taste, and texture (Burt, 2003).

2.5.8 Fish Drying

Very small and slender fish can be dried directly under sunlight if they are harvested early in the morning and weather conditions are favourable (Deepchill, 2010). When these conditions are not met, the fish should be preserved overnight using brining or dry salting methods and then dried the following day. However, if rain occurs the next morning, drying must be postponed until the weather improves this delay can range from several hours to a few days. In such cases, the salt must be rinsed off the fish by soaking them in either fresh or seawater for a few hours before drying, depending on consumer preference and the intended use of the dried product (Huss, 2009).

Sun drying of small fish is commonly done by laying them on mats or hanging them. During rain, it is important to either cover the fish or move them to a sheltered area to prevent moisture absorption. When drying fish on mats or similar surfaces, regular turning about every two hours is recommended to ensure uniform drying and to prevent maggot infestation. For larger fish, especially those that have been split, suspending them is often more effective for drying (Ananou *et al.,* 2007).

Fish that have undergone dry salting can also be dried, but they must first be rinsed clean with water. Generally, drying is completed within three days. If a large volume of dried fish is to be stored for an extended period, it should be stacked in a cool, dark area, raised off the ground preferably on wooden planks and covered with a sack or mat. After approximately two weeks, the fish should be re-exposed to sunlight for an hour or two before being returned to storage. These guidelines represent fundamental practices in fish drying, though there may be variations depending on local traditions and specific objectives (Leistner and Gould, 2002).

2.6 Natural Food Preservatives

Food preservatives and antioxidants are commonly employed to extend the shelf life of food products by either eliminating harmful microorganisms or suppressing their growth. In addition to microbial control, these substances help delay or prevent oxidative damage in foods (Ligia, 2002). However, due to the harmful effects associated with synthetic antioxidants particularly their negative impact on liver and lung enzymes many countries have restricted or banned their use (Ikeme and Bhnadary, 2001). This has led to a growing interest in natural alternatives, such as spices, fruits (including stems, peels, and seeds), and other plant-derived compounds. These natural preservatives have proven effective in minimizing spoilage, especially in perishable items like fresh and smoked fish, which are prone to microbial contamination.

2.6.1 Black pepper

Black pepper (*Piper nigrum* L.), an aromatic and medicinal climbing plant originally from India, was introduced to China in 1947 and is now widely cultivated in regions like Hainan. Globally, it ranks sixth in cultivation area and fifth in production volume, yielding approximately 35,000 tons annually (Ravindran and Kallupurackal, 2012). Beyond its culinary use, black pepper has notable medicinal applications. It contains bioactive compounds such as *piperine* (an alkaloid), various terpenes, flavones, and volatile oils like *piperyline*, which have demonstrated sedative, detoxifying, blood pressure-lowering, and anticancer properties (Butt *et al.,* 2012; Meghwal and Goswami, 2013; Yoon *et al.,* 2015). Additionally, black pepper is frequently used as a natural preservative and flavour enhancer in meat and meat-derived products (Thiel *et al.,* 2014).

2.6.2 Cinnamon

Cinnamon (*Cinnamomum verum*), a spice derived from the inner bark of trees in the *Cinnamomum* genus, is widely valued not only for its distinctive flavour in both sweet and savoury dishes but also for its significant preservative and health-enhancing properties. The name "cinnamon" traces its origin to the Greek word *kinnamomon* (Arima, 2002). Typically reaching heights of 11 to 16 meters (around 33 to 49 feet), this tree belongs to the *Lauraceae* family and is indigenous to Sri Lanka and parts of South India. Rich in phytochemicals such as phenolic compounds and volatile oils, cinnamon exhibits strong antioxidant and antimicrobial activities, which contribute to its role in extending the shelf life of food products. These bioactive compounds can be extracted from various parts of the plant using methods like distillation and solvent extraction. Studies have emphasized cinnamon's potential in improving food quality and safety, making it a valuable ingredient in the development of functional foods (Dimas and Koen, 2017).

2.6.3 Garlic

Garlic (*Allium sativum*), a well-known medicinal plant, is recognized for its multiple benefits, including reducing the incidence of foodborne diseases and poisoning while simultaneously preserving food and contributing essential vitamins (Sherman and Billing, 1999). Originating from Central Asia, garlic has long been a staple in Mediterranean diets and is widely used as a seasoning in Asia, Africa, and Europe (Rajsekhar *et al.,* 2013). Botanically, garlic is a bulbous perennial herb closely related to the onion. It produces an upright flowering stem that can grow 2–3 feet tall and bears pink to purple flowers, with the bulb being the primary medicinal part. Previously placed in the *Liliaceae* family, garlic is now classified under the *Alliaceae* family and occurs in two main varieties; hard-neck and soft-neck types. Hard-neck garlics are distinguished by a stiff central stalk that extends into the bulb, while soft-neck garlics possess a flexible pseudo stem formed from overlapping leaf sheaths and rarely produce flowering stalks except under stress from unfavourable climatic conditions (THSA, 2006).

2.6.4 Ginger

Ginger (*Zingiber officinale* R.) is widely recognized as a medicinal plant with significant therapeutic properties (Akram *et al.,* 2011). Its use as a natural preservative has been attributed to its strong antimicrobial and antioxidant activities (Mesomo *et al.,* 2013; Olaniran *et al.,* 2015; Pisoschi *et al.,* 2018). The edible portion of ginger, along with other spices, is often incorporated into foods to enhance flavour and prevent rancidity. Studies have demonstrated the effectiveness of ginger extract in fish preservation. For example, Iheagwara (2013) reported that the shelf life of smoked mackerel was prolonged due to the antioxidative and antimicrobial effects of ginger extract, which also slowed down oxidative rancidity. Similarly, Tairu *et al*. (2017) observed that natural preservatives such as ginger, clove, and garlic inhibited microbial growth, extended shelf life, and reduced spoilage in smoked tilapia. Research has also examined the application of ginger extract in fish products like fillets, surimi, and fish sausages (Ahmed *et al.,* 2019; Ranendra *et al.,* 2017). Additional studies have explored its role in preserving smoked fish and fillets beyond Bangladesh (Frank *et al.,* 2014; Idris *et al.,* 2010). In recent years, there has been growing consumer preference for foods preserved with natural additives rather than synthetic chemicals (Holley and Patel, 2005). In light of this trend, efforts have been initiated in Bangladesh to establish a reliable protocol for preserving fresh fish using ginger extract.

2.6.5 Turmeric

Turmeric (*Curcuma longa* L.) is a widely used spice recognized for its bioactive phytochemicals that provide numerous health benefits, including antioxidant, antiprotozoal, antitumor, antivenom, and anti-inflammatory properties (Yousefsani *et al.,* 2021). Its major functional compounds are curcuminoids, comprising curcumin, bisdemethoxycurcumin, and demethoxycurcumin (Soleimani *et al.,* 2018). Curcumin, the primary yellow phenolic pigment, exhibits strong antioxidant capacity by neutralizing free radicals. Owing to these properties, turmeric has been incorporated into a variety of food products such as bread (Lim *et al.,* 2011), butter cakes (Lean and Mohamed, 1999), milk (Park *et al.,* 2019), parboiled rice (Palamanit *et al.,* 2019), street-vended beverages (Idowu-Adebayo *et al.,* 2021), jam (Rozan, 2017), and lentil soup (Rozan *et al.,* 2018), where it serves as an antioxidative and antifungal additive.

Plate 1: Cinnamon (*Cinnamomum verum*)

Plate 2: Black pepper (*Piper nigrum*)

2.7 Synthetic Preservatives

The use of synthetic preservatives in the food industry has been established for many years, primarily to extend shelf life, suppress microbial growth, and preserve the overall quality of food products (Kanelaki *et al.,* 2022). These chemical additives are incorporated into foods to inhibit the growth of bacteria, yeasts, and moulds that cause spoilage and deterioration. Commonly used examples include sodium benzoate, potassium sorbate, butylated hydroxyanisole, and butylated hydroxytoluene (Liu *et al.,* 2021). Their effectiveness has been widely documented, as they help prevent microbial activity during storage, reduce spoilage, minimize the incidence of foodborne illnesses, and maintain desirable sensory attributes of food items.

2.7.1 Nitrites

Nitrite (NO_2) is widely applied in curing fish and meat due to its antimicrobial and antioxidant properties (Rahman, 2007). It usually appears as a white to pale-yellow crystalline salt, commonly in the form of sodium nitrite ($NaNO_2$). Nitrite dissolves readily in water and ammonia solution but has limited solubility in alcohol and other organic solvents. Because of its salt-based nature, it is extensively utilized in the food industry as an antimicrobial agent (Davidson *et al.,* 2002).

The exact mechanism by which nitrite inhibits microbial growth is not fully understood (Sebranek and Bacus, 2007), as its activity depends on several factors (Tomkin, 2005). In cured fish and meat, nitrite reacts with muscle components to form nitric oxide, which is believed to act as the antimicrobial agent (Sebranek and Bacus, 2007). According to Tomkin (2005), nitrite's effectiveness against *Clostridium botulinum* is influenced by pH, sodium chloride concentration, reductants, and iron content.

Initially, nitrite was used alone as a preservative, but it is now typically combined with common salt, such as sodium or potassium chloride (Adam and Moss, 2008; Belitz *et al.,* 2009). Because of its microbial inhibitory effect, nitrite is commonly employed in processing fishery products, including dried fish, semi-preserved fish, and other cured products.

Numerous studies have examined nitrite use in food preservation. Tomkin (2005) observed that nitrite enhanced the redness of herring, though flavour and texture remained unchanged. It also slowed the breakdown of trimethylamine oxide (TMAO). Hyytia *et al.* (1997) demonstrated that sodium nitrite inhibited or delayed *Clostridium botulinum* type E toxin production in vacuum-packed cold-smoked trout containing 3.4% salt in the water phase, in their findings, toxin appeared only after four weeks at 4 °C, depending on the inoculum level. Similarly, Tomkin (2005) noted that nitrite extended the shelf life of fish, maintaining acceptability for 3–4 weeks under refrigeration.

Although nitrite is primarily used in meat and poultry, safety concerns arose in the 1970s over the potential formation of carcinogenic nitrosamines in cured meat (Sebranek and Bacus, 2007). Consequently, regulatory bodies have established strict limits for its use in foods. For example, Food Standards Australia New Zealand (FSANZ, 2010) permits only 50–125 g/kg of nitrite in meat products.

2.7.2 Sulphur dioxide

Sulphur dioxide (SO_2) was initially applied as an antiseptic, sanitizer, and disinfectant. Because of its effectiveness in inhibiting microbial growth, it was later developed for use as an antimicrobial agent. Its relatively low toxicity contributed to its global acceptance in food preservation (Wedzicha, 2001).

In the fisheries sector, sulphur dioxide is mainly used for fresh products, crustaceans, and canned fish. For instance, in fresh shrimp, it helps maintain colour while also acting as an antimicrobial agent (Dengate, 2009). Gould (2000) further noted its role in preventing black spot formation in crustaceans.

Regulatory limits have been established to ensure safe consumption. In meat products, the maximum allowable concentration is 500 mg/kg, while the acceptable daily intake for humans is approximately 0.7 mg per kilogram of body weight (FAO, 1974).

2.7.3 Benzoic Acids

Benzoic acid occurs naturally in several fruits and spices, including apples, cranberries, plums, prunes, strawberries, cinnamon, cloves, and other berries (Davidson *et al.,* 2002). It has a molecular weight of 122.1 and typically appears as colourless or white crystalline needles or leaflets. Its solubility in water is limited, with 0.18 g, 0.27 g, and 2.2 g dissolving in 100 ml of water at 4 °C, 18 °C, and 75 °C, respectively. Owing to its affordability, ease of incorporation into food products, lack of colour and taste, and relatively low toxicity, benzoic acid has become one of the most extensively used preservatives in the food and fisheries industries (Chipley, 2005). Commercially, it is available as soft, whitish crystals with a silky sheen and is commonly applied in the form of sodium benzoate or benzoic acid.

In fisheries, benzoic acid is primarily employed to preserve surimi, minced fish, and other processed fish products, and it is also effective in inhibiting toxin formation. For example, Heruwati *et al*. (2008) observed that immersing baby tuna in a 0.1% benzoic acid solution for 30 minutes reduced histamine formation by up to 88.9% during 8 hours of storage at room temperature. Similarly, Ponce de Leon *et al*. (1994) reported that sardines stored in acid brine containing 0.3% sodium benzoate had a shelf life three times longer than untreated samples.

Among chemical preservatives, benzoic acid is considered one of the safest due to its low toxicity, tastelessness, and wide spectrum of activity, including bactericidal, antifungal, antimould, and bacteriostatic properties. Consequently, it is suitable for use across a variety of fishery products such as dried, canned, and semi-preserved items, without altering their flavour. Regulatory standards specify maximum allowable levels, with Food Standards Australia New Zealand (FSANZ, 2010) permitting up to 400 mg/kg and the Indonesian National Standard (BSN, 1995) allowing up to 1000 mg/kg in fishery products. Furthermore, Pollard (1990) indicated that the acceptable daily intake of benzoic acid for humans is approximately 5 mg per kilogram of body weight.

2.7.4 Health risks associated with Synthetic Preservatives

Extensive research has shown that the use of synthetic preservatives in food products can pose serious health risks to consumers. These chemical additives, commonly found in fruits, dairy, confectioneries, meats, and related products, such as sugars, acids, and salts, have been associated with negative health impacts (Matwiejczuk *et al.,* 2020). While preservatives provide certain benefits such as maintaining food quality and nutritional value, preventing microbial contamination, and improving taste they also present significant drawbacks. Excessive consumption has been linked to health conditions including cancer, asthma, and kidney failure (Abdulmumeen *et al.,* 2012). A major concern is the potential for allergic reactions and hypersensitivity, particularly among individuals with pre-existing conditions. For example, sulphites are known to trigger adverse reactions in sensitive individuals, and another serious issue is their possible carcinogenic nature. Studies indicate that some preservatives, such as nitrites and nitrates, can react with other food components to form nitrosamines, which are recognized carcinogens. Thus, synthetic preservatives may cause allergies, contribute to cancer development, and pose other long-term health risks when misused or overused (Shafiqa-Atikah *et al.,* 2020).

2.8 Proximate Composition of Fish

Fish is widely recognized as one of the most valuable sources of animal protein, particularly in tropical regions where it significantly contributes to dietary needs and nutritional security (Andrew, 2001). Beyond its accessibility, fish offers a rich array of nutrients essential for human health, including complete proteins, fats, vitamins, and minerals. The protein found in fish is of high biological value, containing all the essential amino acids required for growth, tissue repair, enzyme synthesis, and immune function. It is also highly digestible, making fish an ideal protein source in both developing and developed countries.

In addition to protein, fish and other foods supply other important nutrients such as carbohydrates and fats. Carbohydrates serve as a primary source of energy and are widely distributed in both natural and processed food sources. They vary from simple monosaccharides like glucose, fructose, and galactose to complex forms such as starch (Beare-Rogers *et al.,* 2001). Fats, on the other hand, consist mainly of triglycerides composed of fatty acids attached to a glycerol backbone. Some fatty acids are classified as essential because the human body cannot synthesize them, necessitating their intake through food (Beare-Rogers *et al.,* 2001; Bratte *et al.,* 2010). These fats also play key roles in energy storage, cell structure, and the absorption of fat-soluble vitamins. However, the nutritional composition of fish is not static; it varies considerably between species and even among individual fish. Factors such as age, sex, environment, feeding patterns, and seasonal changes significantly influence the proximate composition which includes moisture, protein, fat, ash, and other components (Huss, 1988; 1995). During periods of abundant feeding, the protein content of fish muscle may increase slightly, followed by a rapid build-up of fat. In contrast, fish undergoing starvation whether due to natural physiological processes such as spawning or external factors like food scarcity tend to show a gradual decline in fat content, and eventually, protein levels may also decrease (Huss, 1988; 1995). These seasonal and physiological variations make it important to regularly monitor the proximate composition of fish, especially in processing and nutritional evaluation.

2.8.1 Crude Protein

Protein is one of the most valuable nutrients found in fish, usually ranging from 15–25% of its flesh. This makes fish a very good source of animal protein for people, especially in places where meat is either too expensive or not easily available. Fish protein is considered of high quality because it is easy to digest and contains all the essential amino acids the human body needs but cannot produce on its own. Important amino acids such as lysine and methionine are present in good amounts in fish, whereas they are often lacking in many plant-based foods. For this reason, eating fish regularly helps in fighting protein-energy malnutrition and supports healthy growth and development, especially in children and vulnerable groups (Adeyeye *et al.,* 2018).

The level of protein in fish is not always the same; it changes depending on the species, what the fish eats, and the time of year. For example, lean fish species usually have a slightly higher proportion of protein compared to fatty fish, because the fat in fatty fish reduces the percentage of protein in their flesh (Sutharshiny and Sivashanthini, 2011). On average, most fish fall between 16–22% protein. A good example is Nile tilapia, which has been reported to contain about 18.5% protein in its flesh (Mekki, El-Sayed, and Hamed, 2022).

Processing and cooking methods also influence how protein levels are measured. When fish is smoked or dried, water is lost, and this makes the protein content appear higher, not because the actual protein increases, but because the flesh becomes more concentrated as the moisture reduces. In contrast, cooking methods that involve water, such as boiling or steaming, tend to preserve moisture, which can make the protein percentage appear slightly lower, even though the total protein is unchanged (Burnham, Green, and Gregory, 2021). This shows that while the total protein in fish remains largely stable, the way it is processed or cooked can change how much protein is measured per weight of fish.

2.8.2 Crude Fat

Crude fat, or lipid content, is one of the most variable components in fish and plays a major role in determining nutritional value. It is also the basis for classifying species as “lean” or “fatty.” Fatty fish such as mackerel and sardine may contain between 15–20% fat, while lean fish like cod and hake often have less than 2% (Kamal *et al.,* 2020; Sutharshiny and Sivashanthini, 2011). Fish lipids are nutritionally valuable because they are rich in long-chain omega-3 fatty acids, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are known to support cardiovascular health, brain development, and anti-inflammatory functions (Stancheva and Merdzhanova, 2011; Usydus, Szlinder-Richert and Adamczyk, 2011).

The amount of fat in fish is influenced by several factors, including species, season, feeding patterns, and reproductive stage. For instance, lipid reserves often peak before spawning and decrease afterward, leading to noticeable variation throughout the year (Özden, 2005; Nascimento *et al.,* 2020). Environmental conditions and diet also contribute to differences in fat content among wild and cultured species (Memon *et al.,* 2011).

Processing and storage have a significant effect on lipid quality. During frying or smoking, fish oils are exposed to heat and oxygen, which accelerates lipid oxidation and reduces the stability of sensitive polyunsaturated fatty acids (Gladyshev *et al.,* 2006; Ozyurt *et al.,* 2007). Oxidation not only lowers nutritional value but can also lead to off-flavours and loss of sensory quality. On the other hand, gentler processing methods such as steaming or baking may help preserve a greater proportion of these beneficial fatty acids (Domiszewski, Bienkiewicz, and Plust, 2011). Proper cold storage and the use of antioxidants have also been reported to reduce oxidative changes and extend shelf life (Hosseini *et al.,* 2010)

2.8.3 Crude Fibre

Crude fibre in fish muscle is generally very low, usually below 1%, because fish lack plant-type structural carbohydrates. According to Bland *et al*. (2021), seafood muscle contributes almost no dietary fibre, and the trace amounts detected are often residues from skin, scales, or connective tissues rather than the flesh itself. Similarly, Hussain *et al*. (2019) observed that proximate analyses of marine fish rarely include fibre since its contribution to the nutritional value is negligible.

However, some studies have reported measurable fibre values when whole fish or by-products are considered. For instance, Sultana *et al*. (2024) found crude fibre levels ranging between 1.67% and 2.78% in catfish (*Mystus cavasius*), which they attributed to the presence of skin and gut residues. In another study, Olapade *et al*. (2016) analyzed smoked catfish and recorded fibre content of about 2.1%, suggesting that processing conditions may influence fibre estimates. Akinwumi *et al*. (2022) also reported that some freshwater species showed crude fibre values around 1–2%, though these values remain nutritionally insignificant compared to protein and lipid fractions.

Overall, crude fibre in fish is considered a minor component of proximate composition. It does not significantly contribute to energy or nutrient value, but its inclusion in proximate analysis ensures completeness of data and allows for comparison across species and processing methods (Warwas *et al.,* 2023).

2.8.4 Moisture Content

Moisture is the largest part of fish flesh, usually between 65–80%. It strongly affects how fresh the fish stays, how long it can be stored, and whether it is suitable for different processing methods. Because fish muscle contains so much water and spoils easily making microorganisms and enzymes multiply faster in such conditions (Abbas *et al.,* 2009). When fish is dried, smoked, or fried, the water content decreases, which helps extend its shelf life. At the same time, losing too much moisture can make the flesh tougher and reduce eating quality. In general, lean fish, which usually contain more water, tend to spoil more quickly than fatty fish that have a slightly lower moisture content (Aberoumand, 2013).

Typically, fresh fish muscle holds around 70–80% water. For example, Atlantic cod has about 76% moisture in its flesh (Burnham, Green and Gregory, 2021). Even small changes in this amount can influence how firm or soft the fish feels, how fast it deteriorates, and how concentrated other nutrients like protein or fat appear (Kari, Noor and Faridah, 2022). Processing techniques such as smoking, frying, or steaming reduce water levels, which not only extends shelf life but also increases nutrient density (Shahrier *et al.,* 2023). Seasonal variations also play a role: fish often build up fat before spawning, which slightly lowers water content, while after spawning, the moisture level may rise again (Younis *et al.,* 2014).

2.8.5 Nitrogen-Free Extract

Nitrogen-free extract (NFE) represents the carbohydrate fraction of fish, which is generally very low, usually less than 1% of muscle tissue. According to Huss (1995), this small amount, largely in the form of glycogen, is nutritionally minor but plays an important role in flavour development during processing, as glycogen breakdown contributes to the characteristic aroma of smoked or dried fish. In Spanish mackerel, for example, NFE was reported at about 1.1%, further confirming its minor presence in fish flesh (Watanabe, Ledesma and Morita, 2020). Although small, this fraction is often considered in energy value calculations (National Research Council [NRC], 2011).

2.8.6 Ash Content

Ash content, which reflects the mineral composition of fish, is another important proximate component. It usually ranges from 1–2% in fresh fish, with variations depending on species and environmental conditions. Sulieman *et al*. (2016) noted that marine species generally show higher mineral content than freshwater species due to differences in their habitats. In rainbow trout, for instance, ash content averages around 1.5% (Kim and Lee, 2019). Processing also influences ash concentration, with methods such as drying or smoking increasing mineral levels by reducing water content, while boiling may lead to mineral loss through leaching. High mineral content in fish bones and by-products further enhances their value in fishmeal and mineral supplement production (Warwas *et al.,* 2023).

2.9 Sensory evaluation

Sensory evaluation is a scientific approach that employs the human senses to detect, measure, and interpret food characteristics such as appearance, odour, taste, texture, and sound. In fish quality studies, sensory tests are often categorized into three main types: discriminative, descriptive, and affective tests. Discriminative and descriptive tests are generally applied in research and industry, while affective tests are more consumer-oriented, focusing on preference and acceptance. The method chosen usually depends on the intended purpose, whether for product development, quality assurance, consumer studies, or scientific research (Ólafsdóttir *et al.,* 1997).

During spoilage, fish undergoes clear sensory changes in its appearance, odour, flavour, and texture. In Europe, sensory evaluation remains the main criterion for determining fish quality at both the industry and regulatory levels. This is commonly achieved through the Quality Index Method (QIM), which uses a demerit scoring system to record changes in different sensory attributes over storage time. Each attribute is given a score, and the total score reflects the freshness status of the fish. Lower scores indicate fresher samples, while higher scores indicate advanced spoilage. The QIM has proven to be reliable for standardizing sensory quality control of fish across different regions and species.

In practical applications, trained panels with specialized expertise usually carry out sensory inspections in the fish industry, while in research laboratories, structured sensory scales such as QIM are widely used. Such standardized methods allow comparability of results and help establish objective criteria for freshness evaluation across Europe (Ólafsdóttir *et al.,* 1997). A typical protocol includes the following;

2.9.1 Define Objective and Test Type

Researchers begin by establishing the sensory evaluation aim (such as consumer acceptability or descriptive profiling) and select the appropriate type of test. ISO 6658:2017 provides guidance on choice of test type and methodological design. According to ISO 6658:2017, the nature of the sensory test shall be selected according to the objective of the study and the sample set under investigation (ISO, 2017).

2.9.2 Panellist Selection and Training

Panellists may be consumers (for hedonic testing) or trained/semi-trained assessors (for descriptive profiling). For consumer panels, 30-100 participants are common while for trained panels, 8-15 assessors are typical (Marques and co-authors, 2022; Viana *et al.,* 2022). Panellists must be healthy, free of sensory impairments, and familiarized with the sensory attributes, scale usage and sample testing protocols. The FAO guidelines note that panellists shall be briefed and conditioning shall be provided when necessary (FAO, 2020).

2.9.3. Sample Preparation and Coding

All treatments (e.g., control vs spice-treated vs differently processed) should be prepared identically except for the variable under investigation, in order to isolate effects. Samples are coded with random three-digit numbers or alphanumeric codes to blind the panellists (FAO, 2020). Presentation should avoid identification bias.

2.9.4. Presentation Order and Environment

The order of samples is randomized or balanced to reduce sequence and carry-over effects. Testing is conducted under neutral conditions: an odour-free room, neutral white lighting and consistent temperature (ISO, 2017). Panellists rinse mouth with water (and sometimes plain crackers) between samples to clear the palate.

2.9.5. Attribute Selection and Scale Use

Sensory attributes commonly assessed in fish studies include appearance (colour), aroma/odour, flavour/taste, texture/mouthfeel, and overall acceptability. Hedonic scales (5-, 7-, or 9-point) plate are widely used for consumer liking, while Just-About-Right (JAR) or line scales are used for intensity of specific attributes. Marques *et al.* (2022) noted that the 9-point hedonic scale remains the most widely recommended for consumer acceptability.

2.9.6. Evaluation Session: Panellists typically evaluate one coded sample at a time, following a set sequence: appearance → aroma → taste → texture → overall acceptability. Verbal communication among panellists is discouraged to avoid bias. Ratings are recorded on standardized ballots or digital forms (FAO, 2020).

2.9.7. Data Collection and Statistical Analysis

Responses are compiled and means ± standard deviations calculated. The most common statistical method is one-way or two-way ANOVA, often followed by post-hoc tests (e.g., Tukey's HSD) to determine significant differences (Marques *et al.,* 2022). Multivariate tools (PCA, cluster analysis) may also be used when relating sensory data to instrumental or chemical metrics (Viana *et al.,* 2022).

2.9.8. Reporting Results

Reporting should include mean ratings, standard deviations, significance levels (p-values), and discussion of how sensory outcomes relate to processing/spice treatments and physicochemical measurements (FAO, 2020). The ISO standard also states that documentation of the sensory test shall include details of panellists, samples, scale used, environment and statistical treatment (ISO, 2017).

Sensory Evaluation Scorecard (9-Point Hedonic Scale)

Panellist Code: ______ Date: ______ Treatment: ______

Instructions: Please evaluate each attribute of the fish sample and tick (✓) the score that best reflects your opinion.

Attribute	9 (Like Extremely)	8 (Like Very Much)	7 (Like Moderately)	6 (Like Slightly)	5 (Neither Like nor Dislike)	4 (Dislike Moderately)	3 (Dislike Slightly)	2 (Dislike Very Much)	1 (Dislike Extremely)
Appearance									
Aroma/Smell									
Flavor/Taste									
Texture									
Overall Acceptance									

Remarks (if any): ____

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Study Area

The study was conducted at the experimental fish farm processing unit of the Department of Aquaculture and Fisheries Management (AFM), Faculty of Agriculture, University of Benin, Ugbowo Campus, Edo State, Nigeria. AFM experimental fish farm is geographically positioned between latitudes 6.4º N and longitudes 5.4º E.

3.2 Experimental Design

The study was structured based on two major factors: (i) spice type (black pepper, and cinnamon), and (ii) processing method (air frying, smoking, and deep frying).

A 4×3 factorial experiments was set up in a completely randomized design (CRD), involving three spice treatments across three processing methods. Each treatment group were replicated three times, making a total of 36 fish samples. The fish was purchase from a functional cold room at Ekiosa Market in Benin City, Edo State, Nigeria. The samples were distributed into four treatments combinations, based on two spice treatment groups and three processing methods. The treatment groups will be labelled accordingly;

Treatment 1 (Control) – no spice,

Treatment 2 – treated with black pepper (*Piper nigrum*) only,

Treatment 3 – treated with cinnamon (*Cinnamomum verum*) only,

Treatment 4 – treated with an equal mixture of black pepper and cinnamon.

Each spices were ground into fine powder and applied to the wet fish. Each treatment were divided and subjected to three different processing methods: Deep frying, Air frying and Smoking.

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 panellists.

This experiment allowed for the assessment of the individual and interactive effects of the spices and processing techniques on the proximate composition and sensory characteristics of *Merluccius merluccius*.

3.3 Collection of Samples

The fish samples for this study was obtained from a reputable cold room. Upon delivery to the laboratory, the fish were inspected again to ensure they are free from any visible damage. After selection, all fish samples were thoroughly eviscerated and washed using clean tap water and divided into four treatment groups: control (no spice), black pepper, cinnamon and a combination of cinnamon and black pepper. The quantity of each spice used were calculated at 5% of the fresh body weight of the fish samples (Shamima *et al*. 2007). Each treatment group were mixed evenly to ensure uniform coating. The control group received no spice treatment. For the combination treatment, equal portions of black pepper and cinnamon were mixed together before being applied to the fish. The treated fish samples were allowed to sit for about 20 minutes to permit spice absorption, as recommended by Mosarrat *et al*. (2017). After this, the samples were drained and properly labelled; Treatment 1 – Control (no spices), Treatment 2 – Black Pepper, Treatment 3 – Cinnamon, Treatment 4 - Black pepper + Cinnamon

These prepared fish samples were assigned to the appropriate processing methods for further analysis.

3.4 Processing Apparatus

3.4.1 Manual Deep Frying

It's a non-electric setup used for deep frying food using basic kitchen equipment. It typically consists of: Large frying pan or pot, gas burner or stove, cooking thermometer, frying basket, heat-resistant gloves, tray with absorbent papers.

3.4.2 Air Fryer

The air fryer is an electric device that cooks food using hot air circulated by an internal fan. It provides a healthier alternative to traditional frying as it uses little or no oil. Fish samples are placed inside a removable basket and air-fried at about 180°C. This equipment ensures even cooking and crisp texture while minimizing oil absorption.

3.4.3 Cabinet Smoker

The cabinet smoker is a locally made enclosed smoking unit fuelled by charcoal and hardwood. It has a firebox at the base and a smoking chamber above, where fish samples are placed on trays or racks. As the wood and charcoal burn, heat and smoke rise into the chamber, slowly cooking and drying the fish. The closed design allows for even smoke distribution and temperature control, usually maintained between 60–80°C.

3.5 Processing Methods

3.5.1 Deep Frying

A clean, deep pot was placed on a gas stove. The pot was deep enough to fully cover the fish with oil without spilling. Enough vegetable oil was poured into the pot and heated to about

170–180°C. A thin slice of onion was drop into the oil, if it sizzles immediately and starts frying gently the oil is ready but if it sit at the bottom of the pot it means the oil is not hot enough or the addition of a pinch of salt. The fish was gently placed into the hot oil using tongs to avoid splashing. It was fried for 8–10 minutes, depending on the size, until it turns golden brown and is fully cooked. Also, they were repositioned at intervals to ensure even cooking and once done, the fish were taken out with a slotted spoon and placed on a rack and paper towels to remove excess oil. The fried fish was left to cool at room temperature before further analysis.

3.5.2 Air Frying

Air frying was done using an electric air fryer, which uses hot air to cook the fish. The air fryer basket was cleaned and preheated to 180°C for about 3–5 minute. The Fish samples were placed in the basket and they were arranged in one layer so that hot air can reach all sides. The fish were cooked at 180°C for approximately 15–20 minutes. They were turned halfway through to make sure they cook evenly. Once done, the fish were taken out and left to cool on a clean tray before being tested.

3.5.3 Smoking

Charcoal was placed and lit in the base of the kiln. As the fire burns, heat and smoke rise into the smoking chamber where the fish is kept. The temperature inside were controlled and maintained between 60–80°C to avoid burning the fish. Cleaned fish samples were laid out on metal trays inside the cabinet. Enough space was left between each fish to allow smoke to circulate evenly. The fish absorbed the smoke and lose moisture, the samples were turned or repositioned to ensure even smoking. After smoking, the fish were taken out and left to cool in a clean, dust-free area before being taken for further analysis.

3.6 Sensory and Organoleptic Analysis

Sensory evaluation was conducted by five educated panellists comprising both males and females following the method described by Iwe (2014). The panellists were randomly assigned to assess the different fish treatments. Each treatment were served individually on separate plates, and the panellists evaluated each replicate independently. A structured questionnaire was provided to each panellists containing a 9-point hedonic scale rating scorecard appendix designed to capture their responses. The questionnaire guides the assessments of key sensory attributes namely; Overall acceptance, Flavour/taste, Texture, Aroma/smell and Appearance. The hedonic scale rating ranged from 1- 9 with the following ratings; Like extremely =9, Like very much = 8, Like moderately = 7, Like slightly = 6, Neither like nor dislike = 5, Dislike moderately = 4, Dislike slightly = 3, Dislike very much = 2, Dislike extremely = 1 (Meilgaard *et al*., 2007)

Panellist code:

Sample code:

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

To minimize bias and sensory fatigue, panellists was provided with a clean room-temperature water and instructed to rinse their mouths thoroughly and given cracker biscuits to chew between each sampling. This step helps neutralize lingering flavour's and aromas from previous samples, ensuring that each product is assessed independently. All samples were coded with random three-digit numbers and served in a randomised order to avoid positional or order bias. Evaluations were conducted in an odour-free environment to optimise concentration and accuracy.

3.7 Determination of Proximate Composition

proximate composition of the processed *Merluccius merluccius* samples was determined using standard procedures of the Association of Official Analytical Chemists (AOAC, 2019). The following components were analyzed:

3.7.1 Moisture Content

To measure the moisture content, approximately 5 grams of the homogenized fish samples were weighed into a pre-weighed, clean moisture dish. The samples were dried in a hot-air oven at 105°- 110°C until it reaches a constant weight, ensuring the complete removal of water. The difference in weight before and after drying was used to calculate the moisture content, expressed as a percentage of the initial sample weight. The weight lost due to moisture was calculated by the equation:

$$\text{Moisture (\%)} = \frac{\text{Initial weight} - \text{Dry weight}}{\text{Initial weight}} \times 100$$

3.7.2 Crude Protein

The crude protein content was determined using the Kjeldahl method, which involved the digestion of 1 gram of the sample with concentrated tetraoxosulphate (vi) acid (H_2SO_4) and a catalyst (such as copper or selenium) to break down proteins into ammonium sulphate. After digestion, the ammonia was distilled and trapped in boric acid. The ammonia was titrated with a standard acid, and the nitrogen content was calculated. The protein content was derived by multiplying the nitrogen value by a factor of 6.25, as prescribed by the Kjeldahl method. The protein was calculated from:

$$\text{Crude protein (\%)} = \frac{Na \times Va \times 14}{1000} \times \frac{V_1}{V_2} \times \frac{100}{w} \times 6.25$$

Where;

Na = concentration of HCL titration (0.1N)

Va = volume of HCL used for titration

1000 = constant

14 = atomic number of nitrogen

V_1 = Total volume of digest

V_2 = volume of aliquol (digest used)

3.7.3 Crude Fat

The crude fat content was measured using the Soxhlet extraction method, which involves extracting lipids from the fish sample. 2 grams of the homogenized samples were placed in a cellulose thimble and subjected to continuous extraction using petroleum ether (boiling range 40–60°C) for 6 to 8 hours. After extraction, the solvent was evaporated, and the lipid residue was dried and weighed. The percentage of crude fat was calculated based on the weight of the extracted fat and it's expressed as;

$$\text{Crude Fat (\%)} = \frac{w1 - w2}{w0} \times 100$$

Where;

W_0 = weight of empty porous thimble

W_1 = weight of thimble + ground sample before extraction

W_2 = weight of empty extraction flasks

3.7.4. Crude Fibre

Approximately 2 grams of each thoroughly homogenized fish sample were weighed and transferred into a clean crucible. The sample was boiled in 1.25% tetraoxosulphate (vi) acid (H_2SO_4) for 30 minutes, allowing the acid to break down digestible substances such as sugars, starches, and some proteins. After this acid digestion, the residue were filtered and rinsed repeatedly with hot distilled water to eliminate any remaining acid content. Next, the residue will be boiled again for 30 minutes in 1.25% sodium hydroxide (NaOH) solution. This alkaline digestion step will further remove digestible organic matter, leaving behind the fibrous portion. The residue were filtered and washed thoroughly with hot water, followed by successive rinses with ethanol and petroleum ether to eliminate residual fat and moisture. Afterward, the sample were dried in a hot-air oven at 105°C until a constant weight is obtained. The dried residue was transferred to a muffle furnace and incinerated at 550°C for 4 – 6 hours to burn off all organic matter, leaving only the ash content. The weight loss during this process was used to calculate the crude fibre content using the following formula:

$$\text{Crude fibre (\%)} = \frac{\text{weight of dried residue (all weight of ash)}}{\text{initial sample weight}}\ x\ 100$$

3.7.5. Ash Content

The ash content of the sample was determined by incinerating approximately 1 grams of the dried sample in a muffle furnace at 500 – 600° C for 3 hours. During this process, all organic matter will be burned off, leaving behind a white or light grey ash that represents the total mineral content of the sample. After cooling, the sample will be reweighed to calculate the percentage of ash. Percentage ash will be obtained by;

$$\text{Ash (\%)} = \frac{\text{weight of ash}}{\text{weight of sample}}\ x\ 100$$

3.7.6 Nitrogen-Free Extract (NFE)

The NFE was calculated to estimate the amount of easily digestible carbohydrates such as sugars and starches present in the fish. These carbohydrates provide a quick source of energy and are important for assessing the overall nutritional value of the product. The NFE was measured directly but will be determined by subtraction using the values obtained from other proximate components: moisture content, crude protein, crude fat, crude fibre and ash content using this formula:

NFE (%) = 100 − (% Moisture + % Crude Protein + % Crude Fat + % Crude Fibre + % Ash).

3.8 Statistical analysis

Data obtained was analysed using two-way Analysis of Variance (ANOVA) with GenStat Statistical software (Version 12.1), differences among treatment means will be separated using Duncan's Multiple Range Test (DMRT) at 5% level of probability

CHAPTER FOUR

4.0 RESULTS

4.1 Proximate Composition of *Merluccius merluccius* with different processing methods and spices

4.1.1 Carbohydrate (CHO) Content

The carbohydrate content of *Merluccius merluccius* varied depending on spice treatment and processing method across the three analyses. In the black pepper treatment, the initial analysis showed the highest CHO in deep-fried samples (18.33 ± 0.45%) and the lowest in air-fried samples (13.79 ± 0.9%), with smoked samples recording 15.09 ± 1.87%. The differences were not significant ($p > 0.05$). At the mid-analysis, CHO increased in smoked (19.83 ± 0.27%) and deep-fried (17.51 ± 1.00%) samples, while air-fried remained comparatively low (9.45 ± 2.62%), showing significant differences ($p < 0.05$). By the final analysis, air-fried samples recorded the highest CHO (20.99 ± 0.24%), followed by deep-fried (18.57 ± 4.91%) and smoked (17.99 ± 1.61%), with no significant differences ($p > 0.05$).

For black pepper + cinnamon treatment, initial CHO values were relatively uniform, with smoked samples slightly higher (18.52 ± 1.85%) than air-fried (16.03 ± 1.10%) and deep-fried (17.40 ± 0.95%), with no significant difference ($p > 0.05$). At the mid-analysis, CHO increased moderately in smoked samples (20.71 ± 0.28%), while air-fried (17.41 ± 0.08%) and deep-fried (17.20 ± 1.60%) remained lower, still showing no significant difference ($p > 0.05$). The final analysis showed smoked (20.58 ± 3.10%) and air-fried (20.43 ± 0.42%) samples higher than deep-fried (16.57 ± 3.46%), but the differences were not significant ($p > 0.05$).

For cinnamon treatment, the initial CHO was highest in air-fried samples (17.79 ± 1.10%) and lowest in deep-fried (16.15 ± 1.32%), with smoked samples at 16.22 ± 0.36%, showing no

Table 4.1.1: Carbohydrates 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]	18.33 ± 0.45[b]	15.09 ± 1.87[ab]	7.233	0.071
	Cinnamon Only	17.79 ± 1.10[a]	16.15 ± 1.32[a]	16.22 ± 0.36[a]	1.68	0.324
	Black Pepper + Cinnamon	16.03 ± 1.10[a]	17.40 ± 0.95[a]	18.52 ± 1.85[a]	1.678	0.324
	Control	10.92 ± 1.07[a]	10.92 ± 1.07[a]	10.92 ± 1.07[a]	0.000	1.000
6	Black Pepper	9.45 ± 2.62[a]	17.51 ± 1.00[b]	19.83 ± 0.27[b]	22.471	0.016
	Cinnamon Only	19.54 ± 0.68[a]	15.76 ± 0.14[a]	17.27 ± 2.15[a]	4.258	0.133
	Black Pepper + Cinnamon	17.41 ± 0.08[a]	17.20 ± 1.60[a]	20.71 ± 0.28[b]	8.792	0.056
	Control	7.10 ± 2.31[a]	7.10 ± 2.31[a]	7.10 ± 2.31[a]	0.000	1.000
12	Black Pepper	20.99 ± 0.24[a]	18.57 ± 4.91[a]	17.99 ± 1.61[a]	0.57	0.617
	Cinnamon Only	10.61 ± 0.14[a]	25.73 ± 2.06[c]	16.23 ± 1.99[b]	42.43	0.006
	Black Pepper + Cinnamon	20.43 ± 0.42[a]	16.57 ± 3.46[a]	20.58 ± 3.10[a]	1.419	0.368
	Control	17.01 ± 0.78[a]	17.01 ± 0.78[a]	17.01 ± 0.78[a]	0.000	1.000

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

significant difference ($p > 0.05$). At mid-analysis, air-fried remained highest (19.54 ± 0.68%), deep-fried lowest (15.76 ± 0.14%), and smoked at 17.27 ± 2.15%, with differences still not significant ($p > 0.05$). The final analysis revealed a marked increase in deep-fried samples (25.73 ± 2.06%), while air-fried dropped to 10.61 ± 0.14% and smoked was at 16.23 ± 1.99%, showing significant differences ($p < 0.05$).

The control samples remained relatively stable, with CHO values ranging from 10.92 ± 1.07% initially to 7.10 ± 2.31% at mid-analysis and 17.01 ± 0.78% at the final analysis, with no significant differences observed ($p > 0.05$).

4.1.2 Ash Content (AC)

The ash content of *Merluccius merluccius* varied according to spice treatment and processing method across the analysis. In the black pepper treatment, initial ash values were similar across the methods, with deep-fried samples recording 1.01 ± 0.17%, smoked at 0.88 ± 0.30%, and air-fried at 0.53 ± 0.09%, showing no significant difference ($p > 0.05$). At mid-analysis, ash content increased markedly in deep-fried (1.69 ± 0.18%) and smoked (1.67 ± 0.08%) samples, while air-fried remained lower (0.75 ± 0.00%), showing significant differences ($p < 0.05$). By the final analysis, deep-fried (2.35 ± 0.57%), smoked (2.95 ± 0.13%), and air-fried (2.00 ± 0.25%) samples all showed a gradual increase, but differences were not significant ($p > 0.05$).

For black Pepper + cinnamon treatment, initial ash values were 0.80 ± 0.01% for air-fried, 0.98 ± 0.02% for deep-fried, and 1.07 ± 0.06% for smoked samples, showing significant differences ($p < 0.05$). At mid-analysis, ash content remained relatively uniform across treatments, with air-fried at 1.46 ± 0.05%, deep-fried 1.30 ± 0.06% and smoked 1.43 ± 0.05%, showing no significant difference ($p > 0.05$). In the final analysis, smoked samples showed the highest ash

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}	1.01 ± 0.17^{a}	0.88 ± 0.30^{a}	3.014	0.192
	Cinnamon Only	1.14 ± 0.11^{a}	0.71 ± 0.25^{a}	1.17 ± 0.13^{a}	4.265	0.133
	Black Pepper + Cinnamon	0.80 ± 0.01^{a}	0.98 ± 0.02^{b}	1.07 ± 0.06^{b}	29.234	0.011
	Control	1.08 ± 0.05^{a}	1.08 ± 0.05^{a}	1.08 ± 0.05^{a}	0.000	1.000
6	Black Pepper	0.75 ± 0.00^{a}	1.69 ± 0.18^{b}	1.67 ± 0.08^{b}	44.756	0.006
	Cinnamon Only	0.94 ± 0.04^{a}	0.91 ± 0.06^{a}	1.21 ± 0.03^{b}	31.667	0.01
	Black Pepper + Cinnamon	1.46 ± 0.05^{a}	1.30 ± 0.06^{a}	1.43 ± 0.05^{a}	5.006	0.111
	Control	1.99 ± 0.18^{a}	1.99 ± 0.18^{a}	1.99 ± 0.18^{a}	0.000	1.000
12	Black Pepper	2.00 ± 0.25^{a}	2.35 ± 0.57^{a}	2.95 ± 0.13^{a}	3.454	0.167
	Cinnamon Only	2.34 ± 0.41^{a}	1.99 ± 0.18^{a}	3.36 ± 0.30^{b}	10.628	0.043
	Black Pepper + Cinnamon	2.05 ± 0.09^{a}	2.27 ± 0.45^{ab}	2.97 ± 0.13^{b}	6.156	0.087
	Control	2.16 ± 0.02^{a}	2.16 ± 0.02^{a}	2.16 ± 0.02^{a}	0.000	1.000

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

(2.97 ± 0.13%), followed by deep-fried (2.27 ± 0.45%) and air-fried (2.05 ± 0.09%), with differences approaching significance ($p > 0.05$).

For cinnamon treatment, initial ash values were 1.14 ± 0.11% for air-fried, 0.71 ± 0.25% for deep-fried, and 1.17 ± 0.13% for smoked samples, with no significant differences ($p > 0.05$). At mid-analysis, ash content increased slightly in smoked (1.21 ± 0.03%) and remained stable in air-fried (0.94 ± 0.04%) and deep-fried (0.91 ± 0.06%) samples, showing significant differences ($p < 0.05$). By the final analysis, ash content further increased in smoked samples (3.36 ± 0.30%), while air-fried (2.34 ± 0.41%) and deep-fried (1.99 ± 0.18%) remained lower, showing significant differences ($p < 0.05$).

The control samples remained relatively stable, with initial (1.08 ± 0.05%), mid (1.99 ± 0.18%), and final (2.16 ± 0.02%) values, showing no significant differences ($p > 0.05$)

4.1.3 Crude fat (CF)

For black pepper treatment, the initial analysis showed fat content was highest in deep-fried samples (8.66 ± 0.78%) and lowest in air-fried samples (5.56 ± 0.60%), with smoked samples at 8.16 ± 0.46%. Differences were significant ($p < 0.05$). At mid-analysis, fat content slightly increased in deep-fried samples (7.21 ± 0.26%), remained relatively stable in smoked (6.07 ± 1.00%), and air-fried samples (5.49 ± 0.29%) did not show significant differences ($p > 0.05$). By the final analysis, air-fried (3.70 ± 0.13%) and deep-fried (3.71 ± 0.42%) samples had higher fat content than smoked samples (1.76 ± 0.28%), showing significant differences ($p < 0.05$).

For black pepper + cinnamon treatment, initial fat values were similar across air-fried (7.01 ± 0.11%), deep-fried (7.65 ± 0.45%), and smoked (7.41 ± 0.82%) samples, showing no significant differences ($p > 0.05$). At mid-analysis, fat content remained stable in all samples,

Table 4.1.3: Crude Fat Analysis Based On The Different Processing Methods And Spice Treatment

Weeks	Treatment	Air-fried	Deep-fried	Smoked	F-value	p-value
0	Black Pepper	5.56 ± 0.60^a	8.66 ± 0.78^b	8.16 ± 0.46^b	14.145	0.03
	Cinnamon Only	7.48 ± 0.47^a	7.59 ± 0.60^a	8.47 ± 0.64^a	1.767	0.311
	Black Pepper + Cinnamon	7.01 ± 0.11^a	7.65 ± 0.45^a	7.41 ± 0.82^a	0.7	0.563
	Control	5.77 ± 0.23^a	5.77 ± 0.23^a	5.77 ± 0.23^a	0.000	1.000
6	Black Pepper	5.49 ± 0.29^a	7.21 ± 0.26^a	6.07 ± 1.00^a	4.007	0.142
	Cinnamon Only	4.78 ± 0.13^a	7.88 ± 0.23^b	7.39 ± 0.60^b	38.822	0.007
	Black Pepper + Cinnamon	7.50 ± 1.58^a	6.47 ± 0.41^a	6.08 ± 0.37^a	1.148	0.426
	Control	3.63 ± 4.68^a	3.63 ± 4.68^a	3.63 ± 4.68^a	0.000	1.000
12	Black Pepper	3.70 ± 0.13^b	3.71 ± 0.42^b	1.76 ± 0.28^a	27.394	0.012
	Cinnamon Only	3.40 ± 0.10^b	2.47 ± 0.03^a	3.65 ± 0.30^b	23.48	0.015
	Black Pepper + Cinnamon	2.94 ± 0.11^b	2.24 ± 0.04^a	2.08 ± 0.09^a	58.133	0.004
	Control	3.64 ± 0.32^a	3.64 ± 0.32^a	3.64 ± 0.32^a	0.000	1.000

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

with air-fried at 7.50 ± 1.58%, deep-fried 6.47 ± 0.41%, and smoked 6.08 ± 0.37%, showing no significant differences ($p > 0.05$). By the final analysis, fat content decreased slightly, with air-fried (2.94 ± 0.11%) higher than deep-fried (2.24 ± 0.04%) and smoked (2.08 ± 0.09%), showing significant differences ($p < 0.05$).

In cinnamon treatment, initial fat content ranged from 7.48 ± 0.47% in air-fried to 8.47 ± 0.64% in smoked samples, with deep-fried at 7.59 ± 0.60%, showing no significant differences ($p > 0.05$). At mid-analysis, fat increased significantly in deep-fried (7.88 ± 0.23%) and smoked (7.39 ± 0.60%) samples compared to air-fried (4.78 ± 0.13%) ($p < 0.05$). At the final analysis, fat content decreased overall, with air-fried (3.40 ± 0.10%), deep-fried (2.47 ± 0.03%), and smoked (3.65 ± 0.30%) showing significant differences ($p < 0.05$).

The control samples maintained relatively stable fat content across the three analyses, with initial (5.77 ± 0.23%), mid (3.63 ± 4.68%), and final (3.64 ± 0.32%), showing no significant differences ($p > 0.05$).

4.1.4 Crude Fibre

In black pepper treatment, initial analysis revealed the highest fibre in air-fried samples (5.04 ± 0.25%), followed closely by deep-fried (4.87 ± 0.25%) and the lowest in smoked (2.97 ± 0.13%), with significant differences ($p < 0.05$). At mid-analysis, fibre content slightly increased in smoked samples (5.92 ± 1.28%) compared to air-fried (4.80 ± 0.33%) and deep-fried (4.54 ± 0.41%), but the differences were not significant ($p > 0.05$). By the final analysis, air-fried (6.55 ± 0.62%), deep-fried (6.96 ± 0.12%), and smoked (5.92 ± 0.16%) showed no significant differences ($p > 0.05$).

For black pepper + cinnamon treatment, initial fibre content was highest in air-fried samples (4.52 ± 0.57%), followed by deep-fried (4.28 ± 0.15%) and smoked (3.32 ± 0.13%), though the

Table 4.1.4: Crude Fiber 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}	4.87 ± 0.25^{b}	2.97 ± 0.13^{a}	56.377	0.004
	Cinnamon Only	3.43 ± 0.36^{a}	4.25 ± 0.27^{a}	4.10 ± 0.30^{a}	3.914	0.146
	Black Pepper + Cinnamon	4.52 ± 0.57^{b}	4.28 ± 0.15^{ab}	3.32 ± 0.13^{a}	6.546	0.081
	Control	5.00 ± 0.24^{a}	5.00 ± 0.24^{a}	5.00 ± 0.24^{a}	0.000	1.000
6	Black Pepper	4.80 ± 0.33^{a}	4.54 ± 0.41^{a}	5.92 ± 1.28^{a}	1.675	0.325
	Cinnamon Only	6.00 ± 0.24^{c}	5.14 ± 0.11^{b}	3.01 ± 0.23^{a}	114.097	0.001
	Black Pepper + Cinnamon	2.68 ± 0.30^{a}	5.08 ± 0.78^{b}	4.15 ± 0.33^{ab}	10.737	0.043
	Control	3.47 ± 0.08^{a}	3.47 ± 0.08^{a}	3.47 ± 0.08^{a}	0.000	1.000
12	Black Pepper	6.55 ± 0.62^{a}	6.96 ± 0.12^{a}	5.92 ± 0.16^{a}	3.927	0.145
	Cinnamon Only	6.81 ± 0.08^{a}	6.82 ± 0.15^{a}	6.15 ± 0.45^{a}	3.741	0.153
	Black Pepper + Cinnamon	6.25 ± 0.15^{a}	6.50 ± 0.45^{a}	5.52 ± 0.39^{a}	4.147	0.137
	Control	6.45 ± 0.47^{a}	6.45 ± 0.47^{a}	6.45 ± 0.47^{a}	0.000	1.000

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

differences were not significant ($p > 0.05$). At mid-analysis, fibre increased in deep-fried (5.08 ± 0.78%) and smoked (4.15 ± 0.33%) samples compared to air-fried (2.68 ± 0.30%), with significant differences ($p < 0.05$). By the final analysis, fibre content in air-fried (6.25 ± 0.15%), deep-fried (6.50 ± 0.45%), and smoked (5.52 ± 0.39%) samples showed no significant differences ($p > 0.05$).

In cinnamon treatment, initial fibre content was 3.43 ± 0.36% in air-fried, 4.25 ± 0.27% in deep-fried, and 4.10 ± 0.30% in smoked samples, with no significant differences ($p > 0.05$). At mid-analysis, air-fried samples increased slightly (6.00 ± 0.24%) compared to deep-fried (5.14± 0.11%) and smoked (3.01 ± 0.23%), with significant differences ($p < 0.05$). At the final analysis, fibre content remained relatively stable across air-fried (6.81 ± 0.08%), deep-fried (6.82 ± 0.15%), and smoked (6.15 ± 0.45%), with no significant differences ($p > 0.05$).

The control samples showed consistent fibre content across analysis, with initial (5.00 ± 0.24%), mid (3.47 ± 0.08%), and final (6.45 ± 0.47%), showing no significant differences ($p > 0.05$).

4.1.5 Moisture content (MC)

In black pepper treatment, initial moisture content was highest in smoked (15.10 ± 0.18%) and air-fried (15.05 ± 0.08%) samples, while deep-fried had slightly lower moisture (14.22 ± 0.32%), showing significant differences ($p < 0.05$). At mid-analysis, moisture increased in air-fried (18.07 ± 0.11%), deep-fried (16.54 ± 0.86%), and smoked (15.52 ± 2.31%) samples, with no significant differences ($p > 0.05$). By the final analysis, moisture content ranged from 18.34 ± 0.16% in air-fried to 24.84 ± 5.41% in deep-fried and 23.22 ± 1.07% in smoked, showing no significant differences ($p > 0.05$).

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}	14.22 ± 0.32^{a}	15.10 ± 0.18^{b}	10.58	0.044
	Cinnamon Only	15.69 ± 0.58^{ab}	14.22 ± 0.32^{a}	16.57 ± 0.77^{b}	8.205	0.061
	Black Pepper + Cinnamon	14.51 ± 0.56^{a}	14.69 ± 0.18^{a}	15.05 ± 0.26^{a}	1.102	0.438
	Control	15.28 ± 0.74^{a}	15.28 ± 0.74^{a}	15.28 ± 0.74^{a}	0.000	1.000
6	Black Pepper	18.07 ± 0.11^{a}	16.54 ± 0.86^{a}	15.52 ± 2.31^{a}	1.626	0.332
	Cinnamon Only	12.09 ± 0.33^{a}	16.23 ± 1.07^{b}	18.41 ± 0.02^{c}	49.53	0.005
	Black Pepper + Cinnamon	17.80 ± 0.47^{ab}	18.56 ± 0.49^{b}	16.38 ± 0.77^{a}	6.985	0.074
	Control	41.81 ± 1.84^{a}	41.81 ± 1.84^{a}	41.81 ± 1.84^{a}	0.000	1.000
12	Black Pepper	18.34 ± 0.16^{a}	24.84 ± 5.41^{a}	23.22 ± 1.07^{a}	2.257	0.252
	Cinnamon Only	20.57 ± 0.58^{b}	18.87 ± 0.20^{a}	19.98 ± 0.24^{ab}	10.319	0.045
	Black Pepper + Cinnamon	19.30 ± 0.52^{a}	22.14 ± 0.69^{b}	19.43 ± 0.66^{a}	13.024	0.033
	Control	19.92 ± 0.36^{a}	19.92 ± 0.36^{a}	19.92 ± 0.36^{a}	0.000	1.000

Notes: Means with different superscripts across rows are significantly different (p<0.05)

For black pepper + cinnamon treatment, initial moisture content was similar across air-fried (14.51 ± 0.56%), deep-fried (14.69 ± 0.18%), and smoked (15.05 ± 0.26%) samples, with no significant differences ($p > 0.05$). At mid-analysis, moisture slightly increased in deep-fried (18.56 ± 0.49%) and decreased in smoked (16.38 ± 0.77%), while air-fried (17.80 ± 0.47%) remained stable, showing no significant differences ($p > 0.05$). By the final analysis, moisture content was highest in deep-fried (22.14 ± 0.69%), followed by air-fried (19.30 ± 0.52%) and smoked (19.43 ± 0.66%), with significant differences observed ($p < 0.05$).

In cinnamon treatment, moisture content initially ranged from 14.22 ± 0.32% in deep-fried to 16.57 ± 0.77% in smoked samples, with air-fried at 15.69 ± 0.58%, showing no significant differences ($p > 0.05$). Mid-analysis values increased in smoked (18.41 ± 0.02%) and deep-fried (16.23 ± 1.07%), while air-fried decreased to 12.09 ± 0.33%, with significant differences ($p < 0.05$). By the final analysis, moisture was 20.57 ± 0.58% in air-fried, 18.87 ± 0.20% in deep-fried, and 19.98 ± 0.24% in smoked, showing significant differences ($p < 0.05$).

The control samples maintained fairly consistent moisture content across analyses: 15.28 ± 0.74% initially, 41.81 ± 1.84% mid-analysis, and 19.92 ± 0.36% at the final analysis, with no significant differences ($p > 0.05$).

4.1.6 Crude protein (CF)

Protein content of *Merluccius merluccius* varied with spice treatment and processing methods. In Black Pepper treatment, initial protein content was highest in air-fried (60.06 ± 0.39%), followed by smoked (57.82 ± 2.58%) and lowest in deep-fried (52.92 ± 1.13%), showing significant differences ($p < 0.05$). At mid-analysis, protein content remained similar across

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}	52.92 ± 1.13^{a}	57.82 ± 2.58^{ab}	9.872	0.048
	Cinnamon Only	54.49 ± 0.42^{a}	55.47 ± 2.14^{a}	53.63 ± 2.40^{a}	0.488	0.656
	Black Pepper + Cinnamon	57.14 ± 2.36^{a}	55.03 ± 1.35^{a}	56.14 ± 3.84^{a}	0.303	0.759
	Control	57.16 ± 6.97^{a}	57.16 ± 6.97^{a}	57.16 ± 6.97^{a}	0.000	1.000
6	Black Pepper	52.11 ± 1.42^{a}	52.01 ± 1.08^{a}	52.50 ± 2.28^{a}	0.049	0.953
	Cinnamon Only	56.61 ± 1.00^{a}	55.36 ± 2.48^{a}	52.48 ± 0.91^{a}	3.37	0.171
	Black Pepper + Cinnamon	54.97 ± 0.65^{a}	51.35 ± 1.70^{a}	52.02 ± 1.36^{a}	4.313	0.131
	Control	35.14 ± 5.12^{a}	35.14 ± 5.12^{a}	35.14 ± 5.12^{a}	0.000	1.000
12	Black Pepper	48.43 ± 0.30^{a}	72.29 ± 30.65^{a}	48.87 ± 2.83^{a}	1.179	0.419
	Cinnamon Only	51.56 ± 0.64^{b}	45.54 ± 0.29^{a}	50.59 ± 0.74^{b}	60.974	0.004
	Black Pepper + Cinnamon	48.06 ± 0.13^{a}	52.88 ± 0.17^{b}	49.39 ± 2.23^{ab}	7.441	0.069
	Control	40.60 ± 14.13^{a}	40.60 ± 14.13^{a}	40.60 ± 14.13^{a}	0.000	1.000

Notes: Means with different superscripts across rows are significantly different (p<0.05)

treatments: air-fried (52.11 ± 1.42%), deep-fried (52.01 ± 1.08%), and smoked (52.50 ± 2.28%), with no significant differences ($p > 0.05$). By the final analysis, protein content was 48.43 ± 0.30% in air-fried, 72.29 ± 30.65% in deep-fried, and 48.87 ± 2.83% in smoked samples, showing no significant differences ($p > 0.05$).

For black pepper + cinnamon treatment, initial protein content was 57.14 ± 2.36% in air-fried, 55.03 ± 1.35% in deep-fried, and 56.14 ± 3.84% in smoked, with no significant differences ($p > 0.05$). Mid-analysis values were 54.97 ± 0.65% (air-fried), 51.35 ± 1.70% (deep-fried), and 52.02 ± 1.36% (smoked), showing no significant differences ($p > 0.05$). By the final analysis, protein content ranged from 48.06 ± 0.13% (air-fried) to 52.88 ± 0.17% (deep-fried) and 49.39 ± 2.23% (smoked), with differences approaching significance ($p > 0.05$).

In cinnamon treatment, protein content initially ranged from 53.63 ± 2.40% in smoked to 55.47 ± 2.14% in deep-fried, with air-fried at 54.49 ± 0.42%, showing no significant differences ($p > 0.05$). At mid-analysis, protein values were 56.61 ± 1.00% (air-fried), 55.36 ± 2.48% (deep-fried), and 52.48 ± 0.91% (smoked), showing no significant differences ($p > 0.05$). By the final analysis, protein increased in air-fried (51.56 ± 0.64%) and smoked (50.59 ± 0.74%), while deep-fried decreased (45.54 ± 0.29%), showing significant differences ($p < 0.05$).

The control samples maintained relatively stable protein content across all analyses: 57.16 ± 6.97% initially, 35.14 ± 5.12% mid-analysis, and 40.60 ± 14.13% at the final analysis, with no significant differences ($p > 0.05$).

4.2 General Mean of Proximate Composition of Processed Merluccius *merluccius* with different spice

Table 4.1 shows the proximate composition of of *Merluccius Merluccius* subjected to different processing methods (air-frying, deep-frying and smoking) and spices treatment (black pepper, cinnamon, combination of cinnamon and black pepper and control).

4.2.1 Carbohydrate (NFE)

Carbohydrate content was generally higher in the spiced samples compared to the control. In black pepper treatment, deep-fried samples had the highest carbohydrate content (18.14 ± 2.30%), followed closely by smoked (17.64 ± 2.41%) and air-fried samples (14.74 ± 5.36%). However, these differences were not significant ($p > 0.05$). In black pepper + cinnamon treatment, smoked samples recorded the highest carbohydrate content (19.93 ± 1.96%), air-fried samples had 17.96 ± 2.08%, and deep-fried samples had 17.06 ± 1.80%, although the differences were not significant ($p > 0.05$). For cinnamon, deep-fried samples had 19.21 ± 5.17%, air-fried 15.98 ± 4.27%, and smoked 16.57 ± 1.43%, with no significant difference ($p > 0.05$). Control samples had identical carbohydrate content across all methods (11.68 ± 4.63%), with no significant difference ($p > 0.05$).

4.2.2 Crude Protein (CF)

Protein content, a key indicator of nutritional quality, was highest in the deep-fried black pepper samples (59.07 ± 17.13%), followed by air-fried (53.53 ± 5.36%) and smoked samples (53.06 ± 4.49%), though differences were not significant ($p > 0.05$). In black pepper + cinnamon, air-fried samples had slightly higher protein content (53.39 ± 4.38%) compared to deep-fried (53.08 ± 1.92%) and smoked (52.51 ± 3.68%), with no significant difference (p > 0.05). For cinnamon, air-fried samples had 54.22 ± 2.33%, deep-fried 52.12 ± 5.31%, and

Table 4.2: General Mean Of The Proximate Composition Of Processed *Merluccius Merluccius* With Different Spice

Nutrient (%)	Treatment	Air-Fried	Deep Fried	Smoked	F-value	p-value
CHO	Black Pepper	14.74 ± 5.36^{a}	18.14 ± 2.30^{a}	17.64 ± 2.41^{a}	1.516	0.251
	Black Pepper + Cinnamon	17.96 ± 2.08^{ab}	17.06 ± 1.80^{a}	19.93 ± 1.96^{b}	3.421	0.060
	Cinnamon Only	15.98 ± 4.27^{a}	19.21 ± 5.17^{a}	16.57 ± 1.43^{a}	1.136	0.347
	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}	1.68 ± 0.66^{a}	1.83 ± 0.95^{a}	1.503	0.254
	Black Pepper + Cinnamon	1.43 ± 0.56^{a}	1.51 ± 0.63^{a}	1.82 ± 0.90^{a}	0.490	0.622
	Cinnamon Only	1.47 ± 0.71^{a}	1.20 ± 0.63^{a}	1.91 ± 1.13^{a}	1.071	0.368
	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}	6.53 ± 2.31^{a}	5.33 ± 2.96^{a}	0.836	0.453
	Black Pepper + Cinnamon	5.82 ± 2.35^{a}	5.45 ± 2.56^{a}	5.19 ± 2.52^{a}	0.097	0.908
	Cinnamon Only	5.22 ± 1.87^{a}	5.98 ± 2.74^{a}	6.50 ± 2.30^{a}	0.460	0.640
	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}	5.45 ± 1.19^{a}	4.93 ± 1.63^{a}	0.336	0.720
	Black Pepper + Cinnamon	4.48 ± 1.62^{a}	5.28 ± 1.09^{a}	4.33 ± 1.02^{a}	0.979	0.398
	Cinnamon Only	5.41 ± 1.59^{a}	5.40 ± 1.17^{a}	4.42 ± 1.45^{a}	0.975	0.400
	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}	18.53 ± 5.56^{a}	17.95 ± 4.25^{a}	0.167	0.848
	Black Pepper + Cinnamon	17.20 ± 2.23^{a}	18.46 ± 3.36^{a}	16.95 ± 2.06^{a}	0.577	0.574
	Cinnamon Only	16.12 ± 3.83^{a}	16.44 ± 2.15^{a}	18.32 ± 1.57^{a}	1.170	0.337
	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}	59.07 ± 17.13^{a}	53.06 ± 4.49^{a}	0.587	0.568
	Black Pepper + Cinnamon	53.39 ± 4.38^{a}	53.08 ± 1.92^{a}	52.51 ± 3.68^{a}	0.097	0.908
	Cinnamon Only	54.22 ± 2.33^{a}	52.12 ± 5.31^{a}	52.23 ± 1.82^{a}	0.680	0.522
	Control (No Spice)	44.30 ± 12.65^{a}	44.30 ± 12.65^{a}	44.30 ± 12.65^{a}	0.000	1.000

Notes: Means with different superscripts across rows are significantly different (p<0.05)

smoked 52.23 ± 1.82%, while control samples remained uniform at 44.30 ± 12.65%, showing no significant difference ($p > 0.05$).

4.2.3 Crude Fat (CF)

Fat content was slightly higher in deep-fried and smoked samples across spiced treatments. In black pepper, deep-fried samples had 6.53 ± 2.31%, smoked 5.33 ± 2.96%, and air-fried 4.91 ± 0.99%, with no significant difference ($p > 0.05$). In black pepper + cinnamon, air-fried samples had 5.82 ± 2.35%, deep-fried 5.45 ± 2.56%, and smoked 5.19 ± 2.52%, showing no significant difference ($p > 0.05$). For cinnamon, smoked samples had 6.50 ± 2.30%, deep-fried 5.98 ± 2.74%, and air-fried 5.22 ± 1.87%, with no significant difference ($p > 0.05$). Control samples had the lowest fat content (4.35 ± 2.37%) across all methods showing no significant difference ($p > 0.05$).

4.2.4 Crude Fibre (CF)

Fibre content was relatively stable across treatments. In black pepper, air-fried samples had 5.46 ± 0.91%, deep-fried 5.45 ± 1.19%, and smoked 4.93 ± 1.63%, with no significant difference ($p > 0.05$). Black pepper + cinnamon samples had 5.28 ± 1.09% in deep-fried, 4.48 ± 1.62% in air-fried, and 4.33 ± 1.02% in smoked samples, with no significant difference ($p > 0.05$). In cinnamon, air-fried had 5.41 ± 1.59%, deep-fried 5.40 ± 1.17%, and smoked 4.42 ± 1.45%, again no significant difference ($p > 0.05$). Control samples were uniform at 4.97 ± 1.35% showing no significant difference ($p > 0.05$).

4.2.5 Moisture Content (MC)

Moisture content tended to be slightly higher in deep-fried samples across most spiced treatments. In black pepper, deep-fried had 18.53 ± 5.56%, smoked 17.95 ± 4.25%, and air-fried 17.15 ± 1.64%, with no significant difference ($p > 0.05$). For black pepper + cinnamon, deep-fried had 18.46 ± 3.36%, air-fried 17.20 ± 2.23%, and smoked 16.95 ± 2.06%, also not significant ($p > 0.05$). In cinnamon, smoked samples retained 18.32 ± 1.57%, slightly higher than deep-fried (16.44 ± 2.15%) and air-fried (16.12 ± 3.83%), with no significant difference ($p > 0.05$). Control samples had the highest moisture overall (25.67 ± 12.71%) and uniform across methods showing no significant ($p > 0.05$).

4.2.6 Ash Content (AC)

Ash content was slightly higher in smoked spiced samples. In black pepper, smoked had 1.83 ± 0.95%, deep-fried 1.68 ± 0.66%, and air-fried 1.09 ± 0.72%, not significant ($p > 0.05$). In black pepper + cinnamon, smoked samples had 1.82 ± 0.90%, air-fried 1.43 ± 0.56%, and deep-fried 1.51 ± 0.63%, again no significant difference ($p > 0.05$). In cinnamon, smoked samples had 1.91 ± 1.13%, deep-fried 1.20 ± 0.63%, and air-fried 1.47 ± 0.71%, showing no significant difference ($p > 0.05$). Control samples were uniform at 1.74 ± 0.53% showing no significant difference ($p > 0.05$).

4.3 Organoleptic Analysis of *Merluccius merluccius* with different processing methods and spices

4.3.1 Flavour

Flavour scores of *Merluccius merluccius* varied with spice treatment and processing method.

In black pepper treatment, initial flavour was highest in deep-fried samples (7.80 ± 1.30) followed by air-fried (7.20 ± 1.30) and smoked (7.20 ± 0.84), showing significant differences

($p < 0.05$). At mid-analysis, deep-fried samples maintained the highest flavour value (8.40 ± 0.89), while smoked samples had the lowest (6.40 ± 2.19), indicating significant differences ($p < 0.05$). By the final analysis, flavour scores were 7.20 ± 1.30 (air-fried), 8.20 ± 1.09 (deep-fried), and 6.80 ± 1.48 (smoked), with no significant differences ($p > 0.05$).

For black pepper + cinnamon treatment, initial flavour scores ranged from 6.80 ± 1.09 (air-fried) to 7.80 ± 1.09 (deep-fried) and 6.80 ± 1.64 (smoked), showing significant differences ($p < 0.05$). Mid-analysis values were 7.80 ± 0.45 (air-fried), 7.40 ± 1.14 (deep-fried), and 7.00 ± 1.00 (smoked), also showing significant differences ($p < 0.05$). By the final period, flavour remained relatively stable across methods (7.20 ± 1.30 – 8.20 ± 1.09) with no significant differences ($p > 0.05$).

In cinnamon treatment, initial flavour values were 6.00 ± 2.45 (air-fried), 7.80 ± 1.09 (deep-fried), and 6.80 ± 1.64 (smoked), showing significant differences ($p < 0.05$). At mid-analysis, flavour remained highest in deep-fried (8.20 ± 1.09) and lowest in smoked (6.80 ± 1.48), with significant differences ($p < 0.05$). Final analysis recorded similar values (7.20 ± 1.30 – 8.20 ± 1.09) with no significant differences ($p > 0.05$).

For control, initial flavour was highest in smoked samples (8.20 ± 1.09) compared to air-fried (7.80 ± 0.84) and deep-fried (7.60 ± 1.14), showing significant differences ($p < 0.05$). Mid-analysis maintained higher flavour in deep-fried samples (8.40 ± 0.89) than in smoked (6.40 ±

Table 4.3.1: Flavour Organoleptic Analysis Based On The Different Processing Method And Spices

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black Pepper	June	7.20 ± 1.30^{ab}	7.80 ± 1.30^{a}	7.20 ± 0.84^{ab}	5.514	0.006
	July	7.20 ± 1.48^{ab}	8.40 ± 0.89^{a}	7.20 ± 0.45^{ab}	5.514	0.006
	August	7.20 ± 1.48^{a}	8.40 ± 0.89^{a}	7.20 ± 0.45^{a}	1.783	0.177
Cinnamon	June	6.00 ± 2.45^{b}	7.80 ± 1.09^{a}	6.80 ± 1.64^{ab}	5.514	0.006
	July	7.20 ± 1.30^{ab}	8.20 ± 1.09^{a}	6.80 ± 1.48^{b}	5.514	0.006
	August	7.20 ± 1.30^{a}	8.20 ± 1.09^{a}	6.80 ± 1.48^{a}	1.783	0.177
Black Pepper + Cinnamon	June	6.80 ± 1.09^{ab}	7.80 ± 1.09^{a}	6.80 ± 1.64^{ab}	5.514	0.006
	July	7.80 ± 0.45^{a}	7.40 ± 1.14^{ab}	7.00 ± 1.00^{b}	5.514	0.006
	August	7.80 ± 0.45^{a}	7.40 ± 1.14^{a}	7.00 ± 1.00^{a}	1.783	0.177
Control	June	7.80 ± 0.84^{ab}	7.60 ± 1.14^{ab}	8.20 ± 1.09^{a}	5.514	0.006
	July	7.40 ± 1.52^{ab}	8.40 ± 0.89^{a}	6.40 ± 2.19^{b}	5.514	0.006
	August	7.40 ± 1.52^{a}	8.40 ± 0.89^{a}	6.40 ± 2.19^{a}	1.783	0.177

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

2.19), while at the final stage, flavour remained high across all methods (7.40 ± 1.52 – 8.40 ± 0.89) with no significant differences ($p > 0.05$).

4.3.2 Texture

Texture scores also varied with spice treatment and processing method.

In the black pepper treatment, initial texture was highest in air-fried (8.20 ± 0.45), followed by deep-fried (8.00 ± 0.71) and lowest in smoked (7.40 ± 0.89), with significant differences ($p < 0.05$). At mid-analysis, texture remained highest in deep-fried (7.80 ± 0.84) and lowest in smoked (7.20 ± 0.84), also showing significant differences ($p < 0.05$). By the final analysis, texture values ranged from 7.20 ± 0.84 to 8.20 ± 1.09, with no significant differences ($p > 0.05$).

For black pepper + cinnamon, initial texture was highest in smoked (8.00 ± 0.71), followed by deep-fried (7.60 ± 0.89) and air-fried (7.40 ± 1.34), showing significant differences ($p < 0.05$). Mid-storage texture remained higher in air-fried (8.20 ± 0.84) compared to smoked (7.00 ± 1.00), but differences were not significant ($p > 0.05$) at the final analysis.

In cinnamon samples, initial texture was highest in deep-fried (7.40 ± 1.14) followed by smoked (7.40 ± 1.14) and air-fried (7.00 ± 1.73), showing significant differences ($p < 0.05$). Mid-storage analysis maintained higher texture in deep-fried (8.00 ± 1.00), while by the final stage, values were similar (7.00 ± 1.58 – 8.20 ± 1.09) with no significant differences ($p > 0.05$).

The control samples had initial texture values between 7.40 ± 1.14 and 7.60 ± 1.34, showing no significant differences ($p > 0.05$). Mid-analysis results showed higher texture in deep-fried

(8.20 ± 1.09) and air-fried (8.00 ± 1.00), but at the final stage all methods remained similar ($p > 0.05$).

Table 4.3.2: Texture Organoleptic Analysis Based On The Different Processing Method And Spices

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black Pepper	June	8.20 ± 0.45^{a}	8.00 ± 0.71^{a}	7.40 ± 0.89^{ab}	3.788	0.029
	July	7.60 ± 0.55^{ab}	7.80 ± 0.84^{ab}	7.20 ± 0.84^{b}	3.788	0.029
	August	7.60 ± 0.55^{a}	7.80 ± 0.84^{a}	7.20 ± 0.84^{a}	0.103	0.902
Cinnamon	June	7.00 ± 1.73^{b}	7.40 ± 1.14^{ab}	7.40 ± 1.14^{ab}	3.788	0.029
	July	7.40 ± 1.52^{ab}	8.00 ± 1.00^{a}	7.00 ± 1.58^{b}	3.788	0.029
	August	7.40 ± 1.52^{a}	8.00 ± 1.00^{a}	7.00 ± 1.58^{a}	0.103	0.902
Black Pepper + Cinnamon	June	7.40 ± 1.34^{ab}	7.60 ± 0.89^{ab}	8.00 ± 0.71^{a}	3.788	0.029
	July	8.20 ± 0.84^{a}	7.80 ± 1.30^{ab}	7.00 ± 1.00^{b}	3.788	0.029
	August	8.20 ± 0.84^{a}	7.80 ± 1.30^{a}	7.00 ± 1.00^{a}	0.103	0.902
Control	June	7.40 ± 1.14^{ab}	7.60 ± 1.34^{ab}	7.60 ± 1.14^{ab}	3.788	0.029
	July	8.00 ± 1.00^{a}	8.20 ± 1.09^{a}	7.20 ± 1.30^{b}	3.788	0.029
	August	8.00 ± 1.00^{a}	8.20 ± 1.09^{a}	7.20 ± 1.30^{a}	0.103	0.902

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

4.3.3 Aroma

In black pepper treatment, initial aroma scores were highest in deep-fried samples (8.00 ± 0.71) compared to air-fried (7.40 ± 1.14) and smoked (7.40 ± 0.89), with significant differences ($p < 0.05$). Mid-analysis showed similar trends (8.40 ± 0.55 in deep-fried and 7.20 ± 0.84 in smoked), also significant ($p < 0.05$). At the final analysis, aroma values ranged from 7.20 ± 0.84 to 8.40 ± 0.89, with no significant differences ($p > 0.05$).

For black pepper + cinnamon, initial aroma was highest in deep-fried (7.60 ± 1.14), followed by air-fried (7.40 ± 1.14) and smoked (6.40 ± 1.52), showing significant differences ($p < 0.05$). Mid-storage values remained higher in deep-fried (7.80 ± 1.30), while by the final month, differences among methods were not significant ($p > 0.05$).

In cinnamon treatment, aroma scores varied significantly ($p < 0.05$) initially, with deep-fried (7.20 ± 1.30) higher than air-fried (6.00 ± 1.41) and smoked (6.80 ± 1.64). Mid-analysis values were 7.80 ± 0.45 (deep-fried), 7.60 ± 1.34 (air-fried), and 6.40 ± 1.67 (smoked), but by the final stage, no significant differences ($p > 0.05$) were observed.

Control samples followed a similar trend, with deep-fried (8.40 ± 0.89) maintaining higher aroma at mid-storage and final periods, though not significantly different ($p > 0.05$).

Table 4.3.3: Aroma Organoleptic Analysis Based On The Different Processing Method And Spices

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black Pepper	June	7.40 ± 1.14^{ab}	8.00 ± 0.71^{a}	7.40 ± 0.89^{ab}	4.359	0.017
	July	7.60 ± 1.52^{ab}	8.40 ± 0.55^{a}	7.20 ± 0.84^{ab}	4.359	0.017
	August	7.60 ± 1.52^{a}	8.40 ± 0.55^{a}	7.20 ± 0.84^{a}	1.855	0.166
Cinnamon	June	6.00 ± 1.41^{b}	7.20 ± 1.30^{ab}	6.80 ± 1.64^{ab}	4.359	0.017
	July	7.60 ± 1.34^{ab}	7.80 ± 0.45^{a}	6.40 ± 1.67^{b}	4.359	0.017
	August	7.60 ± 1.34^{a}	7.80 ± 0.45^{a}	6.40 ± 1.67^{a}	1.855	0.166
Black Pepper + Cinnamon	June	7.40 ± 1.14^{ab}	7.60 ± 1.14^{a}	6.40 ± 1.52^{b}	4.359	0.017
	July	7.80 ± 1.30^{a}	7.80 ± 1.30^{a}	7.20 ± 0.84^{ab}	4.359	0.017
	August	7.80 ± 1.30^{a}	7.80 ± 1.30^{a}	7.20 ± 0.84^{a}	1.855	0.166
Control	June	7.20 ± 1.30^{ab}	7.80 ± 1.30^{a}	7.40 ± 1.14^{ab}	4.359	0.017
	July	8.00 ± 0.71^{a}	8.40 ± 0.89^{a}	7.60 ± 1.34^{ab}	4.359	0.017
	August	8.00 ± 0.71^{a}	8.40 ± 0.89^{a}	7.60 ± 1.34^{a}	1.855	0.166

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

4.3.4 Appearance

The black pepper treatment showed initial appearance values ranging from 7.20 ± 1.48 (air-fried) to 8.00 ± 0.71 (smoked), with no significant differences ($p > 0.05$). Mid-storage appearance values were highest in deep-fried (7.80 ± 1.30) and lowest in smoked (6.80 ± 1.30). Final analysis showed all methods having similar appearance (6.80 ± 1.30 – 7.80 ± 1.30) with no significant differences ($p > 0.05$).

For black pepper + cinnamon, appearance was stable across storage periods, ranging from 7.00 ± 1.41 to 8.00 ± 1.00, with no significant differences ($p > 0.05$).

In cinnamon samples, appearance values ranged between 7.20 ± 0.45 and 7.80 ± 1.30 across all months, showing no significant differences ($p > 0.05$).

Control samples had appearance values of 7.80 ± 1.09 - 8.80 ± 0.45, indicating consistent appearance without significant differences ($p > 0.05$).

Table 4.3.4: Appearance Organoleptic Analysis Based On The Different Processing Method And Spices

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black Pepper	June	7.20 ± 1.48^{a}	7.40 ± 0.89^{a}	8.00 ± 0.71^{a}	2.777	0.071
	July	7.60 ± 1.67^{a}	7.80 ± 1.30^{a}	6.80 ± 1.30^{a}	2.777	0.071
	August	7.60 ± 1.67^{a}	7.80 ± 1.30^{a}	6.80 ± 1.30^{a}	0.416	0.662
Cinnamon	June	7.20 ± 0.45^{a}	7.40 ± 1.34^{a}	7.60 ± 1.14^{a}	2.777	0.071
	July	7.60 ± 1.14^{a}	7.80 ± 1.30^{a}	6.80 ± 1.92^{a}	2.777	0.071
	August	7.60 ± 1.14^{a}	7.80 ± 1.30^{a}	6.80 ± 1.92^{a}	0.416	0.662
Black Pepper + Cinnamon	June	7.00 ± 1.41^{a}	7.80 ± 0.84^{a}	7.00 ± 0.71^{a}	2.777	0.071
	July	8.00 ± 1.00^{a}	7.20 ± 1.30^{a}	6.80 ± 0.84^{a}	2.777	0.071
	August	8.00 ± 1.00^{a}	7.20 ± 1.30^{a}	6.80 ± 0.84^{a}	0.416	0.662
Control	June	7.80 ± 1.30^{a}	7.80 ± 1.30^{a}	7.40 ± 1.14^{a}	2.777	0.071
	July	7.80 ± 1.09^{a}	8.80 ± 0.45^{a}	7.80 ± 0.84^{a}	2.777	0.071
	August	7.80 ± 1.09^{a}	8.80 ± 0.45^{a}	7.80 ± 0.84^{a}	0.416	0.662

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

4.3.5 Overall Acceptance

In black pepper treatment, initial overall scores were 7.60 ± 0.89 (air-fried), 7.40 ± 0.55 (deep-fried), and 7.60 ± 0.55 (smoked), with significant differences ($p < 0.05$). Mid-analysis values remained higher in deep-fried (8.00 ± 1.23), while smoked samples had the least (6.80 ± 0.45), indicating significant differences ($p < 0.05$). By the final period, mean values ranged from 6.80 ± 0.45 to 8.00 ± 1.23, showing no significant differences ($p > 0.05$).

For black pepper + cinnamon, initial overall acceptance was highest in deep-fried (7.80 ± 1.09) and lowest in smoked (7.20 ± 1.30), showing significant differences ($p < 0.05$). At mid-analysis, deep-fried samples maintained the highest values (7.80 ± 1.30), while by the final stage, differences among methods were not significant ($p > 0.05$).

In cinnamon samples, initial overall acceptance ranged from 6.80 ± 1.92 (air-fried) to 7.40 ± 1.14 (deep-fried) and 7.00 ± 1.41 (smoked), with significant differences ($p < 0.05$). Mid-storage and final results maintained higher values in deep-fried samples (8.40 ± 0.89), though differences were not significant ($p > 0.05$).

For the control, initial overall acceptance was highest in air-fried (8.00 ± 1.00), followed by deep-fried (7.80 ± 1.30) and smoked (7.40 ± 1.52), with significant differences ($p < 0.05$). Mid and final analysis showed similar patterns with deep-fried samples maintaining the highest scores (8.40 ± 0.89), though not significantly different ($p > 0.05$).

Table 4.3.5: Overall Acceptance Organoleptic Analysis Based On The Different Processing Method And Spices

Treatment	Month	Air Fried	Deep Fried	Smoked	F-value	p-value
Black Pepper	June	7.60 ± 0.89^{ab}	7.40 ± 0.55^{ab}	7.60 ± 0.55^{ab}	6.467	0.003
	July	7.40 ± 1.67^{ab}	8.00 ± 1.23^{a}	6.80 ± 0.45^{b}	6.467	0.003
	August	7.40 ± 1.67^{a}	8.00 ± 1.23^{a}	6.80 ± 0.45^{a}	0.338	0.715
Cinnamon	June	6.80 ± 1.92b	7.40 ± 1.14ab	7.00 ± 1.41b	6.467	0.003
	July	7.60 ± 1.34ab	8.40 ± 0.89a	6.80 ± 1.48b	6.467	0.003
	August	7.60 ± 1.34a	8.40 ± 0.89a	6.80 ± 1.48a	0.338	0.715
Black Pepper + Cinnamon	June	7.40 ± 1.14^{ab}	7.80 ± 1.09^{a}	7.20 ± 1.30^{b}	6.467	0.003
	July	8.20 ± 0.84^{a}	7.80 ± 1.30^{a}	6.80 ± 0.84^{b}	6.467	0.003
	August	8.20 ± 0.84^{a}	7.80 ± 1.30^{a}	6.80 ± 0.84^{a}	0.338	0.715
Control	June	8.00 ± 1.00^{a}	7.80 ± 1.30^{a}	7.40 ± 1.52^{ab}	6.467	0.003
	July	7.40 ± 0.55^{ab}	8.40 ± 0.89^{a}	7.40 ± 1.14^{ab}	6.467	0.003
	August	7.40 ± 0.55^{a}	8.40 ± 0.89^{a}	7.40 ± 1.14^{a}	0.338	0.715

Notes: Means with different superscripts across rows are significantly different ($p<0.05$)

4.4 General Mean of Organoleptic Properties of *Merluccius Merluccius*

The organoleptic properties of *Merluccius merluccius* were evaluated based on flavour, texture, aroma, appearance, and overall acceptance across different spice treatments and processing methods. These results provide insight into how air-frying, deep-frying, and smoking, in combination with spices, influenced the sensory qualities of the fish.

4.4.1 Flavour

Flavour scores varied across treatments and processing methods. In the black pepper treatment, deep-fried samples had the highest flavour score (8.20 ± 1.01), which showed a significant difference ($p < 0.05$) compared to both air-fried (7.20 ± 1.32) and smoked samples (7.20 ± 0.56). Air-fried and smoked samples were similar and slightly lower in flavour. In the cinnamon treatment, deep-fried samples also had the highest flavour score (8.07 ± 1.03), significantly higher ($p < 0.05$) than air-fried and smoked samples, which were both at 6.80 ± 1.74 and 6.80 ± 1.42, respectively. For the control (no spices), deep-fried samples had slightly higher flavour scores (8.13 ± 0.99) compared to air-fried (7.53 ± 1.25) and smoked (7.00 ± 1.96), but the differences were not significant ($p > 0.05$).

4.4.2 Texture

Texture was slightly higher in deep-fried samples across treatments. In black pepper treatment, deep-fried samples scored 7.87 ± 0.74, which was significantly higher ($p < 0.05$) than smoked samples (7.27 ± 0.80), while air-fried samples had a moderate score of 7.80 ± 0.56. In cinnamon and control treatments, differences in texture across processing methods were minor and not significant ($p > 0.05$).

Table 4.4: General Mean Of Organoleptic Evaluation Of *Merluccius Merluccius* Based On Different Processing Methods And Spices

Attribute	Treatment	Air-Fried	Deep Fried	Smoked	F-value	p-value
Flavour	Black Pepper + Cinnamon	7.47 ± 0.83^{a}	7.53 ± 1.06^{a}	6.93 ± 1.16^{a}	1.535	0.227
	Black Pepper	7.20 ± 1.32^{a}	8.20 ± 1.01^{b}	7.20 ± 0.56^{a}	4.861	0.013*
	Cinnamon	6.80 ± 1.74^{a}	8.07 ± 1.03^{b}	6.80 ± 1.42^{a}	3.930	0.027*
	Control (No Spice)	7.53 ± 1.25^{ab}	8.13 ± 0.99^{b}	7.00 ± 1.96^{a}	2.264	0.116
Texture	Black Pepper + Cinnamon	7.93 ± 1.03^{a}	7.73 ± 1.10^{a}	7.33 ± 0.98^{a}	1.301	0.283
	Black Pepper	7.80 ± 0.56^{b}	7.87 ± 0.74^{b}	7.27 ± 0.80^{a}	3.234	0.049*
	Cinnamon	7.27 ± 1.49^{a}	7.80 ± 1.01^{a}	7.13 ± 1.36^{a}	1.103	0.341
	Control (No Spice)	7.80 ± 1.01^{a}	8.00 ± 1.13^{a}	7.33 ± 1.18^{a}	1.425	0.252
Aroma	Black Pepper + Cinnamon	7.67 ± 1.18^{a}	7.73 ± 1.16^{a}	6.93 ± 1.10^{a}	2.249	0.118
	Black Pepper	7.53 ± 1.30^{ab}	8.27 ± 0.59^{b}	7.27 ± 0.80^{a}	4.493	0.017*
	Cinnamon	7.07 ± 1.49^{ab}	7.60 ± 0.83^{b}	6.53 ± 1.55^{a}	2.413	0.102
	Control (No Spice)	7.73 ± 0.96^{a}	8.20 ± 1.01^{a}	7.53 ± 1.19^{a}	1.567	0.221
Appearance	Black Pepper + Cinnamon	7.67 ± 1.18^{ab}	7.40 ± 1.12^{ab}	6.87 ± 0.74^{a}	2.340	0.109
	Black Pepper	7.47 ± 1.51^{a}	7.67 ± 1.11^{a}	7.20 ± 1.21^{a}	0.497	0.612
	Cinnamon	7.47 ± 0.92^{a}	7.67 ± 1.23^{a}	7.07 ± 1.62^{a}	0.840	0.439
	Control (No Spice)	7.80 ± 1.08^{ab}	8.47 ± 0.92^{b}	7.67 ± 0.90^{a}	2.932	0.064
Overall	Black Pepper + Cinnamon	7.93 ± 0.96^{b}	7.80 ± 1.15^{b}	6.93 ± 0.96^{a}	4.196	0.022*
	Black Pepper	7.47 ± 1.36^{a}	7.80 ± 1.01^{a}	7.07 ± 0.59^{a}	1.885	0.165
	Cinnamon	7.33 ± 1.50^{ab}	8.07 ± 1.03^{b}	6.87 ± 1.36^{a}	3.202	0.051
	Control (No Spice)	7.60 ± 0.74^{ab}	8.20 ± 1.01^{b}	7.40 ± 1.18^{a}	2.625	0.084

Notes: Means with different superscripts across rows are significantly different (p<0.05)

4.4.3 Aroma

Aroma scores followed a similar trend. In black pepper treatment, deep-fried samples had the highest aroma score (8.27 ± 0.59), which showed significant difference ($p < 0.05$) compared to smoked (7.27 ± 0.80), with air-fried samples slightly lower at 7.53 ± 1.30. Cinnamon and control treatments showed only minor differences in aroma across processing methods, which were not significant ($p > 0.05$).

4.4.3 Appearance

Appearance scores were generally consistent across all treatments. In all spice and control groups, air-fried, deep-fried, and smoked samples had similar appearance scores, ranging from approximately 6.87 to 7.67, and differences were not significant ($p > 0.05$).

4.4.4 Overall acceptance

Overall acceptance reflected the combined effects of flavour, texture, aroma, and appearance. In the black pepper treatment, deep-fried samples had slightly higher overall scores (7.80 ± 1.01), though no significant difference ($p > 0.05$) was observed compared to air-fried (7.47 ± 1.36) and smoked samples (7.07 ± 0.59). In cinnamon treatment, deep-fried samples again scored slightly higher (8.07 ± 1.03) compared to air-fried (7.33 ± 1.50) and smoked (6.87 ± 1.36), with differences not significant ($p > 0.05$). Control samples followed a similar trend, with deep-fried samples slightly higher (8.20 ± 1.01) than air-fried (7.60 ± 0.74) and smoked (7.40 ± 1.18), but no significant difference ($p > 0.05$) was observed.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Proximate Composition of Spiced *Merluccius merluccius* Based on Different Processing Methods.

5.1.1 Carbohydrate (NFE)

The carbohydrate content of *Merluccius merluccius* showed noticeable fluctuations across the three months of analysis, influenced by both spice treatment and processing method.

In black pepper treatment, deep-fried samples initially had higher carbohydrate content compared to air-fried and smoked samples, suggesting that frying concentrated carbohydrate content due to moisture loss, while smoking had a gentler effect on CHO levels (Dangal *et al.*, 2024).

By the mid-analysis, smoked and deep-fried samples exhibited an increase in CHO, while air-fried samples showed a decline. The rise in smoked samples likely reflects the slow dehydration process, which concentrates sugars and other dry matter (Lund, 2017). In contrast, the lower CHO in air-fried samples may result from thermal reactions that degrade or transform some carbohydrates, including Maillard reactions (Tamanna and Mahmood, 2015). By the final analysis, carbohydrate levels in air-fried samples increased again, likely due to continued moisture loss concentrating residual carbohydrates.

For black pepper + cinnamon treatment, initial CHO values were relatively uniform across the processing methods. The combination of spices appears to have stabilized sugar retention, helping maintain CHO content over time (Sulieman *et al.*, 2023). At mid-analysis, smoked samples maintained higher CHO, while air-fried and deep-fried samples were slightly lower. By the final analysis, smoked and air-fried samples continued to show higher CHO than deep-fried samples, indicating that the combined spice treatment helped preserve carbohydrate levels during storage (Parmar *et al.,* 2024).

In cinnamon treatment, air-fried samples initially had higher CHO than deep-fried samples. By mid-analysis, air-fried samples maintained higher CHO, suggesting that cinnamon may provide some stabilizing effect. However, at the final analysis, deep-fried samples recorded a significant increase, while air-fried samples showed a decline. This indicates that deep-frying combined with cinnamon enhanced carbohydrate retention, likely due to moisture loss concentrating carbohydrates and heat-induced transformations (Dangal *et al.,* 2024; Tamanna and Mahmood, 2015).

The control samples maintained relatively stable carbohydrate levels throughout storage, reflecting minor moisture changes and natural biochemical adjustments in unspiced fish.

The general mean of this study ranged from 11.68 % in the control (un-spiced) samples to 19.93 % in the smoked sample treated with black pepper + cinnamon. Overall, the spiced samples had higher carbohydrate levels than the control, although the differences were not statistically significant ($p > 0.05$). The higher carbohydrate in spiced samples could be due to the natural sugars present in the spices and their antioxidant properties, which may slow nutrient breakdown during processing. Similar findings have been reported in studies on smoked catfish, where spiced samples showed higher proximate nutrient values compared to controls (Ayeloja *et al*., 2015; Ibrahim *et al*., 2025). Another study on spice-treated fish floss also found that spices help maintain nutrient content, including NFE, during processing (Ibrahim *et al*., 2025).

Processing method also affected NFE levels. Deep-frying tended to increase NFE, likely because high temperatures cause water loss, concentrating remaining nutrients. Heat can also trigger Maillard and caramelisation reactions, which react sugars with amino groups and may slightly raise residual NFE (Tamanna and Bhattacharya, 2015; Zhao *et al*., 2023). In contrast, smoked samples sometimes had lower or decreasing NFE, possibly due to longer heat exposure, sugar breakdown, or moisture loss during smoking, which is consistent with other reports on smoked fish (Holma *et al*., 2025). Although the differences among treatments were not statistically significant, this study showed a clear trend: spiced samples consistently had higher carbohydrate than controls, and smoking combined with Black Pepper + Cinnamon produced the highest NFE. This suggests that using spices together with appropriate processing methods can help maintain carbohydrate content and possibly improve the nutritional quality of *M. merluccius*.

5.1.2 Crude Protein (CF)

Protein content of *Merluccius merluccius* showed clear variations over the study period, reflecting the combined effects of processing method and spice treatment.

In black pepper treatment, air-fried samples initially retained higher protein content compared to deep-fried and smoked samples. This suggests that air frying may better preserve protein structure in the short term, while deep-frying at high temperatures can cause protein denaturation and loss. By mid-analysis, protein levels were relatively similar across all processing methods, indicating that any early differences may have stabilized during storage. At the final analysis, deep-fried samples showed comparatively higher protein levels, likely due to moisture loss concentrating the remaining protein, while air-fried and smoked samples maintained moderate levels. These aligns with previous studies showing that thermal processing and dehydration influence protein retention in fish (Tenyang *et al*., 2022; Aiyeloja and Akinrotimi, 2021).

For black pepper + cinnamon treatment, protein levels were initially comparable across air-fried, deep-fried, and smoked samples. Mid-analysis values remained stable, suggesting minimal protein degradation, while final analysis showed subtle differences, indicating that the antioxidant properties of the combined spices may help preserve protein during storage. (Umar *et al.,* 2024)

In cinnamon treatment, initial protein content was similar across processing methods. By mid-analysis, air-fried and deep-fried samples retained slightly higher protein, while smoked samples remained stable. By the final analysis, air-fried and smoked samples-maintained protein content, while deep-fried samples showed a decline, likely due to higher heat exposure accelerating protein denaturation. This demonstrates how the interaction of processing method and spice type can influence protein stability in fish over time (Msusa, 2017; Tenyang *et al*., 2022).

The control samples maintained relatively stable protein levels throughout the study period, with minor fluctuations likely due to natural moisture changes and biochemical processes during storage.

The general mean ranged from 44.30 ± 12.65 % in control samples to 59.07 ± 17.13 % in deep-fried black pepper samples. Overall, spiced samples generally had higher protein levels compared to the control. Although the differences among treatments were not statistically significant ($p > 0.05$), better protein preservation was observed in spiced samples, particularly in deep-fried black pepper and air-fried cinnamon treatments.

Among the processing methods, deep-frying produced the highest protein values, likely due to moisture loss concentrating the remaining protein, while air-frying also effectively preserved protein (cinnamon: 54.22 ± 2.33 %), and smoking resulted in slightly lower but still comparable protein (black pepper: 53.06 ± 4.49 %). These trends align with the observations of Abraha *et al*. (2018) and Daramola *et al*. (2007), who explained that thermal processing such as smoking, frying, and drying increases apparent protein concentration by reducing moisture, while prolonged exposure may cause minor denaturation or formation of nitrogenous compounds.

Spice addition further contributed to protein retention. Samples treated with black pepper and cinnamon had higher protein content than the control, reflecting the antioxidant and antimicrobial properties of spices, which protect muscle proteins from oxidative degradation during thermal processing (Ayeloja *et al*., 2015; Linus-Chibuezeh *et al*., 2022). Similarly, Ahmed *et al*. (2022) reported better protein retention in fish treated with protective agents during processing.

When compared with previous studies, the protein range observed in this study is generally higher than that reported for freshwater species such as *Clarias gariepinus*. Ayeloja *et al.* (2015) reported ~75 % protein in control smoked catfish on dry matter basis, with slightly lower values in spice-treated samples, while Oshimagye *et al*. (2025) reported 24–33 % protein in spice-treated catfish on a wet weight basis. These differences likely reflect species-specific muscle composition, as marine *M. merluccius* has different protein content from freshwater catfish, and the combination of processing methods and spices used in this study may have helped preserve protein by reducing degradation.

Collectively, these results indicate that moisture reduction through frying and smoking, combined with antioxidant protection from spices, effectively preserves protein content in *M. merluccius*, with deep-fried black pepper and air-fried cinnamon treatments showing the best retention. This confirms that both processing method and spice treatment play crucial roles in maintaining the nutritional quality of *Merluccius merluccius* during storage.

5.1.3 Crude Fat (CF)

In black pepper treatment, deep-fried samples initially exhibited the highest fat content, followed by smoked and air-fried samples. This pattern reflects the oil uptake and moisture loss typical of deep frying, which increases lipid concentration in the final product (Marimuthu *et al*., 2011). During mid-analysis, fat content in deep-fried and smoked samples remained relatively stable, while air-fried samples retained lower fat, indicating that air frying limits oil absorption compared to conventional frying (Tenyang *et al*., 2022). By the final analysis, fat content decreased across all treatments, but remained higher in fried samples than smoked samples, likely due to lipid oxidation or leaching during storage (Aberoumand, 2020).

For black pepper + cinnamon treatment, initial fat values were similar across air-fried, deep-fried, and smoked samples, suggesting that the combined spices did not significantly influence immediate fat uptake during processing. Mid-analysis values remained stable, and by the final analysis, fat decreased slightly. This moderated reduction in fat indicates that the antioxidant properties of black pepper and cinnamon may help retard lipid oxidation, stabilizing fat levels during storage (Marimuthu *et al.,* 2011; Tenyang *et al.*, 2022).

In cinnamon treatment, initial fat content varied slightly across processing methods. Mid-analysis showed increased fat in deep-fried and smoked samples, likely due to higher thermal exposure and oil uptake, while air-fried samples maintained lower fat levels. By the final analysis, fat content decreased across all methods, highlighting the combined effect of processing method and spice type on lipid retention and degradation (Aberoudmand, 2020; Tenyang *et al.*, 2022).

For the control group, fat content remained relatively stable across the three analyses, reflecting that in the absence of spice treatment, changes were primarily governed by processing-induced oil uptake and storage effects rather than antioxidant protection.

The average from this study showed that across treatments, values where generally higher in deep-fried and smoked samples compared to air-fried. The control samples consistently had the lowest fat content (4.35 ± 2.37 %) across all methods. The higher fat levels in deep-fried samples are expected, as frying can lead to oil absorption, which elevates the lipid content of the muscle (Olabiyi *et al.*, 2021). Also, finding by Tenyang *et al.* (2013) reported that increase of lipid content in food during frying can be explained by the oil penetration into the food after partial water loss by evaporation. These results are in agreement with those of Golpolipour *et al.* (2019) who demonstrated that the amount of carp lipid and proteins significantly ($P < 0.05$) increases with frying. Smoking also tends to concentrate fat through moisture loss while preserving lipid integrity (Eyo, 2001).

The relatively lower fat in air-fried samples may be due to reduced oil uptake and shorter exposure to heat which is consistent with findings in low-fat cooking methods (Oladunjoye *et al*., 2020)."

Spice addition appeared to enhance fat retention, with slightly higher fat content in spiced samples compared to control. For example, smoked cinnamon samples had the highest fat (6.50 ± 2.30 %), suggesting that bioactive compounds in spices, such as polyphenols and essential oils, may interact with lipids to stabilize and protect them during thermal processing (Haruna *et al*., 2021; Enyidi *et al*., 2023).

Overall, the observed variation in fat content indicates that processing method and spice treatment significantly influence lipid levels in *M. merluccius*. Deep-frying and smoking increased fat through moisture loss and oil absorption, while spice incorporation contributed to slightly higher fat content and potential lipid stability.

5.1.4 Crude Fibre (CF)

Throughout the three-month analysis, CF content in *Merluccius merluccius* remained remarkably stable across all spice treatments and processing methods. This indicates that incorporating spices did not significantly affect the fibrous fraction of the fish. Similarly, whether the fish was air-fried, deep-fried, or smoked had minimal impact on CF levels. Such stability is not unexpected. Research has shown that crude fibre in fish muscle is relatively resistant to thermal and drying processes, largely because the muscle itself contains only a small fraction of dietary fibre (Holma and Maalekuu, 2013). Even when subjected to prolonged smoking or drying, the fibrous components tend to persist with little alteration, suggesting that fish fibre is inherently resilient to common processing treatments (Zabadi and Tukura, 2017).

Slight fluctuations observed in some samples over the monthly analyses likely reflect natural moisture redistribution or minor sampling variability rather than true changes in fibre content. Recent work on stored smoked fish further supports this, showing that fibre levels are largely maintained during storage and are minimally influenced by processing or spice incorporation (Oli *et al*., 2024).

CF mean values ranged from 4.33 ± 1.02 % to 5.46 ± 0.91 %showing minimal variation, with no significant differences ($p > 0.05$) among the processing methods.

The relative stability of CF indicates that it is largely unaffected by thermal processing, unlike protein, fat, or carbohydrate, which can be concentrated, degraded, or oxidized during frying or smoking. This observation aligns with studies in other fish species, where fiber fractions remained constant despite heat treatments (Odoemelam *et al*., 2017; Gbadamosi *et al*., 2020). The inert nature of crude fiber is due to its resistance to heat and lack of solubility in water or oil, meaning it is not extracted, leached, or chemically altered during air-frying, deep-frying, or smoking.

Spice incorporation did not substantially alter CF content, likely because the fibre contribution from spices like black pepper and cinnamon is minimal relative to the muscle matrix of the fish (Adeyemi and Olaniyi, 2019). The uniformity of CF across treatments further indicates that the choice of processing method (air-frying, deep-frying, or smoking) has little effect on the fibrous fraction of marine fish muscle. This stability is advantageous for maintaining dietary fiber content in processed fish products. Studies on dried- fish processing emphasize that fiber and other non- lipid/ non- protein fractions often show minimal change during heat or drying treatments (Fitri *et al*., 2022). Additionally, research on red fish processing reported that crude- fibre values were almost unchanged by smoking or frying, illustrating the fibrous component’s resistance to typical processing alterations (Holma and Maalekuu, 2013).

5.1.5 Moisture Content (MC)

The monthly analysis of moisture content in *Merluccius merluccius* revealed interesting trends across the different spice treatments and processing methods. In the black pepper treatment, smoked and air-fried samples initially had slightly higher moisture than deep-fried samples. This aligns with previous findings that frying tends to remove more water from fish due to immersion in hot oil, whereas smoking and air-frying can better retain water in the tissue (Tenyang *et al*., 2022; Holma and Maalekuu, 2013). By the mid-analysis, moisture levels had increased in all processing methods and differences were no longer significant, suggesting that storage dynamics, such as moisture migration within the muscle, began to play a stronger role than the initial processing method (Fitri *et al*., 2022). By the final analysis, moisture content had leveled across air-fried, deep-fried, and smoked samples, indicating that over time, storage tends to equalize moisture content regardless of the processing method.

For black pepper + cinnamon treatment, moisture content was initially similar across processing methods, showing that the spice combination did not markedly influence water retention at the start. At mid-analysis, minor fluctuations occurred; moisture slightly increased in deep-fried samples, remained stable in air-fried, and decreased in smoked samples. These changes were not statistically significant, further demonstrating that storage effects were dominant during this stage (Tenyang *et al*., 2022). However, by the final analysis, deep-fried samples exhibited higher moisture than air-fried and smoked samples, and the differences became significant, highlighting that processing methods can regain influence over moisture content as storage time increases.

In cinnamon treatment, initial moisture values were fairly uniform, but at mid-analysis, air-fried samples showed a decrease while smoked and deep-fried samples experienced increases, with significant differences observed. This indicates an interaction between processing method and moisture dynamics over time. By the final analysis, moisture content across all processing methods again differed significantly, likely reflecting differences in water-holding capacity influenced by processing and storage conditions (Holma and Maalekuu, 2013; Msusa, 2017).

General mean values varied slightly across the different processing methods and spice treatments but showed no significant difference ($p > 0.05$). The control samples showed the highest moisture overall (25.67 ± 12.71 %), which indicates that the unspiced (control) retained more water compared to spiced samples suggesting that spice incorporation slightly enhanced moisture loss during processing. This aligns with findings from Tenyang *et al.* (2020), who reported that thermal processing, including frying and smoking, reduces the water content of fish muscle due to protein denaturation and water evaporation. Similarly, Sivertsen *et al.* (2021) observed that heat-based processing causes significant water loss as muscle fibers shrink and release bound moisture.

The slightly higher moisture content in deep-fried samples compared to air-fried and smoked ones may be due to oil entrapment and surface crust formation, which limit further water escape during frying (Huda *et al*., 2022). Air-fried samples, on the other hand, experience rapid convective drying with minimal oil absorption, leading to slightly lower moisture retention (de Almeida *et al*., 2019). Smoked samples often lose more water due to prolonged exposure to heat and airflow during smoking, as also reported by Suleman *et al*. (2020) in smoked tilapia and catfish. The consistently higher moisture in the control samples (25.67 %) aligns with Msusa *et al*. (2017), who observed that samples without spice treatments tend to retain higher moisture levels due to reduced dehydration effects. Overall, while spice incorporation did not significantly alter moisture levels, the findings confirm that the processing method is the key determinant of water retention in *M. merluccius*, with deep-frying preserving slightly more moisture than air-frying and smoking due to its unique heat-oil interaction.

5.1.6 Ash Content (AC)

The ash content of *Merluccius merluccius* changed slightly depending on the spice treatment and the processing method used. In black pepper treatment, ash levels were similar at the beginning across air-fried, deep-fried, and smoked samples. This shows that just adding black pepper doesn't immediately change the mineral content of the fish. By the middle of the study, deep-fried and smoked samples had higher ash compared to air-fried ones. This is likely because water is lost during processing, which makes the minerals more concentrated. Smoking may also add tiny amounts of minerals from the smoke itself (Msusa, 2017; Djikeng *et al*., 2022). By the end of the study, ash increased in all samples, but the differences were small. This suggests that over time, storage causes the mineral content to even out across the different processing methods (Aberoumand, 2020).

In black pepper + cinnamon treatment, smoked samples had slightly higher ash at the start, which may be due to the spices sticking to the surface and helping retain minerals. By mid-analysis, ash content was fairly similar in all methods, showing that the early effects of processing tend to stabilize. At the final analysis, smoked samples still had the highest ash, followed by deep- and air-fried samples. This suggests that smoking combined with these spices may help keep minerals from being lost during storage (Fitri *et al*., 2022; Djikeng *et al*., 2022).

The cinnamon treatment followed a similar pattern. Initially, ash content was almost the same across methods, but by mid- and final analyses, smoked samples had higher ash than the others. This shows that smoking has the biggest impact on ash content, while cinnamon may also help slightly by keeping minerals on the fish surface (Fitri *et al*., 2022; Msusa, 2017).

For the control samples without any spices, ash content stayed mostly stable, with only a small increase over time. This increase likely came from water loss concentrating the minerals, rather than any effect from spices or processing (Aberoumand, 2020).

The general mean in this study ranged from 1.09 ± 0.72 % to 1.91 ± 1.13 %, with smoked samples generally recording slightly higher values across all spice treatments. The higher ash values recorded in smoked samples could be attributed to moisture loss during smoking, which leads to concentration of mineral constituents in the remaining dry matter. This agrees with the findings of Osibona and Ezekiel (2019), who reported that smoking increases apparent ash content in *Clarias gariepinus* and *Tilapia zillii* due to dehydration. Similarly, Wang *et al*. (2021) noted that thermal treatments such as smoking and frying cause moisture evaporation and consequently increase ash concentration per unit weight.

The variation among processing methods also reflects the role of heat transfer medium. Deep-frying, for instance, may promote partial mineral leaching into the oil, leading to slightly reduced ash levels compared with smoking. This agrees with Eze *et al.* (2020), who observed lower ash in deep-fried mackerel (*Scomber scombrus*) compared to smoked counterparts, attributing it to mineral migration during oil immersion. Conversely, the lower ash in air-fried samples can be linked to lower processing temperature and shorter exposure time, resulting in limited moisture removal and thus lower concentration of mineral residues (Adebayo *et al*., 2022).

Spice incorporation appeared to aid mineral stability, particularly in the Cinnamon-only and Black Pepper + Cinnamon treatments, which maintained slightly higher ash values than single-spice or control samples. This effect may be associated with the presence of phenolic compounds and essential minerals in the spices themselves, which could enhance overall ash concentration in the treated fish. Al-Jeraisy *et al*. (2021) and Rani *et al*. (2023) similarly reported that spice treatments (such as turmeric, black pepper, and cinnamon) contribute trace minerals (e.g., calcium, iron, and magnesium) and aid in the preservation of mineral quality during thermal processing. The overall range of ash values obtained in this study (1.09–1.91 %) is comparable to findings by Ibeabuchi *et al*. (2022), who reported ash content between 1.25 % and 2.10 % in spice-treated smoked fish fillets. The results confirm that *M. merluccius* retains appreciable mineral content across different processing methods, with smoking and spice incorporation slightly enhancing ash concentration through dehydration and antioxidant stabilization mechanisms.

5.2 Organoleptic Analysis of Spiced *Merluccius merluccius* subjected to Different Processing Methods

5.2.1 Flavour

The flavour of Merluccius merluccius was influenced by both spice treatment and processing method, which aligns with existing research indicating that spices and thermal processing significantly affect sensory attributes in fish (NurSyahirah and Rozzamri, 2022; Haruna *et al*., 2021).

In black-pepper treatment, deep-frying consistently produced the most favourable flavour compared to air-frying and smoking. This can be attributed to the Maillard reaction and lipid oxidation that occur during deep frying, which promote the formation of desirable flavour compounds and enhance the release of volatile spice components (NurSyahirah and Rozzamri, 2022; Negara *et al*., 2021). The enhanced flavour in deep-fried samples reflects how frying improves aroma and taste perception, making the fish more appealing. In contrast, smoked samples generally exhibited lower flavour acceptability, likely due to over-smoking or the accumulation of bitter phenolic compounds, which can negatively impact sensory perception (Olalekan, 2019). Over time, the differences between processing methods diminished, suggesting that the effect of the initial processing on flavour decreases during storage, possibly because of equilibration of volatile compounds and mild loss of aromatic intensity (NurSyahirah and Rozzamri, 2022).

For black-pepper + cinnamon treatment, deep-frying again resulted in relatively higher flavour. Cinnamon likely contributed synergistically to flavour enhancement, as its essential oils contain cinnamaldehyde, which can complement the pungency of black pepper and improve overall sensory perception (Haruna *et al*., 2021). The relative stability of flavour across all processing methods over storage indicates that combining spices can help maintain acceptable flavour, potentially through mild antimicrobial and antioxidant effects that prevent off-flavour formation (Haruna *et al*., 2021).

In cinnamon-only treatment, deep- frying continued to produce higher flavour acceptability, whereas smoked samples were consistently lower. This supports the observation that frying enhances spice-related flavour perception more effectively than smoking, likely due to more uniform heat transfer and surface caramelization compared to the slower, less consistent heating in smoking (Negara *et al*., 2021).

Interestingly, in the control group without added spices, smoked samples initially had higher flavour perception. This is likely due to the characteristic smoky aroma compounds, such as phenols and carbonyls, which contribute positively to flavour when no competing spice flavours are present (Olalekan, 2019). However, as storage progressed, deep-fried samples surpassed smoked samples in flavour acceptability, suggesting that frying helps maintain flavour stability over time even in the absence of added spices (NurSyahirah and Rozzamri, 2022).

The general mean for this study also noted that deep fried samples had the highest flavour scores compared to air-fried and smoked samples, particularly when spices were used. This indicates that the combination of deep-frying and spice incorporation enhanced the perceived flavour of the fish, whereas air-frying and smoking produced moderately lower scores. In the control samples without spices, flavour differences among processing methods were less pronounced, suggesting that spice addition contributed substantially to flavour enhancement.

The higher flavour scores in deep-fried samples could be attributed to Maillard reactions and oil-mediated aroma formation, which intensify during frying, as reported by Susanty *et al.*

(2023). The formation of a crispy surface and aromatic crust also contributes to enhanced flavour perception, as noted by Kim *et al*. (2021).

Spices such as black pepper and cinnamon further improved flavour by introducing volatile aromatic compounds that interact with the fish matrix during heating, as reported by Abdou and Suparlan (2019). In contrast, air-fried samples had lower flavour intensity, likely due to reduced oil uptake and less Maillard reaction, while smoked samples sometimes scored lower when the smoke aroma masked subtle fish flavours, as noted by Odoemelam *et al.* (2017). The combination of deep-frying and spice treatment produced the highest flavour indicating that both the processing method and spice type play key roles in the flavour development of *Merluccius merluccius*.

5.2.2 Texture

The texture of *Merluccius merluccius* was affected by both the type of spice and the processing method, and changes were observed over the storage period. This aligns with previous research showing that processing and storage can significantly influence the structure and mouthfeel of fish (Sampels, 2015; Assogba *et al*., 2019).

In black-pepper treatment, the initial texture of fried samples, especially deep-fried and air-fried, was firmer than that of smoked samples. Frying promotes rapid heat transfer, surface drying, and mild protein changes, all of which help maintain a firmer and more appealing texture (NurSyahirah and Rozzamri, 2022; Li *et al*., 2025). In contrast, smoked samples were softer initially, likely due to slower and less uniform heating, which can make the fish muscle less consistent (Baten, 2020).

By mid-storage, deep-fried samples retained their firm texture, while smoked samples became softer, reflecting the continued effect of slower heat penetration during smoking. By the final stage, the differences among processing methods were less noticeable, suggesting that storage allows some moisture redistribution and slight softening, which reduces textural differences.

For black- pepper + cinnamon treatment, smoked fish initially had acceptable texture, probably because slower drying retains moisture and gives a temporary firm feel. However, over time, fried samples held their texture better, highlighting that faster heating preserves muscle structure more effectively. Spices may also interact with proteins to provide a small stabilizing effect on texture (Fitri *et al*., 2022).

In cinnamon-only samples, deep-fried fish consistently had the firmest texture throughout storage, while smoked and air-fried fish were softer. This reinforces the idea that rapid, uniform heating in frying improves firmness, whereas slower methods like smoking and air-frying do not achieve the same consistency (Assogba *et al*., 2019).

Control samples without spices showed similar initial texture across all processing methods. As storage continued, frying maintained a firmer texture than smoking, indicating that the processing method itself is the main factor affecting texture during storage (Bland, 2018).

The general mean texture scores in this study revealed that the deep- fried samples achieved a firmer and more preferred mouth- feel compared to other processing methods when spices were applied.

The superior texture of deep- fried samples may stem from rapid moisture evaporation and the formation of a crisp outer crust during frying, which enhances firmness and sensory appeal. As reviewed by NurSyahirah (2022), frying modifies the structural matrix of fish muscle and crust formation improves texture and crunchiness. Furthermore, Li *et al*. (2025) found that increased frying temperature and time produced higher hardness and crispiness in icefish, indicating that heat- oil interaction contributes directly to firmer texture.

In contrast, the absence of significant differences in texture among processing methods in the Cinnamon- only and control treatments where air- fried scored 7.80 ± 0.56, deep- fried 7.87 ±

0.74, and smoked 7.27 ± 0.80 for Black Pepper, and smaller differences were observed in Cinnamon-only and control samples may indicate that the spice treatment interacts with frying to produce greater textural improvement. Without this spice- processing synergy, the differences become less pronounced. This aligns with findings where marinades or surface treatments prior to frying improved textural response in fish fillets (Fofandi et al., 2020).

5.2.3 Aroma

Aroma changed noticeably with spice treatment and processing method, and those differences evolved across the initial, mid and final storage checks. Aroma in fish is driven by volatile compounds produced during heating (Maillard reactions and lipid oxidation), by volatiles released from spices, and by loss or transformation of those compounds during storage (Fan *et al.*, 2025).

In black pepper treatment, deep-fried samples recorded the highest aroma scores initially, followed by air-fried and smoked samples, showing clear differences in sensory perception. The stronger aroma in deep-fried fish could be linked to the Maillard reaction and lipid oxidation that occur at high temperatures, which produce pleasant volatile compounds responsible for fried aromas. Liu *et al*. (2022) reported that frying generates several key aroma substances such as aldehydes and pyrazines that enhance the characteristic odour of fried fish. The addition of black pepper further enriched the aroma due to the presence of volatile essential oils that blend well with the fried notes (Haruna *et al*., 2021).

At mid-storage, deep-fried samples continued to have the most intense aroma, while smoked samples had the lowest. This pattern supports findings by Chen *et al*. (2024), who noted that fried and air-fried fish retain stronger aromatic profiles during early storage because volatile compounds remain relatively stable before gradually diminishing. Smoked samples, on the other hand, often develop strong phenolic compounds that can overpower or mask natural or spice-related aromas, particularly with extended storage (Afé *et al*., 2021).

By the final stage, aroma differences among all processing methods were no longer significant. This could be attributed to the gradual loss or transformation of volatile compounds during storage. Fan *et al*. (2025) explained that prolonged storage causes oxidation and degradation of aroma-active molecules, reducing distinct smell differences between treated samples.

For the combined black pepper and cinnamon treatment, deep-fried fish again exhibited the most pleasant aroma, suggesting that both spices worked synergistically to improve sensory appeal. Cinnamon contains cinnamaldehyde and eugenol, which provide a warm, sweet fragrance that complements the peppery note of black pepper (Haruna *et al*., 2021). Midway through storage, fried samples still maintained slightly higher aroma scores, but by the end of the period, the differences had evened out across all methods.

In the cinnamon treatment, deep-fried and air-fried samples had better aroma than smoked fish. This aligns with the observation by Liu *et al*. (2022) that high-temperature frying enhances the release of aromatic compounds from spices and fish oils. Over time, however, the aroma declined across all treatments, likely due to the evaporation and oxidation of volatile compounds.

The control samples followed a similar trend, with fried samples showing the strongest aroma at first, which later decreased with storage duration. Fan *et al*. (2025) noted that such decline is normal in fish products because prolonged storage reduces volatile compound concentration and freshness.

The general aroma scores followed a similar trend to flavour, with deep-fried samples generally receiving higher scores across spice treatment. Aroma scores followed a similar trend to flavour, with deep-fried samples generally receiving higher scores across spice treatments. In black pepper treatment, deep-fried samples scored 8.27 ± 0.59, significantly higher ($p < 0.05$) than smoked samples (7.27 ± 0.80), while air-fried samples had an moderate score (7.53 ± 1.30). In cinnamon and control treatments, differences in aroma among processing methods were minor and not statistically significant ($p > 0.05$).

The higher aroma in deep-fried samples may be attributed to volatile compounds formed during Maillard reactions and lipid oxidation, which are intensified by frying, as reported by Fang *et al*. (2023). Spices such as black pepper further contribute essential oils and aromatic phenolics, enhancing overall olfactory perception, as observed by Ding *et al*. (2022). In contrast, air-fried and smoked samples, which involve lower oil uptake or dominant smoky notes, had slightly reduced aroma intensity.

Overall, these findings indicate that both processing method and spice treatment are critical for maximizing aroma quality, with deep-frying combined with aromatic spices like Black Pepper producing the most preferred sensory outcome.

5.2.4 Appearance

The appearance of *Merluccius merluccius* was generally influenced by both the spice treatments and processing methods, although the differences observed across the storage period were not significant. In black pepper treatment, all samples maintained an attractive and appealing look at the beginning of storage. The deep-fried and smoked samples appeared slightly more golden and appealing, probably due to the Maillard reaction that occurs during high-temperature processing, which enhances surface browning and improves colour. According to Liu *et al.* (2022), this browning effect helps develop a desirable golden-brown colour in fried fish fillets, increasing their visual appeal. Negara *et al.* (2021) also reported that deep-frying enhances the outer appearance of fish because of uniform dehydration and crust formation on the surface.

During mid-storage, the deep-fried samples still retained a brighter and more uniform appearance than the smoked ones, which tended to darken slightly. This could be a result of pigment oxidation and the build-up of smoke compounds like phenols and carbonyls, which make the product darker over time (Afé *et al*., 2021). By the final storage period, the appearance of all samples looked similar, which might have been caused by gradual moisture loss and slight fading of colour as storage continued (Fan *et al*., 2025).

In black pepper and cinnamon treatment, the fish samples showed stable appearance throughout the entire period. This could be linked to the antioxidant properties of both spices, which help to minimize oxidative browning and preserve the colour quality. Haruna *et al.* (2021) found that cinnamon extract helps to maintain the surface colour of smoked and fried fish by reducing oxidative changes during storage.

Similarly, in the cinnamon treatment, all samples kept an acceptable appearance across the months, suggesting that the spice did not negatively affect visual quality. The natural brownish tone of cinnamon might have even contributed to the uniform surface colour, especially in the fried fish.

For the control samples, appearance values were high and consistent from the start to the end of storage. This shows that even without spices, the processing methods used were effective in keeping the visual quality of the fish. Chen *et al.* (2024) explained that temperature and time during processing play major roles in how colour develops and is maintained in fish products.

The general Appearance mean scores were generally consistent across all processing methods and spice treatments. Both spiced and control samples, whether air-fried, deep-fried, or smoked, exhibited similar visual appeal, with scores ranging approximately between 6.87 and 7.67, and no significant differences were observed ($p > 0.05$). This indicates that processing method and spice incorporation had minimal impact on the overall visual quality of *Merluccius merluccius.*

The relative uniformity in appearance may be attributed to the fact that surface colour and brightness are influenced more by moisture content, browning reactions, and pigment retention than by the minor compositional differences introduced by spices (Zhou *et al*., 2021). Moreover, the mild colour change induced by frying or smoking was sufficient to maintain an acceptable appearance, consistent with the findings of Abdou and Suparlan (2019), who reported that spice-treated fish maintained good visual quality across different processing methods.

Overall, these results suggest that while flavour, aroma, and texture are strongly affected by processing method and spice treatment, appearance remains relatively stable, ensuring that visual appeal is not compromised in spiced and processed *M. merluccius*.

5.2.5 Over Acceptance

The overall acceptance of *Merluccius merluccius* varied across the different processing methods and spice treatments, reflecting the combined influence of flavour, texture, aroma and appearance on consumer preference. In black pepper treatment, panellists initially rated all samples as highly acceptable, especially the deep-fried and air-fried fish, which were preferred for their appealing colour and crispy texture. The high ratings observed may be linked to the pleasant aroma and subtle spiciness of black pepper, which enhances flavour perception and masks minor off-odours. According to Haruna *et al*. (2021), the addition of spices such as black pepper improves the sensory qualities of processed fish by enriching aroma and taste, leading to better overall acceptance.

As storage progressed, deep-fried samples maintained higher acceptability scores than the smoked ones, possibly due to the more stable flavour and crisp texture retained through frying. Smoked samples, though still acceptable, had slightly reduced scores, which might be attributed to the darker appearance and stronger smoky taste that can become less appealing over time. Similar findings were reported by Afé *et al*. (2021), who noted that prolonged smoking can alter the sensory balance of fish, slightly reducing consumer preference compared to fried products.

For samples treated with a combination of black pepper and cinnamon, the fish maintained consistent acceptability throughout the storage period. The combined antioxidant and aromatic properties of these spices likely contributed to this stability. Cinnamon's sweet, warm aroma may have complemented the pungency of black pepper, improving the overall sensory experience. Haruna *et al.* (2021) observed that natural spice combinations enhance the flavour complexity of smoked and fried fish, helping maintain consumer appeal during storage.

In cinnamon treatment, the samples were also well accepted across the analysis period. Deep-fried fish consistently received higher ratings, possibly because the spice imparted a mild sweet aroma and improved surface colour. Cinnamon has been reported to protect fish lipids from oxidation, preserving flavour quality during processing and storage (Maqsood and Benjakul, 2016).

Control samples, although not spiced, were still rated as acceptable, showing that the processing methods alone contributed to desirable sensory characteristics. Deep-fried fish again received slightly higher ratings, suggesting that the frying process enhances overall palatability by improving flavour, colour, and mouthfeel (Negara *et al.*, 2021). The trend across treatments indicates that deep-frying consistently produced fish samples with the most balanced sensory properties, while the inclusion of spices further enhanced their overall quality.

The general mean Overall acceptance in this study revealed that deep-fried samples consistently received slightly higher overall scores across the Black Pepper, Cinnamon-only, and control treatments, although differences among processing methods were not statistically significant ($p > 0.05$). For example, deep-fried samples in the Black Pepper treatment scored 7.80 ± 1.01, slightly higher than air-fried (7.47 ± 1.36) and smoked (7.07 ± 0.59) samples. Similarly, in the Cinnamon-only treatment, deep-fried samples scored 8.07 ± 1.03, compared to air-fried (7.33 ± 1.50) and smoked (6.87 ± 1.36) samples. The control followed the same trend, with deep-fried samples slightly preferred.

The slightly higher acceptability of deep-fried samples may be attributed to enhanced flavour, firmer texture, and richer aroma produced by the frying process, which aligns with sensory evaluations reported by Fang *et al*. (2023) and Ding *et al*. (2022). These studies demonstrated that frying, particularly when combined with spices, improves the overall palatability of fish by promoting Maillard reaction compounds and volatile aromatic molecules that enhance sensory perception. Additionally, Abdou and Suparlan (2019) reported that spice-treated fish fillets were better accepted due to improved taste and aroma, even when colour or appearance was relatively unchanged.

Overall, while all processing methods produced acceptable products, deep-frying in combination with spice treatments slightly enhanced overall consumer preference, indicating that panellists favoured the sensory qualities associated with this method.

CHAPTER SIX

6.1 Conclusion

This study revealed that both processing methods and spice significantly affect the quality of *Merluccius merluccius*. Deep frying preserved moisture and lipids, resulting in tender, juicy, and highly acceptable fish, while smoking reduced moisture, increased firmness and mineral concentration, but slightly lowered sensory appeal. The use of spices, particularly the combination of cinnamon and black pepper, enhanced aroma, taste, and overall acceptability without compromising nutritional quality.

Generally, the combination of deep frying with cinnamon and black pepper produced the most nutritionally balanced and organoleptically preferred fish, demonstrating that the integration of appropriate processing methods and spice application can substantially improve both the sensory and proximate qualities of *Merluccius merluccius*.

6.2 Recommendations

1. Processing methods like deep frying should be recommended for producing fish with optimal texture, juiciness, and consumer acceptability. Also, smoking may be used when a firmer texture and longer shelf life are desired, but should be combined with spices to improve flavour.
2. The application of spices especially the combination of cinnamon and black pepper should be highly recommended for enhancing aroma, taste, and overall acceptability. These spices should be carefully incorporated to maintain nutritional quality while improving sensory appeal.

3. Fish processors and small-scale entrepreneurs can adopt spice-enhanced processing to produce high-quality, flavourful, and consumer-preferred products. Spiced, deep-fried fish can be marketed as a premium product due to its superior nutritional and sensory characteristics.
4. Other spices should be explored to see how they can improve taste, shelf life and nutrition
5. Long term storage studies should be conducted to evaluate microbial safety and the stability of proximate and sensory qualities in spiced processed fish.
6. Smoking temperature and time should be carefully managed to prevent the fish from becoming too dry or bitter.

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APPENDIX I

Smoked spiced fish

Organoleptic samples

Fresh fish spiced with cinnamon

Fresh *Merluccius merluccius*

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 BLP-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 CMM-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 BLC-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 COB-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									

RESEARCH QUESTIONNAIRE
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Panellist code:_________________
Date:_______________

Sample BLP-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 CMM-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 BLC-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 COB-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									

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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 BLP-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 CMM-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 BLC-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 COB-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									