EFFECTS OF DEEP AND AIR FRYING ON THE SHELF LIFE OF ATLANTIC MACKEREL STORED AT AMBIENT TEMPERATURE

BY

Abetemhelo Esther ABU
AGR2004362

DEPARTMENT OF AQUACULTURE AND FISHERIES MANAGEMENT
FACULTY OF AGRICULTURE,
UNIVERSITY OF BENIN,
BENIN CITY, NIGERIA

SUPERVISOR: PROF. O.J. ABOLAGBA

NOVEMBER, 2025

EFFECTS OF DEEP AND AIR FRYING ON THE SHELF LIFE OF ATLANTIC MACKEREL STORED AT AMBIENT TEMPERATURE

BY

Abetemhelo Esther ABU
AGR2004362

SUBMITTED TO
THE DEPARTMENT OF AQUACULTURE AND FISHERIES MANAGEMENT, FACULTY OF AGRICULTURE, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE.
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF AGRICULTURE DEGREE B. AGRIC (AQUACULTURE AND FISHERIES MANAGEMENT)

NOVEMBER, 2025

CERTIFICATION

This is to certify that this project titled **"EFFECTS OF DEEP AND AIR FRYING ON THE SHELF LIFE OF ATLANTIC MACKEREL STORED AT AMBIENT TEMPERATURE"** was carried out by Abetemhelo Esther ABU (Miss) with matriculation number AGR2004362 under my supervision in the department of Aquaculture and Fisheries Management, Faculty of Agriculture, University of Benin, Benin City, Edo state, Nigeria.

_____ _____

PROF. O.J. Abolagba **Date**
Project Supervisor

_____ _____

Dr. M. Egwenomhe **Date**
Ag. Head of Department

DEDICATION

This project is specially dedicated to God Almighty for his mercies, guidance and protection in my life through my academic pursuit and to my lovely parents Mr. and Mrs Philip Abu for their love, care, moral and financial support.

ACKNOWLEDGEMENTS

I wish to acknowledge the Almighty God for His grace, provision, protection and direction in my life. I give all gratitude to Him.

I want to acknowledge and give thanks to my father, Mr. Philip Abu my lovely mother, Mrs Faith Abu for their care, prayer and support, to my sisters Blessing, Sarah and Decent for their love, care and support and to my wonderful brother David, I love you all.

Appreciation and gratitude also go to my project supervisor, Prof. O.J. Abolagba for his guidance, contribution and support throughout the duration of this project, may God bless you. I want to express my sincere gratitude to the Head of Department of Aquaculture and Fisheries management Dr. M. Egwenomhe, to my honourable lecturers in the Department of Aquaculture and Fisheries Management for their parental care, moral and academic investment into my life; Prof. V.A. Okonji, Prof. O.M. Wangboje, Prof (MRS) F.A.R Ehigiator, Prof (MRS) A.E Odiko, Prof. B.S Aliu, Dr. Kenneth Omoruyi, Dr. A.U Orowe, Dr. J. N. Nuntah, Dr. S.E Osayi, and Mr. N.E Iriowen,. May God richly reward your labour of love.

Special gratitude to Dr. J. N. Nuntah, for his immense contribution and assistance to the success of this project, I am grateful.

I am also grateful to the amazing set of people who have always believed in me and had my back, a big thank you to Mudi Aaliyah, Agbokpolo Happy, Uyi, KB, Edna, Mirabel thank you for standing by me through this journey. To my coursemates, I am grateful I got to do this journey with you all. And to all whom God used to favour me throughout my Academic journey. Thank you all and God bless.

TABLE OF CONTENT

LIST OF TABLES

LIST OF PLATES

Lists of Figures

FIGURE **TITLE** **PAGE**

ABSTRACT

This study investigated the effects of deep and air frying on the shelf life of Atlantic mackerel (*Scomber scombrus*) stored at ambient temperature in Ziplock packages. The fish samples were divided into salted and unsalted portions, fried using both methods, and stored for six days. Microbial analyses were conducted at intervals to determine bacterial and fungal loads. Results showed a steady increase in microbial counts over time, with bacterial counts rising from 7.4 cfu/gm on day 0 to 29.6 cfu/gm on day 6, and fungal counts from 30.7 cfu/gm to 74.9 cfu/gm. Air-fried samples consistently showed lower microbial growth compared to deep-fried ones, while salted samples exhibited slower spoilage rates than unsalted ones. These findings suggest that air frying combined with salt treatment effectively enhances the microbial stability and shelf life of fried Atlantic mackerel stored at ambient temperature.

CHAPTER ONE

1.0 INTRODUCTION

Fish plays a crucial role in human nutrition, it serves as an important source of high-quality protein, omega-3 fatty acids, vitamins and essential minerals to millions of people (Abraha *et al.,* 2018). In Nigeria and many parts of Africa, fish is a staple in daily diets due to its availability, affordability and rich nutritional profile which makes it a valuable part of a balanced diet (Olayemi *et al.,* 2019). However, one of the biggest challenges faced by fish processors, traders and consumers is its high perishability due to its high moisture content and nutrient composition (Udo *et al.,* 2024). Fresh fish begins to spoil within hours of harvest if not properly stored, leading to significant post-harvest losses, economic losses and food insecurity (Akinwumi and Adegbola, 2020). Spoilage is a metabolic process that causes fish to be unpalatable or unacceptable for human consumption due to changes in sensory and nutritional characteristics (Fawole *et al.,* 2020). Without proper preservation, fish deteriorates quickly, leading to significant economic losses for fish farmers, traders and consumers (Omojola *et al.,* 2019). The different methods and procedures used to keep fish fresh after harvest, prolong their shelf life and prevent spoilage are collectively referred to as fish preservation. Since oxidation, enzymatic reactions and microbial development are the main drivers of fish deterioration, slowing them down is the fundamental objective of fish preservation (Adewuyi and Omotosho, 2020). Food security is improved and post-harvest losses are decreased by using the right preservation techniques, which guarantees that the fish is safe and fit for human consumption (Omojola *et al.,* 2019).

Several preservation techniques that includes smoking, drying, salting, freezing and frying exist, and each with varying degrees of success. Frying is considered as one of the widely used method in the food industry because it enhances the taste, texture and limit microbial stability in the processed fish species (Adeyemi and Olufemi, 2021). Frying applies heat and

mass transfer equilibrium causing the oil to be transferred into the products while the water exudes from the food product into the oil (Yu *et al.,* 2020). The deep-frying technique is the traditional method of frying that involves submerging fish in hot oil at temperatures of 150 - 200^{o}C, to rapidly cook the fish and forms a crispy outer layer that helps reduce moisture content (Adewumi and Alabi, 2023). While the Air frying technique makes use of the Air fryer equipment that uses rapid air circulation and little to no oil to cook the fish while still producing fried crispy texture (Song *et al.,* 2020). In recent times, the air frying technique has gained popularity as a healthier alternative to the deep-frying (Fabre *et al.,* 2018).

In processed fish preservation, packaging plays a vital role and often may determine the extent of the shelf life stability of the processed fish especially during storage, as proper packaging methods slow down oxidation, prevent contamination and maintain sensory quality during storage (Fawole *et al.,* 2020). A common packaging method used in fried fish preservation is ziplock packaging (Adeyeye and Oyewole, 2022). Ziplock packaging involves the use of resealable plastic bag typically made from food-grade polyethylene or polypropylene which provide a convenient and semi-airtight environment (Adewumi *et al.,* 2022). Ziplock packages reduce direct exposure to moisture, dust, air and potential contaminants, helping to delay microbial spoilage and maintain the sensory quality of food for several days (Fawole *et al.,* 2018).

1.1 Justification of the Study

Fish spoilage is a major issue in the Nigeria's fisheries sector, contributing to economic losses and food insecurity. The preservation of fish remains a significant challenge due to its highly perishable nature (Olayemi *et al.,* 2019). The Atlantic mackerel (*Scomber scombrus*), like many other fish species, deteriorates rapidly because of its high moisture content, susceptibility to lipid oxidation and microbial activity. Thus, identifying efficient preservation methods is essential for maintaining fish quality and prolonging shelf life.

The conventional frying and air frying are popular fish frying techniques that influences the flesh quality of Atlantic Mackerel in distinct ways. Olayemi *et al.* (2019) and Adeyemi and Olufemi (2021) studied the effects of deep-frying on the quality of croaker, especially in terms of the moisture content and lipid oxidation. The deep-frying of fish was found to enhance the flavor and texture but often increased oil absorption in the fish tissues that accelerates lipid oxidation and rancidity over time. Furthermore, Nwosu *et al.* (2022) on the study of nutritional and preservation benefits of air frying in fish processing stated that it a healthier alternative food processing technology to deep frying. Fabre *et al.* (2018) reported that the air frying technique using the air fryer technology of smaller capacity, shorter cooking time and fewer calories intake is been gradually accepted as an innovative alternative frying method.

Fish packaging techniques provides significant influence on the storage and shelf stability of the fish species. To extend shelf life and keeping qualities of fried Atlantic Mackerel species especially during storage, the ziplock packages may be used. Ajani *et al.* (2020) on the study of the effect of different packaging methods on the shelf life of smoked fish, compared the packaging techniques and found that ziplock packaging generally extends shelf life better than the conventional packaging. The ziplock packages are readily available and affordable alternatives and offer a high level of protection against spoilage (Fawole *et al.,* 2018).

There is a dearth in knowledge on the study that directly compares the effects of deep-frying and air frying on the microbial qualities of Atlantic Mackerel (*Scomber scombrus*) packaged in ziplock bags and stored at ambient temperature. This study therefore intends to fill the knowledge gap and provide improved techniques of fish frying and packaging that will be cost effective, preserve nutrients, limit spoilage and extend shelf life of fried Atlantic Mackerel Species.

1.2 Aim of the Study

The aim of this study was to determine the effects of deep and air frying on the shelf life of Atlantic mackerel (*Scomber scombrus*) stored at ambient temperature.

1.3. Objectives of the Study

The specific objectives of this study were to determine the:

1. Effects of deep-frying on the shelf life of Atlantic mackerel (*Scomber scombrus*) stored at ambient temperature.
2. Effects of air frying on the shelf life of Atlantic mackerel (*Scomber scombrus*) stored at ambient temperature.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Description of Atlantic Mackerel (*Scomber scombrus*)

Atlantic mackerel (*S. scombrus*) is a common fish species found in the North Atlantic Ocean, particularly along the coasts of Europe, North America and parts of Africa. It belongs to the *Scombridae* family, which includes other fast-swimming fish like tuna and bonito (Last and White, 2019). The fish has a sleek, elongated body with a metallic blue-green back and a silvery-white belly. One of its most recognizable features is the series of dark, wavy lines running along its back, which help distinguish it from other fish (Collette and Nauen, 2023).

Atlantic mackerel is known for its speed and schooling behavior, meaning it moves in large groups, often migrating in search of food and suitable water temperatures. It mainly feeds on tiny sea creatures like plankton and small crustaceans (Shulgina *et al.,* 2019). Because it is so abundant in the ocean, it serves as an important food source for larger fish, seabirds and marine mammals. Due to it's high nutritious value it is widely recognized as a good source of protein and healthy fats. It is particularly rich in omega-3 fatty acids, which are beneficial for heart health, brain function and reducing inflammation (Collette and Nauen, 2023). Additionally, it contains essential vitamins and minerals, such as vitamin D, vitamin B12, iodine and selenium, which contribute to overall well-being (Food and Agriculture Organization (FAO), 2020).

Atlantic mackerel is one of the most consumed fish species in Nigeria and plays a key role in household nutrition, it is commonly imported in frozen form and is popularly referred to as "Titus" in local markets. Due to its affordability and high demand, it contributes significantly to food security, especially in urban and rural communities where fish is a major protein source (Akinwumi and Adegbola, 2020).

2.2 Microbial Spoilage of Fish

According to Fawole *et al.* (2020) fish spoilage is a metabolic process that causes food to be undesirable or unacceptable for human consumption due to changes in sensory and nutritional characteristics. Fish is highly perishable due to its high moisture content, neutral pH and rich nutrient profile, which together create an ideal environment for microbial growth (Saliu, 2018). After harvest, fish undergoes rapid deterioration due to enzymatic reactions, oxidation and microbial activity. These changes not only reduce the sensory qualities such as texture, odor and flavor but also render the fish unsafe for consumption (Adekunle *et al.,* 2021). The dominant spoilage organisms include *Pseudomonas sports, Shewanella putrefaciens, Vibrio sp* and *Enterobacteriaceae* (Aitken *et al.,* 2021). In tropical regions, *Bacillus spp* and *Micrococcus spp* are also common (Adeyeye and Oyewole, 2022). These microorganisms degrade proteins and lipids, producing off-flavors, discoloration, slime and gas (Okonkwo *et al.,* 2018).

Mackerel, like most oily fish is highly perishable due to its high moisture and fat content. If left exposed to air and high temperatures, it begins to spoil quickly, developing an unpleasant smell, texture changes and a loss of nutritional value (FAO, 2020). Oxidation and microbial growth are the main factors responsible for spoilage, and these processes happen even faster when the fish is stored in poor conditions (Olayemi *et al.,* 2019).

In Nigeria, mackerel is used in a variety of traditional dishes, whether grilled, fried or cooked in stews and soups. Since it is mostly sold in frozen form, proper handling and storage are essential to prevent spoilage (Akinwumi and Adegbola, 2020). One of the major challenges is maintaining its freshness, especially in areas where access to refrigeration is limited.

2.2.1 Characteristics of a spoiled fish

Fish spoilage occurs due to microbial activity, enzymatic degradation and chemical oxidation, leading to noticeable physical, chemical and sensory changes (Aitken *et al.,* 2021). Identifying these characteristics is essential for determining fish quality and ensuring food safety, the characteristics can be seen in:

1. **Physical Changes:**

•Discoloration: Fresh fish has a bright, natural coloration, but spoiled fish often appears dull, brownish or greenish due to oxidation and bacterial activity (Olayemi *et al.,* 2019).

•Soft and Slimy Texture: Spoiled fish becomes excessively soft and loses its firm, elastic texture. The skin and flesh may feel sticky or slimy due to bacterial biofilm formation (Nwosu *et al.,* 2020).

•Sunken or Cloudy Eyes: Fresh fish has clear, bulging eyes, whereas spoiled fish develops sunken, cloudy or milky-white eyes, indicating decomposition (Conell, 2019).

•Detached or disintegrating scales and fins: In fresh fish, the scales are firmly attached to the skin, but in spoiled fish, they loosen and fall off easily.

2. **Sensory Changes**

•Foul odor: One of the most noticeable signs of fish spoilage is an unpleasant, ammonia-like or putrid smell. This results from microbial breakdown of proteins into biogenic amines such as putrescine and cadaverine (Ozogul and Hamed, 2019).

•Unpleasant taste: Spoiled fish often develops a bitter, sour or rancid taste due to bacterial fermentation and lipid oxidation (Olayemi *et al.,* 2019).

3. **Chemical and Microbial Indicators**

•pH increase: Fresh fish has a slightly acidic to neutral pH (6.0–6.5), but as spoilage

progresses, bacterial metabolism raises the pH above 7.0, making the fish more alkaline (Aitken *et al.,* 2021).

•Formation of gas and toxins: Some spoilage bacteria produce gases, causing bloating in fish. Histamine formation, particularly in species like tuna and mackerel, can lead to scombroid poisoning (FAO, 2021).

•Bacterial growth: High levels of bacteria such as *Pseudomonas, Shewanella* and *Enterobacteriaceae* indicate spoilage, as these microbes degrade fish proteins and lipids, leading to bad odors and toxic byproducts (Nwosu *et al.,* 2020).

2.2.2 Effects of fish spoilage

Fish spoilage has significant consequences on public health, the economy and the environment. Since fish is a highly perishable protein source, improper storage and handling can lead to rapid deterioration, making it unsafe for consumption (Fawole *et al.*, 2020). Some of the major effects of fish spoilage are:

1. Public Health Risks: Consuming spoiled fish poses severe health risks due to the presence of harmful bacteria, toxins and biogenic amines such as histamine and cadaverine (Okonkwo *et al.,* 2018). The main health-related effects include:

•Foodborne illnesses: Spoiled fish often harbors pathogenic bacteria such as *Salmonella spp, Escherichia coli, Vibrio cholerae,* and *Listeria monocytogene*s which can cause severe gastrointestinal infections (Olayemi *et al.,* 2019). These illnesses are characterized by symptoms such as vomiting, diarrhea, fever and abdominal pain.

•Scombroid poisoning: This occurs due to the accumulation of histamine in decomposing fish, particularly in species like tuna and mackerel. High levels of histamine can lead to allergic reactions, including skin rashes, headaches, nausea and difficulty in breathing (Ozogul and Hamed, 2019).

•Neurotoxic effects: Lipid oxidation in fish produces harmful aldehydes and ketones, which can damage cells and increase the risk of neurological disorders when consumed over time (Aitken *et al.,* 2021).

•Parasitic infections: Spoiled fish can become a breeding ground for parasites such as tapeworms (*Diphyllobothrium spp*) and roundworms (*Anisakis spp*) leading to intestinal infections in humans (FAO, 2021).

2. **Economic Losses**: Fish spoilage has severe economic implications for fishermen, traders and consumers. These losses include:

•Financial loss for fishermen and traders: In developing countries like Nigeria, post-harvest losses in the fisheries sector can reach up to 40% due to spoilage (Nwosu *et al.,* 2020). This loss affects the income of small-scale fishers and fish sellers who rely on daily sales for their livelihood.

•Rejection in local and international markets: Spoiled fish fails to meet food safety standards, leading to rejection in domestic and export markets. This particularly affects African countries exporting fish to Europe and Asia, where strict quality controls are enforced (FAO, 2021).

•Increased cost of preservation and storage: To prevent spoilage, fish must be stored under proper conditions, which increases costs for businesses. The need for refrigeration, freezing, and chemical preservatives adds to the production costs for fish processors and sellers (Nwosu *et al.,* 2020).

•Food waste and high consumer prices: Spoilage leads to large quantities of fish being discarded, reducing supply and driving up prices for fresh fish. This affects affordability, especially for low-income populations that depend on fish as a primary protein source (Olayemi *et al.,* 2019).

3. Environmental Impact: Spoiled fish contributes to environmental pollution and waste management challenges. Its major environmental effects include:

•Food waste and resource depletion: Fish spoilage leads to the wastage of valuable resources, including water, feed and labor used in fish production (FAO, 2021). In many Nigerian coastal communities, spoiled fish is dumped into rivers and open landfills, causing environmental degradation.

•Water and soil pollution: Decomposing fish releases ammonia, sulfides and organic acids that can contaminate water bodies and soil. This pollution disrupts aquatic life and reduces the quality of drinking water sources in fishing communities (Nwosu *et al.,* 2020).

•Greenhouse gas emissions: The improper disposal of spoiled fish in landfills contributes to methane and carbon dioxide emissions, which are major greenhouse gases responsible for climate change (FAO, 2021).

4. **Social and Nutritional Implications:**

•Food insecurity: In many African countries, fish is a primary protein source. Spoilage reduces the availability of fish, worsening food insecurity and malnutrition, particularly among children and pregnant women (Olayemi *et al.,* 2019).

•Job losses in the fisheries sector: The economic burden of fish spoilage can lead to job losses among fish processors, traders and transporters, further increasing poverty rates in fishing communities (Nwosu *et al.,* 2020).

•Decline in consumer confidence: When consumers frequently encounter spoiled or low-quality fish, they may lose trust in local fish markets, affecting the sales and sustainability of the fishing industry (Ozogul and Hamed, 2019).

2.3 Fish Preservation Techniques

Fish preservation refers to a set of techniques aimed at prolonging the shelf life of fish by slowing down or inhibiting spoilage processes (Adeoti and Afolabi, 2019). The primary function of preservation is to delay microbial growth and enzymatic activity and to minimize chemical changes (oxidation) that compromise sensory qualities such as texture, odor and flavor (Nwosu *et al.,* 2020). Effective preservation ensures that fish remains safe for consumption while reducing post-harvest losses which is a critical issue in many developing countries where refrigeration infrastructure may be limited (FAO, 2019).

2.3.1 Traditional Preservation Method

In Nigeria, traditional fish preservation methods have been developed over generations to extend the shelf life of fish and reduce post-harvest losses. These methods are deeply rooted in the cultural practices of various fishing communities and are tailored to the local environmental conditions (Onwuka, 2018). Traditionally, communities in Nigeria and across Africa have relied on methods such as sun-drying, smoking, salting, fermentation and frying to preserve fish.

• Sun-drying: This method removes moisture from fish by exposure to sun and wind. This process involves laying fish out in the open to dry under the sun, effectively reducing moisture content to levels that inhibit microbial growth, with moisture content reduced to below 10%, bacterial growth is largely inhibited. (Udo *et al.,* 2024). While sun-drying is cost-effective and energy-efficient, it exposes fish to environmental contaminants and pests, which can affect the quality and safety of the final product (Adewumi and Olaleye, 2019).

• Smoking: Smoking is one of the most prevalent traditional methods of fish preservation in Nigeria, this technique involves exposing fish to smoke from burning wood, which imparts a distinct flavor and aids in preservation (Akinwumi *et al.,* 2021). Smoking serves a dual purpose by both drying the fish and depositing antimicrobial compounds from wood smoke

(Saliu, 2018). It not only enhances flavor but also retards microbial activity. However, traditional smoking kilns may lack temperature control, which can affect product consistency (Omojola *et al.,* 2019)

• Salting and Brining: Salting involves the application of salt to fish, either through dry salting or brining, to draw out moisture and create an environment inhospitable to bacteria. This method is often combined with drying or smoking to enhance preservation (Akinwumi *et al.,* 2021). Salt reduces water activity and creates an osmotic environment that is hostile to many spoilage bacteria. While effective, high salt levels may alter the sensory and nutritional qualities of fish (Adekunle *et al.,* 2021).

• Fermentation : This is an ancient method, it is a biochemical process involving the breakdown of organic compounds by microorganisms such as bacteria, yeasts or fungi, typically in the absence of oxygen (Ibrahim *et al.,* 2024). Fish is fermented to produce distinct traditional products like momone in Ghana and Ugba in Nigeria (Ghaly *et al.,* 2019).

2.3.2 Modern Preservation Methods

With advancements in technology and increased awareness of food safety, modern preservation methods have been adopted to complement traditional techniques. These methods aim to improve the quality, safety and shelf life of fish products (Adekunle *et al.,* 2021). Modern techniques include refrigeration, freezing, vacuum packaging and controlled atmosphere packaging. Refrigeration (0°C) and freezing (below –18°C) are effective methods for preserving fish as they slow down both microbial and enzymatic spoilage processes (Ibrahim *et al.,* 2024). However, these methods require continuous energy supply and advanced infrastructure, which can be challenging in rural or resource-limited settings (FAO, 2019); in many Nigerian communities, especially in rural areas, access to reliable electricity is limited, making these methods less feasible (Ibrahim *et al.,* 2024).

2.4 Frying as a Preservation Method

Frying is both a cooking and preservation method that involves cooking fish in hot oil, which dehydrates the surface and creates a barrier against microbial invasion (Omojola *et al.,* 2019). In Nigeria, frying is a popular method due to its simplicity and the appealing taste and texture it imparts to fish (Akinwumi *et al.,* 2021). Frying is classified as a dry heat cooking method that is widely used at both domestic or industrial levels, it is considered one of the popular processes used in the food industry to provide unique sensory and change the physical properties of the food products (NurSyahirah and Rozzamri, 2022; Ghidurus *et al.,* 2020).

The primary objective of frying is to increase food acceptability and develop desirable sensory characteristics (Ghidurus *et al.,* 2020). The frying process is usually influenced by several factors such as the type of oil and temperature used during frying (Kumar *et al.,* 2020). The process contains a series of physical and chemical changes, which include water evaporation, protein denaturation, starch gelatinization, and the formation of a crispy crust on the fried surface (Aitken *et al.,* 2021).

During this process, the moisture present in food is eliminated as steam due to absorption of heat from the oil or any other sources of energy used. This leads to a noticeable decrease in the volume, moisture level and weight of the food (Zhang *et al.,* 2020). Additionally, frying can effectively destroy microorganisms, deactivate enzymes and decrease the water activity of food items (Hosseini *et al.,* 2019). These effects contribute to the preservation and safety of fried foods (Karimi *et al.,* 2018).

Frying is the simplest and fastest method of processing mackerel, various frying techniques such as vacuum frying, deep-frying and air frying were designed according to several parameters that include the frying medium and frying mechanisms to produce better quality end products (Arslan *et al.,* 2018).

2.4.1 Deep-frying method

The deep-frying method involves immersion of the food in hot oil at temperatures of 150–200°C, the temperature is influenced by the food composition and heat-mass transfer properties (Kumar *et al.,* 2020). According to Hosseini *et al.* (2019) it involves submerging fish completely in hot oil, typically at temperatures between 160°C and 190°C. This method cooks the fish quickly, resulting in a crispy exterior and moist interior. It enhances the flavour and texture of certain dishes, this process enhances the crispiness and texture of food, making it a preferred method for preparing specific dishes (Shabbir *et al.,* 2019). In addition to improving food's sensory appeal, deep-frying raises its nutritional value by adding calories, vitamins, and vital fatty acids (Karimi *et al.,* 2018). However, deep-frying causes lipid oxidation and severe changes to the colour of fried fish (Viera *et al.,* 2018). Lipid oxidation occurs due to the fact that during the process of deep-fat frying, the oil used not only acts as a medium of heating but also gets absorbed into the food being fried, thereby increasing the overall fat content (Aitken *et al.,* 2021).

2.4.2 Air frying method

Air frying is the opposite of deep frying. It is a method that circulates and utilizes hot air to fry food. Under these conditions, oil absorption in food can be minimized (Ferreira *et al*., 2017). Air frying has gradually been accepted as a new frying method because of it’s smaller capacity, shorter cooking time and fewer calories (Fabre *et al.,* 2018). The process is carried out in an air-fryer device which simulates the heat current in boiling oil to dehydrate the fish product, crisp the outside and cook the inside (Tian *et al.,* 2017). Heat is transferred using fine oil droplet mist directly to the food under hot air conditions during frying and this reduces the amount of oil uptake in the fried foods (Dehghannya and Ngadi, 2021). Research by Joshy *et al.* (2020) noted that air frying has different effects on the color, texture and flavor of food compared with traditional frying because of the oil oxidation. Air frying results

in healthier fried foods compared to deep-frying (Viera e*t al.,* 2018).

2.5 Packaging Methods for Fried Fish

Fish preservation relies heavily on packaging, which serves as a physical barrier against environmental pollutants as well as a mechanism for controlling elements like moisture, oxygen and microbial invasion (Olayemi *et al.,* 2019). Proper packaging is essential to maintain the quality and extend the shelf life of fried fish. Packaging protects the product from environmental factors, contaminants and moisture loss (Mohammed *et al.,* 2023). For fried fish particularly in regions like Nigeria where ambient temperature storage is common the choice of packaging can significantly impact the product's shelf life, microbial stability and overall quality (Evivie *et al.,* 2020). Various packaging techniques have been explored over time, ranging from modern vacuum sealing systems to traditional methods such as leaf wrapping.

2.5.1 Ziplock Bags Packaging

Ziplock packaging is commonly made from polyethylene or polypropylene plastics, it is one of the most accessible forms of packaging used by small-scale processors and households in Nigeria (Adewumi *et al.,* 2022). It provides a degree of moisture protection and helps to reduce contamination during short-term storage (Adeyeye and Oyewole, 2022). Fawole *et al.* (2018) observed that while ziplock bags are useful for short-term preservation, their permeability to air can allow gradual oxidation and microbial growth. This limitation makes them less ideal for longer storage periods, especially at room temperature. However, ziplock bags remain widely used due to their affordability, ease of access and reusability, particularly in urban markets where cold storage facilities are scarce (Mensah *et al.,* 2020).

The interlocking seal of ziplock bags helps reduce exposure to air and moisture, but some

oxygen permeability still exists, which can accelerate lipid oxidation over time. Ukoha *et al.* (2021) also found that ziplock packaging preserved the texture and flavor of fried *Clarias gariepinus* for up to 48 hours without refrigeration, suggesting its viability for street vendors and small-scale processors.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Study Area

The study was carried out in the processing unit, Department of Aquaculture and Fisheries Management, Faculty of Agriculture, University of Benin City, situated in Ovia North-East Local Government Area of Edo state. The area is located in the tropical rainforest with evergreen trees, distinct raining and dry seasons and an average rainfall of 1500mm- 2500mm. It has two peaks of rainfall (April and October), with relative humidity and temperature of approximately 27^{O}C.The approximate GPS coordinates of the study location are 6.3951° N, 5.6037° E.

3.2. Experimental Design

The experiment was made up of three factors namely two (2) Frying methods (deep and air frying), two (2) treatment (0 and 5% salt) and 3 storage periods (0, 3, and 6 day). Thus, the experimental design was a 2 × 2 × 3 factorial replicated three (3) times in a complete randomized design to ensure accuracy and consistency.

3.3 Collection of Fish Samples

A total of six (6) fresh Atlantic Mackerel (*Scomber scombrus*) was purchased from a reputable cold room at Uselu market in Benin City and these were immediately placed in a cooler filled with ice to avoid spoilage and minimize initial microbial growth during transportation to the processing unit in the Department of Aquaculture and Fisheries

Management, University of Benin. At the processing unit the fish were frozen at -10^{OC} prior to processing.

Plate 1: Fresh *S.scombrus*

3.4 Preparation of Fish Samples

The fish samples were allowed to thaw at room temperature and then washed with clean sterile water. They were then carefully eviscerated, cut into equal parts to make sure all samples were of the same size for the experiment and the gut contents removed. The fish cutlets were washed in running water and treated in 5% brine solution for 10 minutes pieces. The brine fish samples were placed on clean covered racks to drain prior to frying activities (Adeyeye and Oyewole, 2022).

Plate 2: Prepared *S.scombrus*

3.5 Frying Methods

3.5.1 Deep frying

This is the conventionally fish frying technique commonly used in Nigerian kitchens and eateries. Samples of the Atlantic Mackerel fish cutlets were deep fried by immersing them in hot vegetable oil at 180°C for 10 minutes using a deep-frying pan. The fish samples were flipped at two (2) minutes intervals to allow the fish cook properly and prevent burning. The fried fish were collected and placed on absorbent paper in a sieve to cool and the oil allowed to drain before it is packaged in ziplock bags and store on the shelf at ambient temperature.

3.5.2 Air frying

Samples of the Atlantic Mackerel fish cutlets (control and treated) were fried without oil using a digital air fryer set (Pinnacle 8L air fryer PA-552) for 180°C for 20 minutes. The reason for the extended frying duration for the air frying was to ensure complete cooking of the fish since air frying lacks oil immersion (Zanghi *et al,* 2019). The fish was flipped after 10 minutes to the other side to allow even cooking of both sides (Vieira *et al.,* 2018). The fried fish samples were collected and placed on absorbent paper in a sieve to cool and drain out some of lipids before the fried samples were packaged in ziplock bags and stored on the shelf at ambient temperature.

3.6 Zip Lock Bags Packaging

Zip lock bags are commonly used in domestic settings for short-term storage, (Akinwumi, 2018). Samples of the fried (conventional and air frying) *Scomber scombrus*) each were placed in the conventional zip lock bags and sealed manually allowing as much air as possible to be eliminated from the pack during sealing.

Plate 3: Deep fried *S.scombrus* samples

Plate 4: Air fried *S.scombrus*

Plate 5: Ziplock packaging

3.7 Storage of Samples

Storing the ziplock packaged fried (conventional and air frying) *Scomber scombrus* fish samples at ambient temperature without refrigeration simulates real-life scenarios in areas with limited electricity access, which is a challenge widely acknowledged in fish post-harvest studies in Africa (Olayemi *et al.,* 2019; Yusuf *et al.,* 2020). The ambient temperature conditions 28 - 32°C represent a typical indoor temperature in Southern Nigeria. The fried samples were stored for about 7 days duration.

3.8 Sample Collection and Analysis

The fried packaged samples were subjected to microbiological analysis using standard procedure and techniques. The microbial assessments were carried out on Days 0, 3, and 6.

3.9 Microbiological Analysis

3.9.1 Materials

Sterile scalpels or knives, digital weighing balance, blender or stomacher, sterile stomacher bags or blender jars, distilled or sterile water, test tubes with 9 ml sterile distilled water,

sterile pipettes or micropipettes (1 ml), sterile pipette tips, sterile petri dishes, glass rods or sterile L-shaped spreaders, incubator (set to 37°C), room temperature environment or second incubator (25–28°C), Nutrient Agar (NA), MacConkey Agar, Sabouraud Dextrose Agar (SDA), labels and marker pens, autoclave or pressure pot, ethanol (70%) or disinfectant, disposable gloves, lab coat, face mask, waste disposal bin (biohazard-safe), Colony counter, calculator or spreadsheet software.

3.9.2 Sample preparation

For microbiological examination, 25 grams of each sample were aseptically weighed and homogenized in 225 ml of sterile peptone water. The homogenates were serially diluted and plated using the pour plate method. This standard method is recommended by FAO (2020) for the assessment of microbial load in fishery products.

3.9.3 Total Viable Count (TVC)

Total viable bacteria were assessed using Plate Count Agar (PCA). Ten grams (10g) of the fish sample were homogenized in 90 ml of sterile peptone water to create a 10^{-1} dilution. Serial dilutions were then prepared up to 10^{-5}. From each dilution, 1 ml was plated on sterile Nutrient Agar using the pour plate or spread plate method, plates were incubated at 37°C for 24 – 48 hours. After incubation colonies were counted and expressed as colony-forming units per gram (CFU/g). TVC provides an overall indication of microbial load and is one of the most commonly used microbiological indicators of food spoilage (Onwuka, 2018). A high TVC indicates microbial proliferation, which is commonly associated with spoilage. Lower TVC values are preferred and are indicative of better preservation.

3.9.4 Bacterial Count

To determine the presence of coliform bacteria, 1 ml of samples were inoculated onto

MacConkey agar plates using the pour plate or spread plate method and incubated at 37°C for 24 hours. Typical coliform colonies appear pink or reddish on the agar due to lactose fermentation. Coliforms are considered hygiene indicators and suggest possible post-processing contamination (Udo *et al.,* 2024).

3.9.5 Fungal Count

Fungal analysis was conducted using Potato Dextrose Agar (PDA) supplemented with chloramphenicol to inhibit bacterial growth. After serial dilution of the homogenized fish sample, 1 ml from the appropriate dilution was plated on PDA containing chloramphenicol using the spread plate technique. The plates were incubated at room temperature, 25 appropriate dilution was plated on PDA containing chloramphenicol using the spread preserved protection against microbial moulds showed filamentous or fluffy growth.

Fungi, especially molds, are known to thrive in low-moisture environments and can contribute to spoilage through off-odours and toxins (Akinwumi *et al.,* 2021).

3.10 Statistical Analysis

The results from the microbial tests were first changed to log values and a two-way Analysis of Variance (ANOVA) was used to determine the effects of frying method, packaging type, storage duration and their interactions on microbial growth. Duncan's Multiple Range Test (DMRT) will be applied to separate means at a 5% level of significance ($p < 0.05$). Statistical analyses will be carried out using SPSS version 25.

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of Storage Periods on the Overall Mean Bacterial counts of Fried Atlantic Mackerel

The study revealed a distinct and progressive increase in the overall mean bacterial count (cfu/gm) in the Atlantic mackerel throughout the ambient storage period. The measure count on Day 1 was relatively low (7.4×10^{-3}cfu/gm) and this doubled to 13.9×10^{-3} cfu/gm by Day 3. The most significant ($P<0.05$) increase occurred between Day 3 and Day 6, where the count increased to its highest level of 29.6×10^{-3} cfu/gm. (Figure 1)

4.2 Effects of Storage Periods on the Overall Mean Fungal counts of Fried Atlantic Mackerel

Similarly, the overall mean fungal count (cfu/gm) showed a marked increase throughout the storage period, though the magnitude of the increase was higher than that observed for bacteria. The initial fungal load on Day 1 was 30.7×10^{-3} cfu/gm. This count increased to 51.1×10^{-3} cfu/gm by Day 3 and reached a peak mean count of 74.9×10^{-3} cfu/gm by Day 6.(Figure 2).

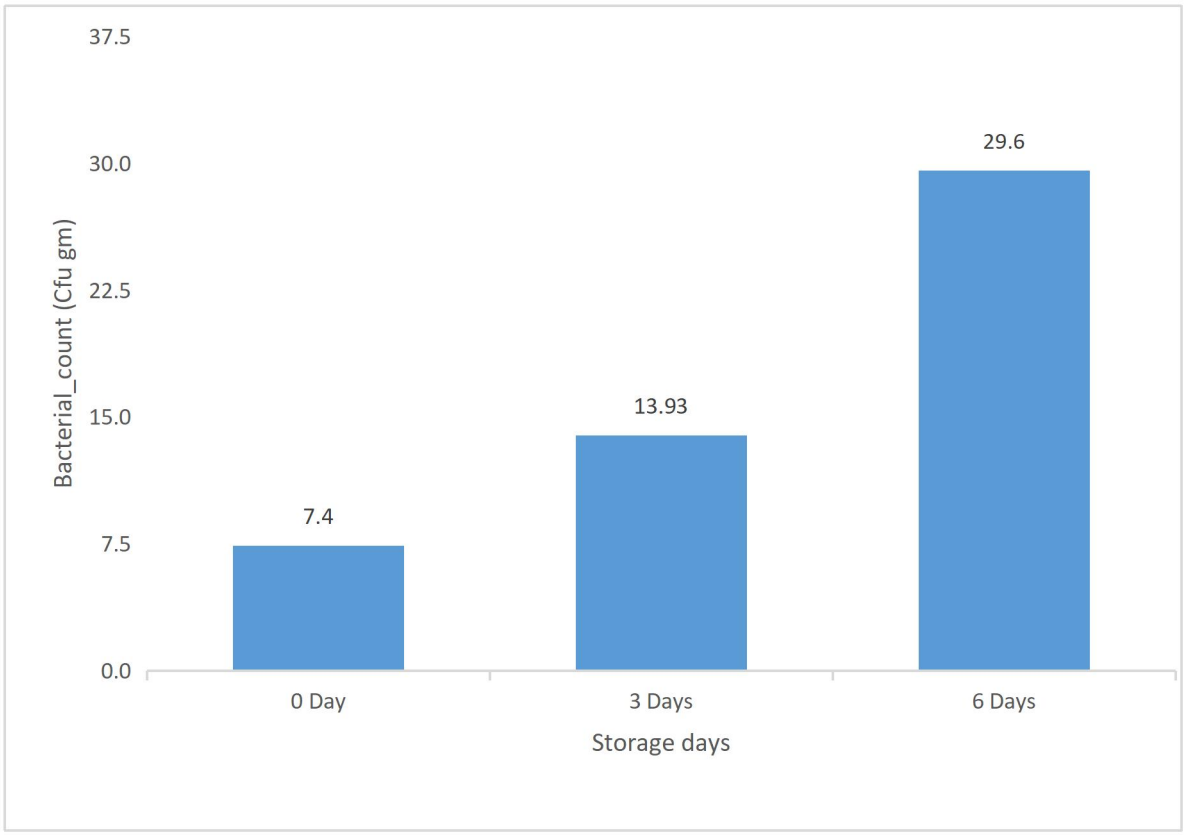

Figure 1: Effects of Storage Periods on the Overall Mean Bacterial counts of Fried Atlantic Mackerel

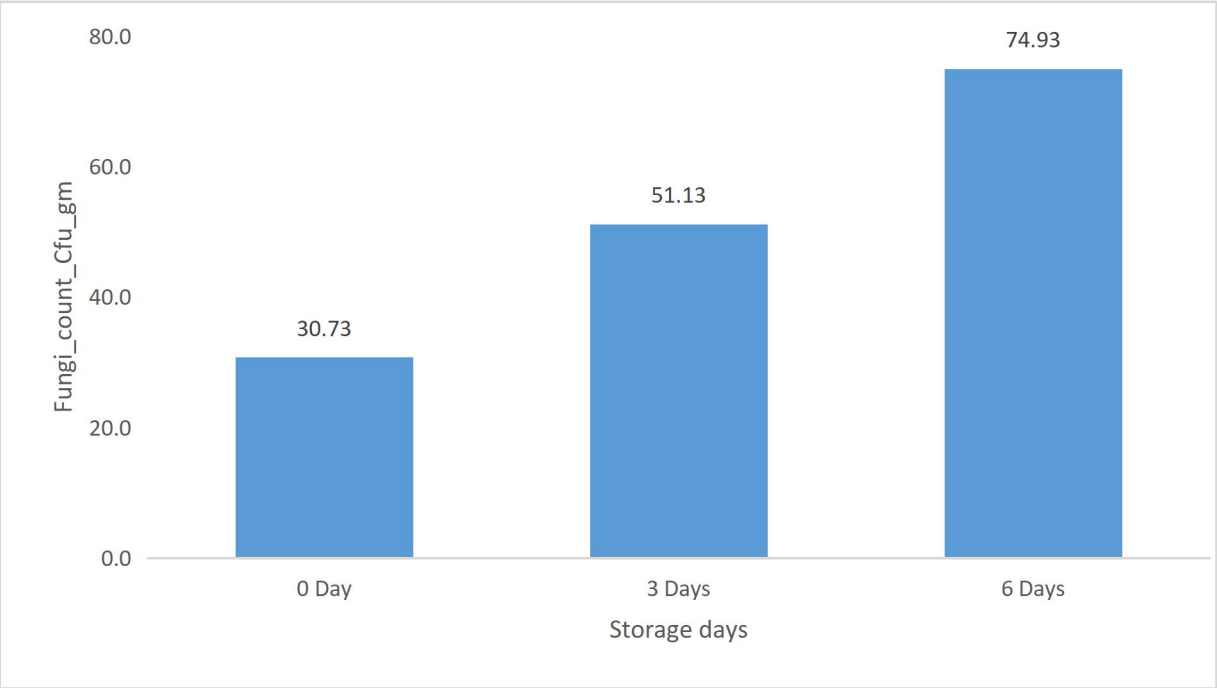

Figure 2: Effects of Storage Periods on the Overall Mean Fungi counts of Fried Atlantic Mackerel

4.3 Effects of frying Technique and Salt Treatment on the Mean Microbial Loads of Atlantic Mackerel

Table 1 showed the effects of the different frying techniques and salt treatment on the mean microbial loads of Atlantic mackerel, it is expressed in 10^{-3} cfu/gm. The results showed that there were significant differences ($P<0.05$) in the mean bacterial count. The fish samples from Deep-frying with 0% Salt exhibited the highest mean bacterial count (25.8×10^{-3a} cfu/gm) followed by Air frying with 0% salt (19.4×10^{-3b} cfu/gm) while samples from Air frying with 5% salt ($10.8\text{x } 10^{-3bc}$ cfu/gm) and fresh samples ($11.3 \text{ x } 10^{-3c}$ cfu/gm) had the lowest mean bacterial count.

It was also observed that there was significant difference ($P<0.05$) across all samples in the mean fungi load, the highest overall mean fungi count was observed in the Air Frying+ 0% salt group (62.1×10^{-3a} cfu/gm) and the lowest was in Fresh + 0% salt group ($38.0\text{x } 10^{-3b}$ cfu/gm).

Table 1: Effects of frying Technique and Salt Treatment on the Mean bacteria and Fungi Loads of Atlantic Mackerel in 10^{-3} Cfu/gm

Treatments	Bacterial Counts	Fungi Counts
AIR FRYING + 0% SALT	19.4^{b}	62.1^{a}
AIR FRYING + 5% SALT	10.8^{c}	59.9^{a}
DEEP-FRYING + 0% SALT	25.8^{a}	44.0^{b}
DEEP-FRYING + 5% SALT	17.6^{b}	57.3^{a}
FRESH + 0% SALT	11.3^{c}	38.0^{b}
LSD	4.94	11.32

4.4 Effects of frying Technique, Salt Treatments and Storage Periods on the Mean bacteria and Fungi Loads of Atlantic Mackerel in 10^{-3} Cfu/g

From table 2 expressed in 10^{-3} cfu/gm the interaction between frying technique, salt, and storage period was observed to have a great influence on the microbial load of the samples.

At Day 0, it was observed that there was slight significant difference ($P < 0.05$) in the bacteria counts of samples. Bacteria count was low across samples with an exception of samples from Deep-frying + 0% Salt (11.7×10^{-3cd} cfu/gm) which had an increase above samples from Fresh + 0% salt (11.3×10^{-3cd} cfu/gm), the lowest bacterial count was found in Air frying + 5% salt (3.7×10^{-3d} cfu/gm). There was significant difference ($P < 0.05$) in the fungi count of samples, samples from group air frying + 0% salt (39.3×10^{-3def} cfu/gm) had the highest fungi count followed by fresh + 0% salt (38.0×10^{-3def} cfu/gm) with the least fungal count found in Air frying + 5% salt (17.7×10^{-3f} cfu/gm). (Table 2)

By Day 3 it was observed that there was significant difference ($P < 0.05$) in the bacteria counts of samples, samples from group Deep-frying + 5% salt (25.3×10^{-3b} cfu/gm) had the highest bacteria count and samples from Air frying + 5% Salt (8.7×10^{-3cd} cfu/gm) had the lowest bacteria count. There was also significant difference ($P < 0.05$) in the fungi counts of samples, samples from group air frying + 5% salt (74.0×10^{-3ab} cfu/gm) had the highest fungi count and samples from Deep-frying + 5% salt (44.7×10^{-3cde} cfu/gm) had the lowest fungi count.

By Day 6, there was significant difference ($P < 0.05$) in the bacteria counts of samples, samples from Air frying + 5% salt (46.0×10^{-3a} cfu/gm) had the highest bacteria count and samples from Air frying+ 0% salt (14.0×10^{-3c} cfu/gm) had the lowest bacteria count. There was also significant difference ($P < 0.05$) in the fungi counts of samples, samples from group

Air frying + 5% salt (94.7 x 10^{-3a} cfu/gm) had the highest fungi count and samples from Deep-frying + 5% salt (64.0 x10^{-3bc} cfu/gm) had the lowest fungi count.

It was observed that the bacteria and fungal counts of Fresh + 0% salt (11.3 x10^{-3cd} and 38.0 x 10-^{3def} cfu/gm) remained constant throughout the storage period of 6 days.

The least significant difference in bacteria count was 8.56 and in fungi count it was 19.62

Table 2: Effects of frying Technique, Salt Treatments and Storage Periods on the Mean bacteria and Fungi Loads of Atlantic Mackerel in 10^{-3} Cfu/gm

Storage Period	Treatments	Bacterial Counts	Fungi Counts
0	AIR FRYING + 0% SALT	8.0^{cd}	39.3^{def}
	AIR FRYING + 5% SALT	3.7^{d}	17.7^{f}
	DEEP-FRYING + 0% SALT	11.7^{cd}	35.3^{def}
	DEEP-FRYING + 5% SALT	2.3^{d}	23.3^{ef}
	FRESH + 0% SALT	11.3^{cd}	38.0^{def}
3	AIR FRYING + 0% SALT	10.3^{cd}	49.0^{cd}
	AIR FRYING + 5% SALT	8.7^{cd}	74.0^{ab}
	DEEP-FRYING + 0% SALT	14.0^{c}	50.0^{cd}
	DEEP-FRYING +5 % SALT	25.3^{b}	44.7^{cde}
	FRESH + 0% SALT	11.3^{cd}	38.0^{def}
6	AIR FRYING + 0% SALT	14.0^{c}	91.3^{a}
	AIR FRYING + 5% SALT	46.0^{a}	94.7^{a}
	DEEP-FRYING + 0% SALT	27.0^{b}	86.7^{a}
	DEEP-FRYING + 5% SALT	49.7^{a}	64.0^{bc}
	FRESH + 0% SALT	11.3^{cd}	38.0^{def}
	LSD	8.56	19.62

4.5 Total Percentage Frequency and Diversity of Microbes isolated from Samples During Storage Period

At Day 0, the bacterial isolates found in sample AD (0% salt deep fried) and CA (% Air fried) were *Proteus sp, Micrococcus sp, Staphylococcus epidermis and Bacillus subtilis,* in sample BD (5% salt deep fried) were *Proteus sp, Micrococcus sp and Bacillus subtilis,* in sample DA(5% deep fried) were *Proteus sp, Micrococcus sp, Staphylococcus epidermis and Staphylococcus aureus* and in FR (Fresh sample) *were Proteus sp, Micrococcus sp, Bacillus subtilis and Staphylococcus aureus.*

The total bacterial frequency of occurrence and percentage for day 0 was 19 and 50.1%, sample AD, CA, DA and FR was 4 and 21.0% respectively, sample BD was 3 and 15.18%. The total bacteria diversity was 4 and 21.1%, sample AD, CA and FR was 4 and 100% and sample BD and DA was 3 and 75% (Table 3).

The Fungal isolates present at day 0 in sample AD were *Aspergillus flavus, Penicillium sp, Pencillium oxalicum* and *Saccharomyces sp,* in sample BD were *Aspergillus flavus, Pencillium oxalicum, Mucor sp* and *Saccharomyces sp*, in sample CA were *Aspergillus flavus, Mucor sp* and *Saccharomyces sp,* in sample DA were *Aspergillus flavus, Penicillium sp and Mucor sp* and in sample FR were *Aspergillus flavus, Pencillium oxalicum, Mucor sp* and *Saccharomyces sp.*

The total fungi frequency of occurrence and percentage for day 0 was 19 and 50.1%, for sample AD and BD it was 4 and 21.0%, CA and DA was 3 and 15.8% and FR was 5 and 26.3%. The total fungal diversity was same as that of bacterial, Sample AD, CA and DA was 3 and 75% and BD and FR was 4 and 100% (Table 4).

After 3 days, sample AD had only two bacteria isolates present *Proteus sp, Micrococcus sp,* sample BD had *Proteus sp and Streptococcus sp,* sample CA and DA had *Proteus sp,*

Staphylococcus aureus and Streptococcus sp,

The total bacterial frequency of occurrence and percentage for day 3, reduced to 10 and 34.4%, for sample AD and BD it reduced to 2 and 20% and for CA and DA the bacterial frequency reduced to 3 each but there was an increase in frequency 30%. The total bacteria diversity remained 4 with bacteria % diversity increasing to 40%, The bacteria diversity and bacteria % diversity across samples AD, BD and DA reduced with only sample CA remaining constant (Table 3).

After 3 days of storage three new fungi isolates were noticed, *Aspergillus niger* was found in sample AD, BD and DA, *Mucor mucedo* was found in sample BD and CA and *Choanephora sp* was found in sample BD.

The Fungi percentage frequency increased to 65.3 %, the fungi diversity and percentage diversity increased to 5 and 55.6%.

After 6 days of storage two new bacteria isolates were noticed, Bacillus *cereus* was found in sample CA and DA and *Bacillus sp* in samples AD, BD and CA. The bacterial frequency and percentage frequency also increased to 14 and 46.6%. Sample CA had the highest bacteria frequency and percentage frequency 5 and 35.7% (Table 3). *Penicillium italicum* and *Cryptococcus neoformans* were found in samples BD, CA and DA. The fungi frequency and percentage frequency reduced to 16 and 53.4% while its diversity percentage diversity reduced to 31.3%

The results showed a reduction in microbial frequency across the storage days with an increase in microbial diversity and percentage diversity

TABLE 3: TOTAL PERCENTAGE FREQUENCY AND DIVERSITY OF BACTERIA ISOLATED FROM STORED AIR AND DEEP FRIED FISH SAMPLES

BACTERIAL ISOLATES	AFTER 0 DAY OF STORAGE							AFTER 3 DAYS OF STORAGE						AFTER 6 DAYS OF STORAGE					
	F	F(%)	AD	BD	CA	DA	FR	F	F(%)	AD	BD	CA	DA	F	F(%)	AD	BD	CA	DA
Proteus sp.	5	13.2	✓	✓	✓	✓	✓	4	13.8	✓	✓	✓	✓	4	13.3	✓	✓	✓	✓
Micrococcus sp.	5	13.2	✓	✓	✓	✓	✓	1	3.4	✓	x	x	x	4	13.3	✓	✓	✓	✓
Staphylococcus epidermis	3	7.9	✓	x	✓	✓	x	-	-	-	-	-	-	2	6.7	✓	x	✓	x
Bacillus subtilis	4	10.5	✓	✓	✓	x	✓	-	-	-	-	-	-	-	-	-	-	-	-
Staphylococcus aureus	2	5.3	x	x	x	✓	✓	2	6.9	x	x	✓	✓	-	-	-	-	-	-
Streptococcus sp.	-	-	-	-	-	-	-	3	10.3	x	✓	✓	✓	-	-	-	-	-	-
Bacillus cereus	-	-	-	-	-	-	-	-	-	-	-	-	-	1	3.3	x	x	✓	✓
Bacillus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	3	10	✓	✓	✓	x
Bacteria Frequency	19	-	4	3	4	4	4	10	-	2	2	3	3	14	-	4	3	5	2
Bacteria % Frequency	-	50.1	21.0	15.8	21.0	21.0	21.0	-	34.4	20	20	30	30	-	46.6	28.6	21.4	35.7	14.3
Bacteria Diversity	4	-	4	3	4	3	4	4	-	2	2	3	3	4	-	4	3	4	2
Bacteria % Diversity	-	21.1	100	75	100	75	100	-	40	50	50	75	75	-	28.6	100	75	100	50

TABLE 4: TOTAL PERCENTAGE FREQUENCY AND DIVERSITY OF FUNGI ISOLATED FROM STORED AIR AND DEEP FRIED FISH SAMPLES

FUNGI ISOLATES	AFTER 0 DAY OF STORAGE							AFTER 3 DAYS OF STORAGE						AFTER 6 DAYS OF STORAGE					
	F	F(%)	AD	BD	CA	DA	FR	F	F(%)	AD	BD	CA	DA	F	F(%)	AD	BD	CA	DA
Aspergillus flavus	5	13.2	✓	✓	✓	✓	✓	4	13.8	✓	✓	✓	✓	-	-	-	-	-	-
Aspergillus tamarii	1	2.6	x	x	x	x	x	1	3.4	x	x	x	✓	2	6.7	x	x	✓	✓
Penicillium sp.	2	5.3	✓	x	x	✓	x	1	3.4	✓	x	x	x	-	-	-	-	-	-
Penicillium oxalicum	3	7.9	✓	✓	x	x	✓	-	-	-	-	-	-	2	6.7	x	✓	✓	✓
Mucor sp.	3	7.9	x	✓	✓	x	✓	4	13.8	✓	✓	✓	✓	2	6.7	✓	x	✓	x
Saccharomyces sp.	5	13.2	✓	✓	✓	✓	✓	3	10.3	✓	x	✓	✓	4	13.3	✓	✓	✓	✓
Aspergillus niger	-	-	-	-	-	-	-	3	10.3	✓	✓	x	✓	1	3.3	x	✓	x	x
Mucor mucedo	-	-	-	-	-	-	-	2	6.9	x	✓	✓	x	1	3.3	x	✓	x	x
Choanephora sp.	-	-	-	-	-	-	-	1	3.4	x	✓	x	x	-	-	-	-	-	-
Penicillium italicum	-	-	-	-	-	-	-	-	-	-	-	-	-	2	6.7	x	x	✓	✓
Cryptococcus neoformans	-	-	-	-	-	-	-	-	-	-	-	-	-	2	6.7	x	✓	✓	✓

FUNGI ISOLATES	AFTER 0 DAY OF STORAGE							AFTER 3 DAYS OF STORAGE						AFTER 6 DAYS OF STORAGE					
Fungi Frequency	19	-	4	4	3	3	5	19	-	5	5	4	5	16	-	4	3	4	5
Fungi % Frequency	-	50.1	21.0	21.0	15.8	15.8	26.3	-	65.3	26.3	26.3	21.0	26.3	-	53.4	25	18.8	25	31.3
Fungi Diversity	4	-	3	4	3	3	4	5	-	4	3	3	3	5	-	3	2	3	4
Fungi % Diversity	-	21.7	75	100	75	75	100	-	55.6	80	60	60	60	-	31.3	60	40	60	80
Microbial Frequency	38	-	8	7	7	7	9	29	-	7	7	7	8	30	-	8	6	9	7
Microbial % Frequency	-	100.2	21.0	18.4	18.4	18.4	23.7	-	99.7	24.1	24.1	24.1	27.6	-	100	26.7	20	30	23.3
Microbial Diversity	8	-	7	7	7	6	8	9	-	6	5	6	6	9	-	7	5	7	6
Microbial % Diversity	-	21.1	87.5	87.5	87.5	75	100	-	31.0	66.7	55.6	66.7	66.7	-	30	77.8	55.6	77.8	66.7

F = FREQUENCY

F(%) = % FREQUENCY

AD = 0% SALT DEEP FRIED

BD = 5% SALT AIR FRIED

CA = 0% AIR FRIED

DA = 5% DEEP FRIED

FR = FRESH SAMPLE

CHAPTER FIVE

5.0 DISCUSSION

Microbial counts increased steadily from day 0 to day 6 across all treatments confirming that ambient temperature storage accelerates spoilage, the increase in bacteria and fungi loads during storage is attributed to the gradual breakdown of protective barriers and the availability of nutrients from lipid and protein degradation. This agrees with Okonko *et al.* (2020) who reported that the microbial load of fried samples increase progressively with storage duration reflecting the natural tendency of microbial populations to multiply once favourable conditions such as moisture and nutrient availability are present even after thermal processing.

On the sixth day, all samples showed microbial counts beyond the acceptable limits for ready-to-eat fish products, as specified by ICMSF (2011), which recommends $\leq 10^5$ CFU/g for safe consumption. This suggests that even with frying and salt treatment, ambient storage beyond four days poses safety concerns.

The incorporation of 5% salt significantly reduced the overall mean bacterial load compared to the 0% salt treatments, this showed that the addition of 5% salt was the most effective single factor for overall bacterial reduction, these effects can be attributed to the osmotic pressure created by salt, which draws out intracellular water and inhibits microbial metabolism. According to Adeyemi and Olufemi (2021), salting not only enhances flavour but also suppresses bacterial growth in fried fish by reducing water activity. Therefore, the combination of air frying with salt treatment yielded the lowest bacterial load and the best microbial stability during storage. The Deep-frying + 0% Salt group recorded the highest mean bacterial load and was significantly different from the other samples, indicating that deep-frying without a preservative created the most favorable environment for bacterial

multiplication over time.

While the addition of salt generally reduced the fungal loads, the effects was less noticeable than that observed for bacteria. Notably, the fungal loads in the air-fried treatments were consistently higher than those in the deep-fried treatments, hinting at a potential difference in the effectiveness of the two techniques in inactivating fungal spores.

Between the two frying methods, air-fried samples consistently exhibited lower bacterial counts than deep-fried samples across all storage days, Air frying applies hot air circulation that dehydrates the surface and reduces residual oil limiting microbial proliferation. Deep-frying however, retains more oil and moisture within the fish muscle creating an environment that supports microbial activity. This finding supports Adeyemi and Olufemi (2021), who reported that air-fried Tilapia had lower microbial load than deep-fried samples after three days of storage at ambient temperature.

Deep-frying treatments generally resulted in lower fungal counts compared to the air-fried treatments suggesting the hot oil contact may have been slightly more effective at fungal reduction. This agrees with the findings of Adeyeye and Oyewole (2016) which noted that Deep-fried fish nuggets recorded significantly lower yeast and mold counts indicating that deep-frying produces a more effective microbial and fungal load reduction due to higher surface temperatures.

Several bacterial species were isolated from the stored fried samples, the most frequently occurring genera included *Proteus sp., Micrococcus sp., Staphylococcus epidermidis, Bacillus subtilis, Staphylococcus aureus,* and *Bacillus cereus. Proteus* and *Micrococcus species* were among the earliest recontaminants observed after frying, especially in deep-fried samples. These bacteria are common environmental contaminants and can survive heat treatment through spores or post-processing exposure. *Staphylococcus aureus* and

Staphylococcus epidermidis are known to originate from human handling and poor post-frying hygiene, while *Bacillus cereus* and *Bacillus subtilis* are spore-forming bacteria capable of surviving high temperatures and proliferating once favourable conditions return (Olayemi *et al.,* 2019).

The prevalence of *Bacillus* and *Staphylococcus s*pecies agrees with the findings of Akinwumi *et al.* (2021), who isolated similar organisms from fried *Clarias gariepinus* and *Scomber scombrus* stored at room temperature. Their presence indicates the need for improved hygienic handling and temperature control after frying, as these organisms can produce toxins or cause spoilage when allowed to multiply.

Air frying + 0% salt had higher fungal counts compared to other samples in day 0 and in the other storage days Air frying + 5% salt had the highest fungal count. The most common fungi isolated included Aspergillus *flavus, Penicillium sp, Saccharomyces sp,* and *Mucor sp*. which are typical spoilage fungi in processed fish products (Omoruyi and Obasohan, 2024)). These fungi are known to cause discoloration, off-flavours, and textural deterioration during storage.

The rapid fungal growth could also contribute to rancidity and off-odours which are among the earliest sensory signs of spoilage in fried fish. Air frying delayed this effect compared to deep-frying because it produces a drier texture with less oil absorption, thus limiting the moisture that fungi need for growth (Adeoti and Afolabi, 2019). Nonetheless, by day six, both treatments showed significant microbial increase, indicating that the shelf life of the product was nearing its limit.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study examined the effects of Air frying and Deep-frying on the shelf life of Atlantic mackerel stored at ambient temperature, the results revealed that Air frying with the combination of salt had the best effect on bacteria reduction while deep-frying with salt combination had the best effect on fungi reduction, this shows that the combinations had varying antibacterial and antifungal effects respectively. According to the microbial frequency and diversity from each sample group it can be concluded that Air frying + 5% salt has a higher effect on microbial reduction due to the isolates found.

According to ICMSF (2011) standards, ready-to-eat fish products should not exceed 10^5 CFU/gm. While the counts here were still below that limit, the rapid increase indicates that the product was already deteriorating and may soon become unfit for consumption. This implies that regardless of frying method, fried Atlantic mackerel should be consumed within a short period if stored without refrigeration.

6.2 RECOMMENDATIONS

Based on the findings from this study, the following recommendations are suggested to improve fish preservation and ensure food safety:

1. Since both frying and salt application showed complementary antimicrobial effects, it is recommended that a combination of frying (preferably Air frying) with 5% salt

concentration be adopted to achieve optimal reduction of both bacterial and fungal contaminants in Atlantic mackerel.

2. For longer shelf life, combining air frying with improved storage methods such as vacuum sealing or refrigeration is strongly recommended.

REFERENCES

Abraha, B., Admassu, H., Mahmud, A., Tsighe, N., Shui, X.W. and Fang, Y. (2018). Effects of processing methods on nutritional and physico-chemical composition of fish: a review. *Journal of Food Processing and Technology*, **6**(4): 376-382.

Adekunle, O.T., Alabi, O.A. and Eniola, B.T. (2021). Post-harvest losses and preservation methods of catfish in Nigeria: Challenges and prospects. *African Journal of Food Science and Technology*, **12**(4): 112-123.

Adeoti, A.O. and Afolabi, O.O. (2019). Comparative study of deep-fried and air-fried mackerel stored at ambient conditions. *Journal of Food Safety and Preservation*, **43**(11):14121.

Adewumi, A.A. and Alabi, O.O. (2023). Air frying as an emerging healthy technique for fish processing: Nutritional and microbial implications. *International Journal of Food Science and Nutrition,* **8**(1):14–22.

Adewumi, A.A., Ayeloja, A.A. and Ogunsola, F.O. (2022). Comparative study of traditional and modern packaging methods on shelf life of processed catfish in southwestern Nigeria. *Nigerian Journal of Fisheries and Aquaculture*, **10**(2):35–44.

Adewuyi, G.O. and Omotosho, B.A. (2020). Comparative study of traditional and modern fish preservation techniques in Nigeria. *Journal of Aquatic Sciences*, **35**(1): 77-89.

Adeyemi, T.A. and Olufemi, O.T. (2021). Lipid oxidation and quality changes in fried fish during storage. *Nigerian Journal of Fisheries and Aquatic Sciences*, **12**(3): 45-57.

Adeyeye, S.A O. and Oyewole, O.B. (2016). Comparative effect of frying and baking on microbial load and sensory quality of fish nuggets. *African Journal of Food Science*, **10**(3):30**–**35.

Adeyeye, S.A.O. and Oyewole, O.B. (2022). Microbiological safety of processed fish products in Nigeria: Challenges and prospects. *African Journal of Food Science*, **16**(4): 92–101.

Aitken, A., O'Sullivan, M.G. and Kerry, J.P. (2021). Lipid oxidation in fish: Mechanisms, consequences, and control. *Comprehensive Reviews in Food Science and Food Safety*, **20**(1): 738–758

Ajani, E.K., Oladele, M.A. and Ojelabi, S.A. (2020). Effect of different packaging methods on the shelf life of smoked fish. *Journal of Fisheries Research*, **14**(2): 89-97.

Akinwumi, F.O. (2018). Evaluation of packaging materials for the storage of fried fish in Nigeria. *Journal of Postharvest Technology*, **3**(2): 45–52.

Akinwumi, F.O. and Adegbola, J.A. (2020). Post-harvest losses in Nigeria's fisheries sector: Challenges and solutions. *African Journal of Food Science and Technology*, **8**(4): 120-132.

Akinwumi, F.O., Adeyeye, S.A.O. and Akinwumi, B.C. (2021). Quality and safety of smoked fish: Current status and future perspectives. *Journal of Food Quality*, Article ID 8898763.

Arslan, M., Xiaobo, Z., Shi, J., Rakha, A., Hu, X., Zareef, M. and Basheer, S. (2018). Oil uptake by potato chips or french fries: a review. *European Journal of Lipid Science and Technology*, **120**(10):1800058.

Collette, B.B. and Nauen, C.E. (2023). FAO species catalogue. Vol. 2: Scombrids of the world. FAO Fisheries Synopsis No. 125. FAO, Rome.

Conell, J.J. (2019). Control of fish Quality. Fourth Edition, Fishing News Books. 44-46

Dehghannya, J. and Ngadi, M. (2021). Recent advances in microstructure characterization of fried foods: different frying techniques and process modeling. *Trends in Food Science and Technology*, **116**: 786-801.

Evivie, S.E., Ogundele, O.M. and Adedeji, O.M. (2020). Packaging and the Nigerian food industry: Challenges and opportunities. *International Journal of Food Studies*, **9**(2): 122–133.

Fabre, R., Dalzotto, G., Perlo, F., Bonato, P., Teira, G. and Tisocco, O. (2018). Cooking method effect on Warner-Bratzler sheer force of different beef muscles. *Meat Science*, **138**:10–14.

FAO (2021). Assessment of post-harvest losses in small-scale fisheries in Africa. FAO Fisheries and Aquaculture Technical Paper 500. Rome: Food and Agriculture Organization of the United Nations. 6-28.

FAO. (2020). The state of world fisheries and aquaculture 2020. Sustainability in action. Rome. 3-14.

Fawole, O.A., Ogundiran, M.A. and Ayandiran, T.A. (2018). Assessment of post-harvest losses and preservation techniques of fish in major fish markets in Ibadan, Nigeria. *Nigerian Journal of Fisheries and Aquaculture*, **6**(1):48–56.

Fawole, O.O., Adewumi, A.A. and Shittu, O.A. (2020). Effect of packaging methods on the microbial load and sensory attributes of fried fish during storage. *Nigerian Journal of Fisheries and Aquaculture*, **8**(2): 17–26.

Ferreira, F.S., Sampaio, G.R., Keller, L.M., Sawaya, A.C., Chávez, D.W., Torres, E.A. and Saldanha, T. (2017). Impact of air frying on cholesterol and fatty acids oxidation in sardines: protective effects of aromatic herbs. *Journal of Food Science*, **82**(12):2823-2831.

Food and Agriculture Organization (FAO) (2019). Handling of fish and fish products. Fisheries and Aquaculture Department, Rome. 1-8.

Ghaly, A.E., Dave, D., Budge, S. and Brooks, M.S. (2019). Fish spoilage mechanisms and preservation techniques: review. American Journal of Applied Sciences, 7(7):859

Ghidurus, M., Turtoi, M., Boskou, G., Niculita, P. and Stan, V. (2020). Nutritional and health aspects related to frying (I). *Romanian Biotechnological Letters*, **15**(6):5675-5682.

Hosseini, H., Ghorbani, M., Meshginfar, N. and Mahoonak, A.S. (2019). A Review on Frying: Procedure, Fat, Deterioration Progress and Health Hazards. *Journal of the American Oil Chemist s' Society*, **93**:445–466.

Ibrahim, S.A., Audu, B.S. and Olalekan, J.M. (2024). Effects of ambient temperature storage on microbial load of fried Clarias gariepinus packaged in different wraps. *Journal* of *Applied Agriculture and Agricultural Sciences* (JAAAS), **4**(1): 31–40.

ICMSF. (2011). Microorganisms in Foods 8: Use of Data for Assessing Process Control and Product Acceptance. Springer.

Joshy, C.G., Ratheesh, G., Ninan, G., Kumar, A. and Ravishankar, C. (2020). Optimizing air-frying process conditions for the development of healthy fish snack using response surface methodology under correlated observations. *Journal of Food Science and Technology*, **57**(7):2651–2658.

Karimi, S., Wawire, M. and Mathooko, F.M. (2018) Impact of frying practices and frying conditions on the quality and safety of frying oils used by street vendors and restaurants in Nairobi, Kenya. *Journal of Food Composition and Analysis*, **62**:239–244.

Kumar, Y., Yadav, D.N., Ahmad, T. and Narsaiah, K. (2020). Recent trends in the prevention of fish lipid oxidation and associated health implications. *Journal of Food Science and Technology*, **57**(12): 4473–4485.

Larsen, D., Quek, S.Y. and Eyres, L. (2010). Effect of cooking method on the fatty acid profile of New Zealand King Salmon (*Oncorhynchus tshawytscha*). *Food Chemistry*, **119**(2):785-790.

Last, P.R. and White, W.T. (2019). The biodiversity and biogeography of mackerels (*Scomber* spp.) in the Atlantic Ocean. *Journal of Fish Biology*, **95**(3): 645–660.

Mensah, A.K., Boateng, D.O. and Osei-Wusu, A. (2020). Comparative study on the shelf life of fried fish in polyethylene and aluminum packaging in Kumasi, Ghana. African *Journal of Food Science and Technology*, **11**(3):45–51.

Mohammed, A., Bala, J. and Musa, M.K. (2023). Performance evaluation of polypropylene film packaging materials for storage of dried fish in Nigeria. *Arid Zone Journal of Engineering*, *Technology and Environment*, **19**(3): 481–489.

NurSyahirah, S. and Rozzamri, A. (2022). Effects of frying on fish, fish products and frying oil – a review. *Food Research*, **6**(5): 14 - 32.

Nwosu, F.P., Adewale, O.T. and Oboh, C.B. (2022). Nutritional and preservation benefits of air frying in fish processing. *African Journal of Food and Nutrition*, **15**(1): 60-75.

Okonko, I.O., Ogunjobi, A. A. and Ogunnusi, T.A. (2020). Microbiological quality and safety evaluation of raw and processed fish from Ibadan markets. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, **9**(5): 1000–1011.

Okonkwo, C.N., Okechukwu, R.I. and Oladimeji, A.A. (2018). Post-harvest spoilage and preservation techniques of fish among artisanal fishermen in Nigeria. *Journal of Fisheries and Aquatic Studies*, **6**(4):56–61.

Olayemi, F.F., Akinyosoye, F.A. and Kolawole, O.O. (2019). Comparative study of drying methods on the quality attributes of African catfish (*Clarias gariepinus*). *Nigerian*

Food Journal, **37**(1): 55–63.

Olayemi, T.T., Adebayo, O.A. and Ige, S.A. (2019). Quality and storage stability of deep-fried and smoked fish. *International Journal of Food Science and Technology*, **25**(1): 72-85.

Oluwaniyi, M.A., Fagbenro, O.A. and Adedokun, R.A. (2020). Comparative study of vacuum and conventional packaging on the quality of fried fish during ambient storage. *Nigerian Journal of Fisheries Science*, **38**(2): 64–72

Omojola, A.B., Adegbite, D.A. and Alade, O.A. (2019). Economic implications of fish spoilage in Nigeria: The need for improved preservation techniques. *Nigerian Journal of Agricultural Economics*, **14**(1):67-79.

Omojola, A.B., Oladimeji, Y.U. and Olatunde, O.O. (2019). Traditional fish preservation methods in Nigeria: Effectiveness and challenges. *Journal of Aquatic Sciences*, **34**(3): 112–124.

Omoruyi, K. and Obasohan, O.A. (2024). Effects of spring onion (*Allium fistulosum*) and turmeric (*Curcuma longa*) marinade. *Journal of Agriculture and Environment*, **20**(1): 277- 290

Onwuka, G.I. (2018). Food microbiology and preservation. Lagos: *Naphtali Print*s. 110-115.

Özogul, F. and Hamed, I. (2019). The importance of biogenic amines in seafood: Occurrence, effects and control. *Trends in Food Science and Technology*, **86**:146–155.

Saliu, J.K. (2018). Effect of smoking and frozen storage on the nutrient composition of some Africa fish. *Advanced Natural Applied Science*, **2**(1): 1620.

Shabbir, M.A., Raza, A., Anjum, F.M., Khan, M.R. and Suleria H.A. (2019) Effect of thermal treatment on meat proteins with special reference to heterocyclic aromatic amines (HAAs). *Critical Reviews in Food Science and Nutrition*, **55**(1):82–93

Shulgina, L.V., Davletshina, T.A., Pavlovsky, A.M., Solodova, E.A. and Pavel, K.G. (2019). Composition of lipids and fatty acids in muscle tissue of chub mackerel *Scomber japonicus*. *Izvestiya Tinro*. **196**:93–203.

Song, G., Li, L., Wang, H., Zhang, M., Yu, X., Wang, J., Xue, J. and Shen, Q. (2020). Real-time assessing the lipid oxidation of prawn (*Litopenaeus vannamei*) during air-frying by iKnife coupling rapid evaporative ionization mass spectrometry. *Food Control*, **111**: 107066.

Tian, J., Chen, S., Shi, J., Chen, J., Liu, D., Cai, Y., Ogawa, Y. and Ye, X. (2017). Microstructure and digestibility of potato strips produced by conventional frying and air-frying: an in vitro study. *Food Structure*,14:30-35.

Udo, P. J., Oboh, G. and Ogunlade, I. (2024). Biochemical and microbial spoilage indicators in stored mackerel (*Scomber scombrus*) under different storage conditions. *Journal of Food Microbiology and Safety*, **12**(1): 1–11.

Ukoha, P.O., Nwogu, N.A., and Okorie, C.A. (2021). Effect of packaging method on the microbial stability of fried *Clarias gariepinus*. *African Journal of Food Processing and Preservation*, **13**(2):112–119.

Uzeh, R.E. and Akinyele, I.O. (2013). Coliform contamination of smoked fish in Lagos. *Nigerian Journal of Microbiology*, **27**(1): 2170–2177.

Vieira, E.C.S., Márcico, E.T., Conte-Junior, C.A., Damiani, C., Canto, A.C.V.D.C.S., Monteiro, M.L.G. and Silva, F.A.D. (2018). Effects of different frying techniques on the color, fatty acid profile, and lipid oxidation of *Arapaima gigas. Journal of Food Processing and Preservation,* **42**(11): 13820.

Yu, X., Li, L., Xue, J., Wang, J., Song, G., Zhang, Y. and Shen, Q. (2020). Effect of air-frying conditions on the quality attributes and lipidomic characteristics of surimi during processing. *Innovative Food Science and Emerging Technologies*, **60**: 102305. Yusuf, K.A., Adeyemi, R. O. and Olanrewaju, A.T. (2020). Challenges of fish storage in Nigerian coastal communities. *African Journal of Fisheries and Aquatic Resources*, **6**(1): 20–28.

Zaghi, A.N., Barbalho, S.M., Guiguer, E.L and Otoboni, A.M. (2019). Frying Process : From Conventional to Air Frying Technology. *Food Reviews International*, **35**: 763–777.

Zhang, X., Zhang, M. and Adhikari, B. (2020). Recent developments in frying technologies applied to fresh foods. *Trends in Food Science and Technology*, **98**:68-81.