

**INFLUENCE OF SEASONAL VARIATION AND PROCESSING ON
PROXIMATE COMPOSITION AND OIL QUALITY OF *LETHRINOPS*
GOSSEI (CHISAWASAWA) FISH FROM LAKE MALAWI**

MASTER OF SCIENCE IN FOOD SCIENCE THESIS

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UNIVERSITY OF MALAWI

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MSc. (FOOD SCIENCE) THESIS

By

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Submitted to the School of Natural and Applied Sciences in partial fulfilment of the
requirements for the degree of Master of Science in Food Science

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September, 2024

DECLARATION

I, Mayeso Sabola Kachingwe, declare that this thesis represents my original contribution, submitted to the University of Malawi, School of Natural and Applied Sciences, Department of Human Ecology and Agricultural Sciences. I confirm that none of its content has been previously submitted for any academic qualification at the University of Malawi or elsewhere. Proper acknowledgments have been made for any external sources used in this work.

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CERTIFICATE OF APPROVAL

We, the undersigned, certify that this thesis is the result of the author's work and that, to the best of our knowledge, it has not been submitted for any other academic qualification at the University of Malawi or elsewhere. It has been submitted with our approval.

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DEDICATION

To God almighty be all the glory. To my beloved late dad, Mr. Sabola Kachingwe, my late mom, Mary Julius, my uncle, Mr. John Kalepa, and my brothers and sisters. You remain dear to me for your wonderful support and patience. To my dearest friends, Catriona Price, Glenys Hughes, and the entire board of trustees of the Malawi Music Fund (MMF), your undisputable love, sacrifice, encouragement, and faith in me throughout my academic journey have been the driving force that has ultimately led to this end.

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ABSTRACT

Fish provides high-quality protein, omega-3 fatty acids, and essential vitamins and minerals crucial for human health. This study evaluated the effects of seasonal variation and processing methods on the proximate and mineral composition, and fat quality of *L. gossei* fish species from Lake Malawi, using the AOAC and Wijis' methods for iodine value (IV) determination. Results from one-way ANOVA revealed the highest ash ($18.72 \pm 1.20\%$) and protein ($12.62 \pm 0.21\%$) levels during the hot-dry season. Fat content (FC) was highest during the rainy season ($28.80 \pm 2.01\%$) and the hot-dry season ($27.87 \pm 3.23\%$). However, the cold season exhibited significantly lower FC ($12.17 \pm 2.02\%$). The IV was higher in hot-dry season (238.48 ± 2.36 gI₂/100 g) compared to cold (153.62 ± 3.21 gI₂/100g) and rainy seasons (165.01 ± 2.30 gI₂/100 g). Female *L. gossei* had highest fat ($36.08 \pm 0.20\%$) and polyunsaturated fatty acids (259.91 ± 0.10 gI₂/100g) than males during rainy and hot-dry seasons. Mineral content was also highest in the hot-dry season. Processing methods like solar drying increased ash ($20.98 \pm 2.81\%$) and fat content ($27.50 \pm 8.62\%$) while smoking increased protein content ($33.60 \pm 2.02\%$) than boiling and solar drying. However, boiling and solar-drying significantly increased IV (182.67 ± 3.90 gI₂/100g) and (164.32 ± 3.50 gI₂/100g) respectively, compared to smoking (144.95 ± 2.01 gI₂/100g). Therefore, *L. gossei* is most nutritious when harvested in the hot-dry and rainy seasons, with solar drying retaining minerals and IV, and smoking enhancing protein content.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorbance Spectrophotometry
AOAC	Association of Officiating Analytical Chemists
DHA	Docosahexaenoic acid
DRI	Dietary Recommended Intake
EPA	Eicosapentaenoic acid
FAO	Food and Agriculture Organisation of the United Nations
IV	Iodine Value
LCPUFAs	Long-chain polyunsaturated fatty acids
MC	Moisture Content
MUFA	Monounsaturated fatty acids
n-3	Omega 3
NCDs	non-communicable diseases
PCM	Protein-calorie malnutrition
PUFA	Polyunsaturated fatty acids
PUFAs	Polyunsaturated fatty acids
SADC	Southern African Development Community
SEA	South East Arm
IBM-SPSS Sciences	International Business Machines - Statistical Package for the Social Sciences
WHO	World Health Organization

DEFINITION OF TERMS AS USED IN THIS DISSERTATION

<i>L. gossei</i>	<i>Lethrinops gossei</i> (Gosse's Haplo), a cichlid species from Lake Malawi
Ash	Measure of the total mineral content of food material
Hidden hunger	Lack of essential micronutrients
Iodine value	Indicator of the degree of unsaturation in fats and oils
Vessel	Ship/boat used to catch fish from the water body
Platoon	Group of different fish species

CHAPTER 1

INTRODUCTION

This chapter introduces the structure of the dissertation and provides relevant background information leading to the problem statement and significance of the study. The objectives and hypotheses of the study are also presented in this chapter.

1.0 Organization of the Dissertation

To ensure a logical flow of information, from identifying the research problem to analyzing results and formulating conclusions, this thesis has been structured into several key chapters, each addressing different aspects. Chapter One introduces the study by outlining its background and significance. Emphasis has been placed on the nutritional importance of fish, specifically *Lethrinops gossei* from Lake Malawi. It also presents the problem statement, research objectives, and hypotheses. Chapter Two, the literature review, examines relevant literature on fish nutrition, seasonal and sex variation, and the impact of processing techniques on the nutrient composition of this species. Chapter Three, the materials and methods, details the experimental design, sampling techniques, and analytical methods used to assess the proximate composition, mineral content, and fat quality of *L. gossei* across different seasons, sexes, and processing methods. Chapter Four

the results and discussion, presents and analyzes the study's results, focusing on how seasonal variation, sex, and processing techniques influence the nutritional quality of *L. gossei*. Finally, Chapter Five, the conclusion and recommendations, summarizes the key findings, discusses their implications for fish processing, consumption, and nutritional optimization, and offers recommendations for stakeholders, including processors, fishermen, and consumers. It also provides suggestions for future research.

1.1 Background Information

Fish is one of the nutritionally dense foods and a great source of essential nutrients that play a significant role in numerous biological processes in the body (Zhang, et al., 2020; Calviello & Serini, 2010). It is composed of the following nutrient ranges; 70–84% water, 15–24% protein, 0.1-22% fat, and 1–2% minerals (Abraha, et al., 2018). Fish is also considered a cheap source of animal protein and other essential vitamins and fatty acids (FAs) including n-3 polyunsaturated fatty acids (PUFAs) and fat-soluble vitamins needed by the body for most developing countries (Fallah, Nematollahi, & Saei-Dehkordi, 2013). According to Jangampali (2019), fish is rich in high-quality protein, which supports muscle development and overall growth, especially in children and individuals suffering from protein deficiency. Fish also contains omega-3 fatty acids such as EPA and DHA, which have been linked to reducing the risk of cardiovascular diseases, improving brain function, and supporting mental health. Additionally, fish is a key source of micronutrients like iodine, which is crucial for thyroid function, and selenium, which acts

as an antioxidant. These nutrients help to contribute to reducing malnutrition and lower the risk of NCDs such as heart disease, diabetes, and obesity (Jangampalli, 2019; Kaimila, et al., 2019). Fish plays a big role in enhancing the food and nutrition security of most developing countries including Malawi, as it provides Malawians with over 70% of their dietary animal protein with 40% total protein supply (FAO, 2023).

Over 400 million people in Africa, consume fish as their most important source of protein (Nankwenya, Kaunda, & Chimatiro, 2017). Among the several freshwater lakes in Africa, Lake Malawi reportedly has over 1,000 fish species, with over 90% being endemic to the lake, contributing to majority of the fish catch in the country (Environmental Affairs Department, 2010). The majority of the fish caught from Lake Malawi is consumed domestically (FAO, 2020). The commonly caught and consumed fish species include but are not limited to Utaka (*Copadichromis*, *Otopharynx*), Kampango (*Bagrus meridionalis*) Mbuna (*Tropheus*, *Petrotilapia*), Mcheni (*Rhamphochromis species*), Chambo (*Oreochromis sp.*), Mlamba (*Clarias gariepinus*), Matemba (*Barbus paludinosus*), Usipa (*Engraulicypris Sardella*) and Chisawasawa (*Lethrinops gossei*) (Bulirani, et al., 2018). The species of interest in this study is *L. gossei*, locally known as Chisawasawa. This demersal freshwater fish species is gaining popularity in Malawi because of its commercial value, commonly consumed species, a major contribution to the deeper fish catches of the lake (Changadeya, Ambali, & Malekano, 2004; Kaunda, Kassam, & Msukwa, 2011). In addition, fish processors and regular consumers have orally reported observable fat content variations among and

among fishing seasons along Lake Malawi's Southern East Arm (SEA), hence attracting the interest of researchers. Further studies done elsewhere have also reported seasonal and sex variability not only in fat composition in fish but also its proximate composition (Antonio, et al., 2020; El, et al., 2019). Similar findings were also reported by (Chetoui, Darej, & Moujahed, 2019) in their study on the impact of season and sex variations on the total lipid contents and fatty acid composition of *scomber scombrus* fillets from the Middle East Coast of Tunisia. However, little to no information to the author's knowledge is known about such seasonal variability and the impact of thermal processing techniques on the nutrient composition of the fish caught from Lake Malawi.

The perishability of fish attracts different thermal processing techniques by consumers and fishermen to enhance the fish's quality in terms of storability, palatability, and nutrient bioavailability (García-Arias, et al., 2003). Some of the most common fish processing methods include: boiling, smoking, salting, freezing, solar or sun-drying, filleting, and frying. These processes have been reported to alter the fish's nutritional composition in different fish species (Kiczorowska, et al., 2011). For instance, Smida. Et al., (2014) reported that solar drying affects the protein quality since the drying process removes the moisture that is trapped inside protein hence promoting protein degradation. Further, the exposure of the fish to sunlight for long periods, promotes lipid oxidation hence, affecting the PUFA quality Tenyang, et al. (2017).

Although the processing or cooking methods influence different fish species' proximate composition and fat quality (Aydın, et al., 2011), the questions regarding which optimal season, processing technique, and sex to consume fish for maximum fish nutritional benefits remain unanswered, especially for fish species caught from Lake Malawi. In addition, a scientific study on the simultaneous impact of various processing techniques, sex, and season variability on the fish's oil quality, and proximate and mineral composition has not been thoroughly conducted in Malawi. Therefore, this study aims to investigate the effects of seasonal changes and different processing techniques on proximate and mineral composition, and fat quality. The study will also examine the effect of sex differences on the same parameters.

1.2 Problem statement

Seasonal variation has been reported to affect the fish's nutritional composition and its nutritional quality (Ntzimani , et al., 2022). Fishermen processing *L. gosseii* in the Southern part of Lake Malawi, have long observed changes in fat contents of this species in different seasons. However, it is not known whether these changes are only in fat quantities, or they also affect fat quality of this fish species. Further information on how seasonal variation, processing techniques, and sex affect the proximate and mineral composition of different fish species in Lake Malawi including *L. gosseii* is scanty. In addition, this species is among those that are mainly consumed and utilized after processing to extend its shelf life, improve palatability, and reduce quality loss.

Therefore, it is also important to study the effect of different processing techniques such as boiling, smoking, and solar-drying used by the fish processors in Malawi on the proximate and mineral composition, and fat quality.

1.3 Significance of the study

This study will help provide scientific evidence of the observed changes in the fat content of *L. gossei* by fishermen by indicating if the changes are indeed just in quantities of fats or even in the quality of the fats across the three fishing seasons. Thus, for the latter, the study will also reveal the degree of unsaturation of this fish's oil across seasons, between sexes, and after processing by determining their IV as an indicator of oil saturation. Information on proximate and mineral composition across the seasons will help inform not only the consumers but also the fishermen and fish processors to make informed decisions on when to consume, catch, and process *L. gossei* for increased nutritional and health benefits. Such information is necessary to advocate fish catching for such components to be useful for nutritional, processing, and food product development purposes. The fish fat quality data can also be useful to food scientists and nutritionists to develop dietary formulations for different food products that offer beyond basic nutritional importance (Muhamad & Mohamad, 2012). The optimization of fish oil extraction and utilization of essential PUFAS like omega-3 can also be considered for the fortification of baby food products and processing them into nutritional supplements to increase the intake of PUFAs.

Further, in terms of processing techniques, the study's findings will provide information to guide processors to explore and employ processing and storage techniques bearing in mind that PUFAs degrade at a lower moisture content and can easily undergo oxidation reactions and lose quality (Mgwede & Banda, 2018; Secci & Parisi, 2016).

1.4 Objectives of the Study

1.4.1 Main Objective

The main objective was to assess the impact of seasonal variations, sex, and processing techniques on the proximate and mineral composition, and fat quality of *Lethrinops gossei*.

1.4.2 Specific Objectives

The specific objectives were to:

- i. Determine proximate and mineral composition, and iodine value of raw *Lethrinops gossei* fish species in different seasons.
- ii. Analyse proximate and mineral composition, and iodine value of processed *Lethrinops gossei* fish using different techniques.
- iii. Compare proximate and mineral composition, and iodine value of male and female *Lethrinops gossei* fish species caught in different in different seasons.

1.5 Research hypotheses

- i. Seasonal variation does not affect the proximate and mineral composition, and oil quality of *L. gossei* fish species from Lake Malawi in all fishing seasons
- ii. The processing techniques do not affect the proximate and mineral composition, and fat quality of the *L. gossei* fish from Lake Malawi.
- iii. Sex does not affect the proximate and mineral composition, and fat quality of the *L. gossei* fish from Lake Malawi.

This chapter has introduced the structure of the dissertation and provides relevant background information, including the significance of the study on *L. gossei*, a commercially important fish species from Lake Malawi. It has outlined the research problem, objectives, and hypotheses, which focus on assessing the impact of seasonal variations, sex differences, and processing techniques on the nutritional quality of this fish species. Additionally, the chapter has discussed the importance of fish as a key nutritional resource in Malawi, setting the foundation for the research presented in subsequent chapters.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the previous work on variations in processing techniques, proximate composition, and iodine value of fish. The literature has been arranged in four sub-sections including different fish species from Lake Malawi, fish nutrient and mineral composition, seasonal variations in proximate composition, and fish processing and preservation.

2.0 Fish as a source of essential nutrients

Global fish production is estimated to reach 194 million tons by 2026 from 175 million tons recorded in 2017 (Välilmaa, et al., 2019). According to (FAO, 2020), about 156.4 million tons of fish are consumed by humans and the value keeps on increasing due to a higher demand for high-quality fish and its products for nutrition and health benefits

(Shukla, et al., 2018). Fish contains diverse macro and micronutrients that are key in addressing dietary needs for the majority of the population in developing countries where over 400 million people consume fish as their source of essential nutrients (Abraha, et al., 2018; Rasul, et al., 2021).

For countless generations, fish has been an important component of the diets of most communities in developing nations including some African countries where over 400 million people consume fish as their source of essential nutrients (Rasul, et al., 2021). Different studies have reported that fish is the most economical source of essential nutrients, including fat-soluble vitamins, amino acids, and EPUFAs like n-3, which are crucial for various biological processes in the body. Additionally, fish tends to be more easily digestible (Zhang, et al., 2020; Ghosh, et al., 2018). Due to the increase in prices of terrestrial animal protein-based foods, there is a growing demand for cheaper protein-rich foods that provide essential nutrients in developing countries including Malawi (Ghosh, Pal, Das, & Barik, 2018).

2.1 Fish in Lake Malawi

According to the Environmental Affairs Department, 2010, the majority of fish consumed in Malawi is sourced from Lake Malawi, the largest lake in the country (Environmental Affairs Department, 2010). Lake Malawi has over 1,000 species of fish, of which over 90% are endemic to the Lake hence contributing significantly to the country's fish catch. The lake has different types of fish species that include but are not limited to Utaka (*Copadichromis*, *Otopharynx*), Kampango (*Bagrus meridionalis*) Mbuna (*Tropheus*, *Petrotilapia*), Mcheni (*Rhamphochromis species*), Chambo (*Oreochromis sp.*), Mlamba

(*Clarias gariepinus*), Matemba (*Barbus paludinosus*), Usipa (*Engraulicypris Sardella*) and Chisawasawa (*Lethrinops gossei*) (Bulirani, Kaunda, Likongwe, Turner, & Olaf, 2018). Apart from providing nutritional benefits for over 11.9 million people, these fish species act as a domain for fish-related income activities to over 90% of the households living in developing countries with the majority of people directly depending on fish as the main source of animal protein and micro-nutrients (Bene, et al., 2016). The *L. gossei* fish species is one of the species commonly consumed domestically and contributes to the food and nutrition security of most people in Malawi (FAO, 2020; Kaimila, et al., 2019). However, little has been studied regarding proximate, mineral composition, or fat quality.

2.2 Nutrient and Mineral Composition of Fish

The fish's proximate composition is typically composed of the fresh body's estimated moisture content, protein, fat, and ash (Azim, Islam, Hossain, & Minar, 2012). These constituents account for approximately 96–98% of the total tissue composition in fish except carbohydrates and non-protein compounds because they are found in minimal quantities and hence not included especially when fish nutrient reporting (Ghadikolaei, Kamali, Soltani, & Sharifian, 2017). Fish constitute water (66%–81%), protein (16%–21%), minerals (1.2%–1.5%), fat (0.2%–25%) fat, and carbohydrates (0%–0.5%) (Boran & Karaçam, 2011; Mridha, et al., 2005). These compositions of fish have been reported with wide variation between species and even within the same species due to several factors. As such, it is critical to study variations in fish nutrient composition to

inform consumers, food processors, nutritionists, cooks, and the fisheries industry on when and how to catch and process fish for various purposes, respectively (Azim, Islam, Hossain, & Minar, 2012). Similar studies have been done before in India, Iran, and Turkey but the emphasis has been on a particular body part or organ of a fish such as fish muscle, viscera, or whole small fish species (Ahmed, et al., 2022; Fallah, Nematollahi, & Saei-Dehkordi, 2013; Görgün & Akpinar, 2009). Additionally, the findings of these studies cannot be applied to Malawian fish species hence necessitating the need to focus on the variation of nutrient composition in a whole medium-sized fish commonly consumed in the southern part of Lake Malawi to add to the current literature (FAO, 2020; McKaye & Stauffer, 1956).

Different authors in their studies have reported the variation in fish nutrient composition of various fish species being influenced by factors including food composition and feeding habits, feeding rate, season, age, sex, and size (Ahmed, Ahmed, Ebrahim, & Adm, 2017; Alas, Ozcan, & Harmankaya, 2014). These studies revealed that fish in the dry season have less moisture content (4.26%) than in the wet season (5.63%). Whereas, ash content was higher in the dry than wet seasons at 6.10% and 4.66% respectively. The protein was higher (64.47%) in the wet season than in the dry one (63.10%). Fat content slightly varied between the dry (4.03%) and wet (4.09%) seasons within the same species. According to (Alves, et al., 2016; Ng, Chew, & Chong, 2015), the fat, ash, and protein content were higher in Nile *tilapia* supplied with diets containing animal and plant by-products than those not fed this type of feed. Similarly, (Durmuş, et al., 2017; Kulcu, 2014) revealed that season and sex affect the mineral, protein, fat, moisture, and

ash content of red mullet (*Mullus barbatus Linnaeus 1758*) caught from the Middle Black Sea and North-eastern Mediterranean Sea. Their study reported that Na was higher (265.00 mg/100g) in females than in males (100.95 mg/100g) during the hot-dry season yet the same female fish reported the highest (58.93 mg/100g) Mg in the rainy season followed by hot-dry season and the lowest in the rainy season, unlike the males. As much as these factors have been reported to affect fish's proximate composition, the information on how and to what extent this applies to other Malawian fish species like *L. gossei* has not been documented.

2.2.1 Moisture content as an indicator of fat content in fish

The moisture content (MC) of fish is of significant importance since it is related to the fish fat content. It is used to predict the concentration of other nutrients including protein, calories, and fat content (Ahmed, et al., 2022). For instance, those with decreased MC are associated with higher fat, protein, and caloric densities putting other factors constant (Barua, et al., 2012). Among other internal and external factors that have a big role to play in determining the nutrient content, season variation has considerably been reported to affect the levels of these nutrients (Ahmed, Jan, Fatma, & Dawood, 2022). As such, determining the MC of *L. gossei* is important as it affects nutrient levels, especially bioactive compounds like EPUFAs, which are higher in fish with lower MC and beneficial for addressing NCDs as reported by (Kaur, Chugh, & Gupta, 2012; AlAmmar, et al., 2021; Kokubun, Nemoto, & Yamakawa, 2020).

2.2.2 *Proteins*

Apart from the MC, Tocher (2003) reported that proteins are major organic constituents suppressing carbohydrates, vitamins, and other inorganic elements in fish. Fish contains about 20% proteins, which is a dominant macronutrient, hence a main protein source for over 60% of people from developing countries and helps to fight against protein-calorie malnutrition (PCM) (Sujatha, Joice, & Kumar, 2013; Mohanty, et al., 2019). Fish muscle is more digestible and its nutrients are easily absorbable compared to other animal proteins as it has lower connective tissue and collagen fibre found in animal meats hence it provides greater satiety (Balami, Sharma, & Karn, 2019; FAO, 2020).

Fish and fishery products are the third most important sources of protein with a significant proportion of essential amino acids after cereals and milk (FAOa, 2020). Fish intake accounts for 17.1%-20% of the high-quality total animal protein supply, which is higher in essential amino acids than what terrestrial meat products can supply (FAOa, 2020; Tacon, Lemos, & Metian, 2020). Over 22% of total animal protein intake in sub-Saharan Africa comes from fish, with about 60% of people in many developing nations relying on fish for over 30% of their animal protein sources (Akpambang, 2015; Mishra, 2020). Apart from the nutritional reasons for such trends, affordability contributes to such consumption. The production unit cost of fish as a protein source is cheaper as compared to other dietary protein sources like chicken, mutton, pork, and beef, to list a few (Mishra, 2020). As one of the few foodstuffs rich in protein, fish contains all the important amino acids that the body needs in the correct proportion, making it a complete protein

(Geremew, Abdisa, & Goshu, 2020). This protein plays various important roles in the human body, including functioning as enzymes, hormones, transport proteins, and antibodies that the living cells need for biological body processes. Additionally, fish is essential for the development, maintenance, and repair of muscles, tissues, and organs of the human body as reported by Geremew, Abdisa, and Goshu (2020).

Fish is reported to be rich in essential amino acids such as lysine and methionine though low in tryptophan but it is available in a matrix with a higher degree of digestibility than any other mammalian protein (Ahmed, Jan, Fatma, & Dawood, 2022; Begum, Akter, & Minar, 2012). These fish protein concentrations have been linked to health-beneficial effects. Fish consumption is linked to a reduction in the risk of cancer because the protein composition of the chemical taurine is found in significant concentrations in fish (Välímaa, et al., 2019). Taurine inhibits the synthesis of tumor necrosis factor α (TNF α) responsible for cancer development, the pro-inflammatory interleukin-6 (IL6) and interleukin-1 β (IL-1 β) which are responsible for the prevention of inflammation (Välímaa, et al., 2019). Therefore, some amino acids and taurine found in fish exhibit the potential to address anti-inflammatory issues similar to long-chain n-3 PUFA (Tilami & Sampels, 2018). However, as it stands, there is limited information on the quantification of the protein in *L. gossei* despite it being a great contributor to catch in the southern east arm fish species (FAO, 2022).

2.2.3 *Fats*

Fish is a primary source of omega-3 fatty acids for humans due to their consumption of algae that are rich in Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA) which are long-chain omega-3 fatty acids primarily found in fatty fish and seafood (Mateusz, Monika, & Michał, 2021). The significance of fish lipids is well-known because of the composition of the polyunsaturated fat content of the long-chain n-3 polyunsaturated fatty acids (n-3 PUFA) whose Eicosapentaenoic Acid (EPA, 20:5 n-3) and Docosahexaenoic Acid (DHA, 22:6 n-3), these fatty acids play significant roles in human nutrition, health and disease prevention, contributing to optimal brain and neurodevelopment in children and improving cardiovascular health (Ahmed, et al., 2017; Sujatha, Joice, & Kumaar, 2013; Abraha, et al., 2018). To experience these health benefits, one must reach the daily recommended intake EPA of 0.5g for omega-3, regardless of the source (Mateusz, Monika, & Michał, 2021). Since humans cannot convert ALA to EPA and DHA at a rate sufficient to meet their fundamental biochemical requirements, these molecules are provided from the diet (Brennan, 2020). Achieving this daily recommended intake of EPAs, particularly omega-3 is crucial for earning these health benefits. However, it can be challenging, especially without knowledge of the season when fish accumulate more beneficial components or the processing techniques that retain them. The functionality of these EPUFAs in the body can be rendered when fish are consumed directly, when supplemented to the diet, or when extracted and fortified to other foods (Calviello & Serini, 2010).

However, the degree of unsaturation of fat reflecting the fatty acid composition in certain fish species like *L. gosseii* remains understudied. To bridge such a gap, the determination of the impact of the seasonal variation and the processing techniques on EPUFA accumulation cannot be emphasized. Studies on different fish species have reported that omega 3 series (DHA and EPA) and omega 6 are the most important long-chain PUFAs found in abundance in fish species such as *Oreochromis mossambicus*, *Clarias gariepinus*, and *Cyprinus carpio* and that they vary with season variation (Mateusz, Monika, & Michał, 2021). This information is not available for the common *L. gosseii* from Malawi hence the study will generate new information that will add to the present literature.

2.2.4 Minerals and vitamins

Fish is a valuable source of micronutrients crucial for human health, particularly in populations with limited dietary options like Malawi. Abraha, et al. (2018), reported that fish contains almost all of the minerals found in seawater, with values ranging from 1 to 2%. Iron, calcium, zinc, phosphorus, selenium and iodine are among the minerals found in fish that are more bioavailable than in terrestrial animal food sources (Jag et al., 2018). These micronutrients are reported as total ash, inorganic residue obtained after the whole organic matter has been burnt. Ash content is an indicator of mineral composition and in fish, it ranges from 0.5% to 5% of the total body weight of fish (Adewumi et al., 2014). The fish mineral content has been directly linked to the regulation of acid-base balance in the body when consumed (Ayanda, Ekhaton, & Bello, 2019). Minerals in fish also help

form haemoglobin and are involved in catalysing metabolic reactions, controlling water balance, and helping in the formation and strengthening of bones (Mendil, et al., 2010). Additionally, minerals help prevent deficiencies associated with cardiovascular disease, cancer, and impaired thyroid function (Schweigert, et al., 2016). As such, fish can be an alternative means of preventing micronutrient deficiencies such as iron, zinc, calcium, selenium, and magnesium in most developing countries (Maire, et al., 2021). For such health benefits to be appreciated, proper timing on the season to catch fish species like *L. gosseii* and its processing techniques should be considered, of which according to the author's knowledge, such information is limited.

2.3 Seasonal variations in Proximate composition of fish

Seasonal variations of the proximate composition of fish have been well-documented by different researchers (Ali , et al., 2013; Azim, et al., 2012; Boran & Karaçam, 2011; Adelakun, et al., 2017). Such changes in biochemical composition have been reported to happen within and between fish species have been reported by (Zlatanov & Laskaridis, 2007; Houssain & et al., 2019; Ali , et al., 2013; Boran & Karaçam, 2011; Tufan, Koral, & Kose, 2011). The proximate composition of catfish (*Clarias gariepinus*) from Upper Jebba Basin, Nigeria significantly varied with season. The moisture content was 4.26% and 5.63% in the dry and wet seasons respectively. Similarly, ash content significantly varied between the dry and wet seasons, with differences of 6.10% and 4.66% respectively. The crude protein and fat content were slightly higher in the rainy season at 64.47% compared to 63.10% in the dry season and 4.03% and 4.09% for dry and wet

seasons (Adelakun et al., 2017). A similar observation was made in Sobaity sea bream (*Sparidentexhasta*) reported from Kuwait waters in the study by (Houssain & et al., 2019). In Portugal, studies on two unexploited (*Serranus cabrilla*, *Capros aper*) and three low commercial value fish species (*Trachurus picturatus*, *Spondyliosoma cantharus*, and *Trigla lyra*), captured in different seasons reported that all of them had a higher fat content in the dry season compared to the wet season, with an annual variation ranging from 10% to 43% across different species studied (Duarte, et al., 2022). The works of (Simoes, et al., 2013) further reported that high proportions of *n*-3 PUFA (53.87%) and quantities of oleic acid (27.58%) were found during the rainy season compared to other seasons. The fish fat quality of *Siluriformes* species was affected by seasonal variations. Similarly, the study conducted by (Petenuci, et al., 2021) on fatty acid composition in fractions of neutral lipids and phospholipids of *Hemisorubim platyrhynchos* revealed the seasonal variation of the LC-PUFA with the highest value of 505 mg per 100g⁻¹ of a muscle tissue sample in rainy flood period. The predominant bioactive fatty acids, EPA and DHA, totalled 199 mg per 100g⁻¹ of muscle tissue sample during the flood season and 147 mg per 100g⁻¹ during the drought season (Petenuci, et al., 2021). The proximate composition was also reported to vary with seasonal variation in the study conducted by Lopes de Souza, José Inha Barai, Ferreira Rufino, & Viana da Costa (2023). They found that protein (20.44%), ash (1.03%), and lipid (3.55%) were significantly higher, in the flood season than during the drought season where protein (18.85%), ash (0.92%), and lipid (2.57%) in *curinata* fish species from Amazonas water in Brazil. The study conducted by (Kacem, et al., 2011) in three species revealed that seasonal variations

greatly affected the proximate composition, specifically moisture, lipid, protein, and ash contents of the viscera from the three marine species (*Sardinella aurita*, *Sarpa salpa*, and *Sepia officinalis*). Where, moisture content varied across samples, with *Sardinella aurita* viscera having the lowest at 61.96%, while *Sepia officinalis* and *Sarpa salpa* viscera exhibited the highest values at 81.60% and 87.34%, respectively. Lipid content displayed seasonal fluctuations inversely related to water content. For example, lipid content from *Sardinella aurita* viscera varied significantly throughout the year, ranging from 3.90% in May to 25.40% in November. The viscera of *Sepia officinalis* and *Sarpa salpa* showed lipid content variations from 0.58% to 4.02% and 0.36 % to 3.63%, respectively. They also reported that apart from seasonal variation of fish proximate content, temperature, location, breeding cycle, diet, age, size, and sex contributed to the same scenario. However, these studies are done elsewhere and their results cannot be applied to Malawian fish species. Therefore, it is necessary to also study the nutrient composition of *L. gosseii* across the season to scientifically determine if this species can be affected by season.

A study in the southern part of America emphasized the importance of considering the biochemical composition changes of fish as they are exposed to various factors such as capturing season, water temperature, water salinity, geographical location, and fish feed composition (Prato & Biandolino, 2012). According to Lopes, Souzaa, et al. (2021), seasonal variations affect the proximate and fatty acid composition that influences the quality of the fish fat. The works of (Oudiani, et al., 2019) on sex and seasonal variation in proximate composition and fatty acid profile of *Scomber scombrus* (L. 1758) fillets

from the Middle East Coast of Tunisia, reported that during the spring season, the fat content of fish was highest in both females and males (18.9 and 13.2%) with a significant decrease in summer to 5.4 and 3.4% for females and males respectively. In this season, lake levels rise to the point where floods may be experienced and the water from the flooded areas into the lake, brings in rich *ichthyofaunal*, accumulating in the deeper parts of the lake and favouring the growth and multiplication of phytoplankton and zooplankton, hence providing a plentiful of food substrate for demersal fish species (Oudiani, Chetouib, Darej, & Moujahed, 2019). Since *L. gosseii* species feed on the deeper sediments in their environment through shoveling, the scenario can hypothetically be implicated that the rainy season can lead to an improved shift in the biochemical composition of demersal fish species (Bulirani, et al., 2018). However, there is no study conducted in Malawi, especially on this species to determine the impact of the seasonal variation on *L. gosseii*'s nutritional composition from Lake Malawi.

Malawian seasons are very distinct throughout the year. This is according to (Olaf , Ribbink , & Tweddle, 2010), who reported that Lake Malawi is very calm from January to March, and there is noticeable growth of aquatic plants. It is crystal clear during the "African Autumn" season, lasting from April through May. Malawian winter lasts from June through July when the day is warmer than the night. From August to mid-November, the dry and hot season is experienced, whereas late November to December is summer, described as a humid season with occasional showers. Similar variations have been reported to have an impact on the fish's proximate and fatty acid composition by several researchers elsewhere (Adelakun et al., 2017; Adewumi, Adewole, & Olaleye ,

2014; Ahmed, et al., 2017). These variations affect the availability and composition of feeds in the fish's environment which is later reflected in the nutrient composition of the fish (Shija, Shilla, & Mihale, 2019). In Malawi, there are three main fish-catching seasons, especially in the Southern East Arm (SEA) of the Lake. These are; the rainy season running from December to April, a cold-dry season from May to early August, and the dry-hot season from October to November.

Despite different studies being conducted on various fish species in Malawi, the only study that related seasonal variation to Malawian fish was in 2017. This study focused on how seasonal variations affect the growth and spawning of *E. Sardella* of Lake Malawi (Gabagambi & Skorping (2017). The study revealed that the growth rate of juveniles hatched during the rainy season is faster than those hatched during the dry season. This was attributed to the fact that during the rainy season, food is abundant in the lake hence supporting growth. However, the knowledge about the impact of seasonal variations on the nutritional composition of Malawian fish in general is not clear, yet the season varies.

2.4 Factors Affecting Nutrient Variation

Several factors have been reported to affect the nutrient composition of fish, these include age, seasonal changes, sex, feed composition, reproductive cycle and geographical location (Všetičková, Suchy, & Straková, 2020). These factors also vary largely depending on the feed quality, sex and seasonal variations that are considered to be the main factors affecting the chemical composition of fish (Abraha B. , et al., 2018; Kwasek, Thorne-Lyman, & Phillips, 2020).

2.4.1 Sex of the fish

The sex of the fish has been scientifically reported to impact its nutritional composition (Jour, et al., 2010). Studies have quantitatively reported the differences between individual fatty acids in liver and muscle tissues in *trout* fish species as an impact of fish sex (Jour, et al., 2009). Similarly, (Jour, Biró, Hancz, Szabó, & Tamás, 2010), reported the qualitative differences in proximate in the *sardine* sexes from Turkey. The authors further reported the effects of seasonal and sexual differences on the metal levels and proximate composition of red mullet (*Mullus barbatus Linnaeus 1758*) caught from the Middle Black Sea. The phosphorus was higher than potassium, which was higher than sodium, calcium, and magnesium for male fish species. Whereas in females, potassium was reported to be higher than phosphorus, sodium, calcium, and magnesium. However, the trend of trace elements like iron, zinc, manganese, and selenium was reported in decreasing order for both male and female species (Durmus, et al., 2017). The findings revealed no statistical difference in males in terms of protein, unlike in females among seasons. The highest lipid level was reported in winter, compared to autumn. The amounts of moisture in both males and females were significantly lower in winter than in other seasons. Similarly, the study on the impact of season and sex variations on the total lipid contents and fatty acid composition of *scomber scombrus* fillets from the Middle East Coast of Tunisia was also determined by (Chetoui, Darej, & Moujahed, 2019). Their study revealed that fishing season induced significant changes in the lipid profile of which the highest values for total lipids were obtained in the spring for females at 13.2% and for males at 18.9% in terms of protein content, it was higher in summer for females

with 22.0% and males with 21.8%. This is only cementing what other studies have revealed that season and sex affect the content of proteins, lipids, and fat quality in terms of fatty acid contents mainly n-3 PUFA. So, figuring out how sex affects the nutritional value of *L. gosseii* fish from Lake Malawi is important to recommend the season and sex of this species with the best nutritional value for various purposes.

2.4.2 Geographical location

The study by Romotowska, Karlsdóttira, et al., (2016) on Atlantic mackerel fish, focusing on one particular season in several years in different locations. They found that this species' proximate composition did not change throughout the summer catching season of the year 2012 and 2013 except for fatty composition which varied depending on the location. The study indicated that saturated fatty acids (SFA) and PUFA levels changed with higher values in samples from the East of Iceland (25.5%, 33.8%) compared to those from the Northeast of Iceland (21.6%, 32.2%) during the same catching period. Conversely, monosaturated fatty acids (MUFAs) levels exhibited an opposite geographical pattern, with higher values in the Northeast (36.8%) compared to the East (32.9%). Since the fatty acid composition has been reported to change with geographical location as reported by (Romotowska, et al., 2016), there is a need to determine the degree of saturation of FAs of *L. gosseii* from three seasons through IV determination within the same location to observe if such changes also happen in Malawian *L. gosseii*.

2.5 Fish as a perishable food

It is evident that fish and its products are great sources of nutritious food, but its perishability is the major challenge to its preservation (Likongwe, Kasapila, Katundu, & Mpeketula, 2019). These authors reported that after a fish is caught, the rigor mortis occurs and this process is responsible for the changes that occur in the fish after it is caught. The breakdown of biochemical components and the formation of new compounds are responsible for the changes in odor, flavor, and texture that occur during the spoilage process that occurs very quickly after the fish is caught. The deteriorative processes occur faster due to various mechanisms triggered by microorganism metabolic activity, endogenous enzymatic activity, and lipid chemical oxidation (Prabhakar, et al., 2020). The spoilage and deterioration processes occur faster in tropical fish species because of the high ambient temperatures prevalent in the tropics. These conditions are similar to Malawi's hot dry season, where fish caught in such a season, easily go bad and becomes unfit for consumption within 12 to 20 hours of capture unless some processing techniques are employed (Aberoumand, 2013). Aside from temperature, the fish's health status, parasites, wounds and bruises, mode of capture, and post-capture handling all contribute to fish quality loss processes. Such quality losses attract various fish processing techniques to inhibit microbial growth and deteriorative processes prolonging its shelf-life. The techniques employed include: lowering water activity through the addition of salts, solar and sun drying, smoking, or adjusting storage conditions either by freezing brining, or the application of thermal treatment (Likongwe et al., 2019; Kapute & Gissurarson, 2008; Tavares, et al., 2021).

2.6 Fish Processing and Preservation Methods

According to (Torell, et al., 2020) transporting processed fish from the landing locations to the markets contributes to a deteriorating process leading to losses of fish products. The author added that the time it takes a fish from the time it is caught until it gets to the landing sites also contributes to fish quality losses due to the tendency of fishermen to remain out so long after catching them. During such delays, there is a promotion of enzymatic autolysis, microbial spoilage, and chemical activities that lower the value that would have otherwise been achieved (Torell, et al., 2020), and contribute approximately 25% of gross primary agricultural and fishery product losses each year (Ali, et al., 2022). The 25% of gross primary agricultural and fishery product losses accounted for 30% of fish product losses in 2021 (Ali, et al., 2022). Various thermal processing techniques, such as boiling, smoking and sun drying, have been used to avoid microbiological deterioration in fish while maintaining its nutritional content, increasing shelf life, and improving the flavour and texture of the fish. (Speranza, et al., 2021). According to (Martínez, et al., 2020), there are several reasons why fish is thermally processed, including extending the shelf life of the fish, enhancing its flavour in soups and sauces, reducing waste during periods of abundant harvest, preserving the fish for future use and easing packaging for transportation to market centers.

Fish is processed using different techniques around the globe. Boiling, frying, smoky roasting, and sun drying are typical methods of fish preservation employed by different customers. In Malawi, a larger proportion of the fish is utilized after being processed

using various methods, except a small portion of the fish species like *Engraulicypris* *Sardella* (Usipa), *Oreochromis-tilapia* (chambo), *Copadichromis* species and *Diplotaxodon* species (Ndunduma) that are caught and sold in both dry and fresh form (Holma & Maalekuu, 2013). According to FAO, (2024) and; Mutungi and Affognon, (2013), approximately 90% of fish from capture fisheries in Malawi is preserved through smoking or roasting (40%), sun-drying (50%) and 10% being available in fresh, chilled, and frozen forms. The most common fish processing methods used to preserve the fish before being sold to wholesalers, retailers, and consumers include solar or open sun drying, smoking, boiling, deep frying, and pan roasting (Likongwe, et al., 2017). These techniques have been employed in various fish species such as Mcheni (*Rhamphochromis* species) (*Pisces: Cichlidae*) and Ndunduma (*Diplotaxodon*).

These processing and preservation techniques have been reported to affect the nutritional composition and sensory quality of the fish product. Smoking has been reported to minimize food spoilage while improving taste, aroma, and appearance (Msuku & Kapute, 2018). Due to unstable power supplies or low economic power in most developing countries, smoking is the most favoured method of fish preservation in most rural areas, riverine and lakeshore fishing communities, particularly in Delta State, Nigeria, and in Malawi (Msuku & Kapute, 2018; Mutungi & Affognon, 2013). About 3% of the world's catch is processed using the widely accepted traditional technique of smoking fish. Chemicals produced by the fuel wood during smoking lengthen the fish's shelf life, increase utilization, and enhance taste. The heat from the fire evaporates water from the fish, reducing its moisture content to 30% or less, thereby extending the time it can be

stored and protecting it from bacterial and mold growth (Likongwe, Kasapila, Katundu, & Mpeketula, 2019). The technique lowers the water activity in the fish to a level that inhibits the activity of spoilage microbes, hence extending the shelf life (Likongwe, et al., 2017).

Solar drying technique has also been reported to be a better method of drying compared to the open-sun drying method because of the reduced contamination and its applicability during dry seasons with low relative humidity (Abraha, et al., 2018). In most Malawian households, stewed fish is typically made by boiling technique. However, it has been reported to alter the nutrient composition of foods due to leaching out of the water and fat-soluble vitamins (Abraha, et al., 2018; Akintola, 2014; Likongwe, Kapute, Mtethiwa, & Sikawa, 2017).

2.7 Effects of processing on nutrient composition

Fishing is the most important commercial activity on the Malawian lakes with an annual catch of up to 80,000 metric tons every year and is still on the rise (Jamu, Banda, Njaya, & Hecky, 2011). With this massive harvest, the fish is often processed and cooked using different techniques for preservation purposes to ensure fish availability throughout the year. Fishes are known for their nutritional and mineral composition and therefore to preserve these nutrients the fish has to be handled and processed in the right way (Abraha, et al., 2018). According to (Abraha, et al., 2018), fish begin to deteriorate as soon as they are captured from the water. This means, that if the fish are not properly handled and preserved after being caught, the spoilage process will occur faster. As such,

processing fish in a good way, at the right time, and in the right way helps to maintain both the quality and quantity of the fish (Holma, Ayinsa, & Maalekuu, 2013). It is because of that rationale of preserving the quality, that different preservation methods are employed. Studies elsewhere have revealed that such processing methods affect the nutrient composition of fish (Martínez, Armesto, Gómez-Limia, & Carballo, 2020; Smida, et al., 2014). As such, the choice of a processing technique plays a major role in ensuring that the nutrients remain intact until consumption.

The study conducted by (Smida, et al., 2014) on *Atherina boyeri* fish from the Tunisian coast and reported that solar drying has negative effects on the protein quality since the drying process removes the moisture and some moisture is trapped inside which promotes protein degradation. Further, the exposure of the fish to sunlight for long periods promotes the oxidation of lipids hence affecting the PUFAs that affect nutritional quality Tenyang, et al. (2017).

Smoking fish can be categorized into two forms: cold and hot smoking. Hot smoke drying of Tilapia (*Oreochromis niloticus*) has also been shown to affect the quality of dried fish since the excess heat affects some of the valuable nutrients like protein and lipids in the fish (Idah & Nwankwo, 2013). According to (Katola & Kapute, 2017), smoking *Oreochromis mossambicus* fish, exposes it to compounds like benzopyrene which affect the fish's nutrient functionality especially protein and the safety of the final product. Likewise, the study conducted by (Chavan, Basu, & Kovale, 2008) on *Otolithus argenteus* fish reported that smoking decreases the soluble protein and increases the

amount of insoluble protein thereby reducing the available protein. Other studies on three fish species (*Synodontis clarias*, *Trachurus trecae*, and *Clarias gariepinus*) have shown a higher loss of nutritional components in boiled and solar-dried fish than those that were processed by smoking (Oparaku & Nwaka, 2013).

Boiling as both a preparation and a processing technique has been reported to affect the protein quality through denaturation and loss of minerals and amino acids (Abraha, et al., 2018). A further study done in Malawi and Iran on the characterization of the effects of processing methods on the nutritional composition of three popular fish species *Oreochromis karongae* (Trewavas, 1941) and *Tilapia rendalli* (Boulenger, 1896) and *pampus argenteus* (white pomfret), respectively, reported that processing methods affected the fish's nutritional components differently and varied with the species (Aberoumand A. , 2020; Longwe & Kapute, 2016). With various studies already conducted on many fish species, no data has been reported on the effect of these processing techniques on the proximate and oil quality of the *L. gossei* fish. As it stands, people who are in fish processing, do not know which method out of solar-drying, boiling and smoking retains more nutrients than the other, especially on this *L. gossei*. With the help of the right use of analytical methods, there is a need to investigate how such processing techniques affect this species' proximate and fat quality for people to know the optimal processing technique to preserve fish quality and quantity.

2.8 Analytical techniques used for proximate, mineral composition and iodine value

For the analysis of proximate and mineral composition, and oil quality in fish, various analytical methods have been developed and standardized to ensure accuracy and reliability. Several studies have utilized methods such as supercritical fluid extraction (SFE) for fat content, the Dumas method for protein determination, combustion methods for moisture and ash content, and the Cyclohexane-Acetic Acid Method for iodine value (AOAC, 2019). Among these, the Association of Official Analytical Chemists (AOAC) methods are widely accepted for proximate analysis due to their robustness and validation across different studies (Latimer, 2016). In this study, AOAC methods were employed to determine the MC, ash, protein, and lipid content of *Lethrinops gosseii* due to their precision and consistency in food composition analysis (Nielsen & Carpenter, 2017). Additionally, the quality of fish oil was assessed using a slightly modified Wiji's method for iodine value determination, a well-established technique used to evaluate the degree of unsaturation in oils (Samanta, Kataria, & Dobhal, 2023). The application of these standardized methods provides reliable results, ensuring comparability with other similar studies in the field.

In summary, this literature review chapter has provided an in-depth analysis of existing research related to fish nutrition, focusing on the nutritional composition of fish and its significance, particularly in developing countries like Malawi. It has explored the seasonal and sex-related variations in fish composition, discussing how factors such as protein, fat, and mineral content can fluctuate depending on these variables. The impact

of various fish processing techniques, such as smoking, boiling, and solar drying, on the nutritional quality and shelf-life of fish has also been reviewed. The gaps in current knowledge, particularly regarding the *L. gosseii* species have been exposed necessitating the need for the study.

CHAPTER 3

MATERIALS AND METHODS

This chapter outlines the experimental design of the study, which was conducted to assess the influence of season, sex, and processing methods on the proximate composition and oil quality of *L. gosseii*. Fish samples were collected from designated deep-water areas of Lake Malawi during three different fishing seasons. The processing methods like smoking, solar drying, and boiling are thoroughly explained in terms of their execution. Standard analytical methods, chemicals and reagents were employed to determine moisture, protein, ash, mineral, fat content, and iodine value. The data on seasonal variations and processing techniques were analysed using one-way ANOVA, while sex-based variation was assessed using a t-test.

3.0 Research design

The experimental research design was used in this study. This research design seeks to establish a cause-effect relationship within a group by satisfying both the needs of a

control group, which was subjected to changes such as season, processing techniques, and sex.

3.1 Fish Sampling Area

Both male and female *L. gossei* fish species were caught from the deepest locations covering areas of Abimu Majasi (S 14.051882^o, E 34.950275^o) and Abimu Nkokobe (S 13.945152^o, E 35.009319^o) in the southern east arm of the Lake Malawi as shown in Figure 1. This site represents 10% of the total surface area of the lake and accounts for about 60% of the annual fish landings from the whole of Lake Malawi (USAID, 2017).

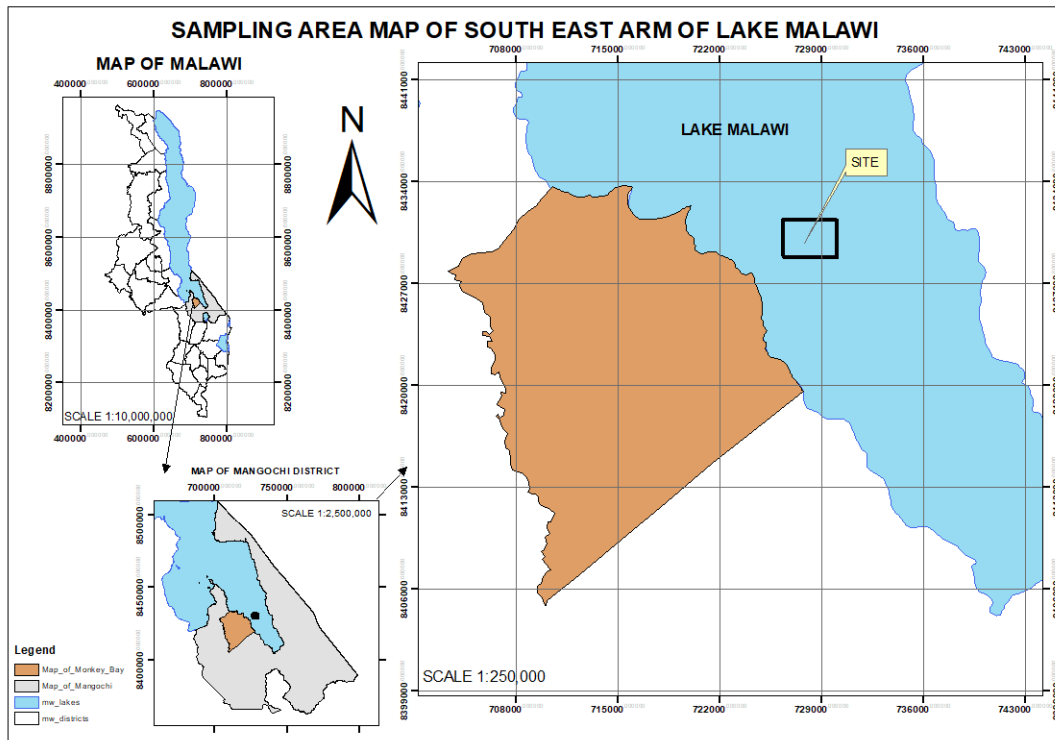


Figure 1: Map of the sampling area on the South East Arm of Lake Malawi

3.2 Sampling techniques, sample handling and preparation

In each fishing season, a combination of random and purposeful sampling techniques was employed to sample the species of interest. A platoon of both male and female fish, with similar weights, medium sizes, and length ranges, was sampled, amounting to 10 kg. These fish, generally medium-sized, weighing between 150-220 g and measuring 15-20 cm in length, are commonly caught, processed, and consumed.

They pass through the recommended cod-end mesh size of 38 mm, as shown in Figure 2. This sampling process was repeated throughout all three fishing seasons.

The weight, size, and length of fish samples from each of the three fishing seasons; cold (May-August), hot (September-November), and rainy (December-April) in the years 2022 to 2023, according to (Torella, et al., 2020), were recorded using a weighing balance and a measuring board, respectively. With the assistance of fisheries experts, the species and the sex determination of *L. gossei* were conducted by observing their deep-bodied, vertically-barred and small ventrally placed mouths as reported by (Changadeya, Ambali, & Malekano, 2004). In terms of the sex distinction, the colour pattern of the skin was used where male *L. gossei* has a more visible pattern than females.

The samples were then packed into separate polyethylene Ziploc bags and placed in a cooler box filled with ice cubes and transported directly to the Chemistry laboratory at the University of Malawi (UNIMA) for analyses. The temperature of the fish in the cooler box was maintained in transit so as not to induce significant biochemical changes. Upon arrival at the laboratory, the fish were descaled and cleaned using minimal water to reduce excess absorption, and limited air exposure to prevent moisture loss. After moisture content determination, the rest of the fish samples were sealed in plastic Ziploc bags and stored at -20°C for further analyses. Fresh whole fish was utilized for the determination of both IV and proximate analyses to reflect the *L. gossei* fish's true

nutrient content as consumed.



Figure 2: *Lethrinops gossei* Fish samples

3.3 Chemicals and Reagents

All chemicals and reagents used were of analytical grade. The solvents used include sodium hydroxide, Chloroform (CHCl_3), Methanol (CH_3OH), Sulphuric Acid (H_2SO_4), Cupric Sulphate (CuSO_4), Sodium Hydroxide (NaOH), Potassium Sulphite (K_2SO_4), Anhydrous Boric acid (H_3BO_3), Hydrochloric Acid (HCl), Diethyl Ether ($\text{C}_4\text{H}_{10}\text{O}$), n-hexane (C_6H_{14}), Sodium Sulphate (Na_2SO_4), deionized water, 70% perchloric acid (HClO_4), Nitric Acid (HNO_3) and Pet ether (C_6H_{14}). Then A.C.S. grade chemicals such as potassium Iodide, carbon Tetrachloride, hydrochloric, sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$) and iodine were used.

3.4 Materials

Three thimbles (30 x 100-1.5mm thickness, 25 pieces per pack), Whatman No. 1 Filter Paper, Ziploc bags, cooler box, analytical weighing balance, 100°C heating block, test tube shaker and tabletop centrifuge.

3.5 Sample processing methods

The fish samples were washed and divided into four portions which were further divided into two based on their sex. One portion of the four was smoked right there at the Monkey- Bay fisheries using their traditional smoking kiln. The remaining fresh fish samples were washed and grouped into three batches for solar-drying, boiling, and fresh for control at the Food and Nutrition Laboratory in the Human Ecology and Agricultural Sciences Department, UNIMA in Zomba.

3.6 Solar drying

A modified version of the cabinet passive food solar dryer was used shown in figure 3. The modified cabinet could maintain temperatures ranging from 40-55 °C. The fish samples were positioned on the second drying rack made of nylon netting constructed at a height of 42 cm with a clear polythene plastic sheet stretched over the frame and bottom. After sunrise, the tent was stocked with fish samples and turned on every hour to guarantee even exposure to solar radiation with heat at 40 °C-55°C. At sundown, the fish were removed to avoid overnight rehydration. It took the samples only four days to

obtain consistent moisture levels of about 9.89%, 9.87%, and 9.89% before they were stored at -20 degrees Celsius for the subsequent analyses.



Figure 3. Modified solar drier tent

3.7 Smoking using traditional kiln

The hot smoke-drying of the samples was done at Monkey Bay fisheries, as reported by (Akintola, 2014) with slight modifications as presented in Figure 4. The fish samples were laid out on a platform of wire mesh supported by a circular frame of a perforated metal drum measuring 0.846 m² to smoke for three hours. The base of the drum was filled with 10 inches of jagged sand. Seven firewood sticks with an average length of 0.6 meters and a thickness of 0.05 meters, matchsticks, were used to start a fire that was allowed to heat for approximately 15 minutes. Then the clinical mercury thermometer in a glass was used to record the temperature which was about 71 °C on average.

Then the smoked samples' moisture content was determined at the Chemistry Laboratory and the rest samples were labelled and packed in Ziploc bags and stored at -20 °C for the subsequent analyses.



Figure 4: Traditional smoking oven

3.8 Boiling

In Malawi, wet cooking (boiling) is the most common technique that serves as both a pre-processing technique and a way of preparing fish for consumption. In this study, the boiling treatment was done at approximately 98 °C for 15 min. The whole fish samples were randomly selected and mixed with water in the ratio of 1: 2 weight/volume basis in a medium saucepan to boil. The samples were boiled till the mean core temperature of *L. gosseii* samples was recorded to be 98 ± 3 °C using a kitchen thermometer, the temperature that signifies a well-cooked fish according to (Noel, et al., 2022). Then the portion of the sample was taken for moisture content determination before being packed in a Ziploc bag for further nutrient analysis.

3.9 Proximate composition analysis

The moisture content, ash, mineral, crude protein, and crude fat were assessed according to the analytical protocols described in AOAC methods with chemicals and reagents that were of analytical grade (AOAC, Official methods of analysis., 2010).

3.9.1 Determination of Moisture content

The determination of moisture content was gravimetrically conducted using the oven drying method (AOAC, Official methods of analysis., 2010). Where six aluminium dishes, free from any contaminants, were used for weighing samples after being dried for an hour at a temperature of $100 \pm 5^{\circ}\text{C}$. After drying, the dishes were placed in a desiccator with granular silica gel using a tong for 30 minutes to cool. Then the samples were weighed using an analytical balance with a 0.1g sensitivity. Six fishes, three of each sex in each season were randomly picked, minced, and homogenized using a stainless knife and a blender. Then the triplicates of the homogenized fresh carcass were sampled out and weighed to approximately 5 grams. Then the weighed sample was transferred to the dried and weighed dishes for weighing of the fresh samples and moisture dishes before drying. The dishes and their contents were placed in the drying oven and dried for 3 hours at 105°C before placing it in a desiccator for 30 minutes to cool. After this, they were weighed and recorded. This process was repeated every 30 minutes until a constant weight was reached. Then the moisture content was calculated as a percentage of the original sample using the following formula.

$$\text{Percent moisture content} = \frac{W_1 - W_2}{W_1} \times 100 \dots \text{equation 1}$$

Where: W_1 = Weight of the moisture dish with the fresh sample, W_2 = Constant weight of the sample in a moisture dish after drying.

$$\% \text{ Dry Matter (MD)} = 100\% - \% \text{ Moisture content} \dots \text{equation 2}$$

3.9.2 Determination of Ash content

Ash content was determined following the methods recommended by (AOAC, Official methods of analysis., 2010). The crucibles were heated first in a muffle furnace for 30 minutes at 700 °C, then put in a desiccator for 30 minutes to cool before being weighed and labelled. Then 5g of the pre-dried samples in triplicates from each sex sample were weighed using an analytical balance before heating in an electric muffle furnace at 550 °C for 24 hours. Thereafter, the furnace was turned off and allowed to cool for a few hours. Finally, crucibles were removed from the muffle furnace and placed into a desiccator using a tong to cool before weighing and recording the weight of the crucible plus the ashed sample. Percentage ash content was computed by carrying out the following calculations:

$$\% \text{ Ash (wet)} = \frac{(\text{wt. crucible and ash} - \text{wt. crucible})}{(\text{wt. crucible and sample} - \text{wt. crucible})} \times 100 \dots \text{equation 3}$$

3.9.3 Determination of Mineral Composition

Some major minerals such as Ca, Na, K, P, and Mg and trace minerals such as Fe, Mn, Zn, and Cd were analysed from both male and female samples across all the seasons and processing techniques, using a slightly modified method recommended by Schweigert et al. (2016). Briefly, ashes from the previously weighed sample were accurately put into the clearly labelled digestion flask. Then 20 mL of 65% HNO₃ and 10 mL of 70% HClO₄ were added to all the samples and mixed well. Then samples were digested in a fume hood at an ambient temperature till the sample flask turned brown-red, colour due to the HNO₃ formed during the reaction of an acid with the sample. Flasks were then placed in the heating mantle of the digester at 120°C till the sample's brown-red colour was turned to lighter yellow as a result of the decomposition of the nitric acid and the formation of nitrogen dioxide (NO₂). Then samples were diluted by the addition of 30 ml of deionized water and filter using Whatman No. 1 filter paper in 100 mL volumetric flasks. The dilution was continued to an appropriate level till the concentration was not higher than any of the standards used to make the calibration curve. The mineral composition of the digested samples was determined by flame atomic absorption spectrophotometry (BUCK Scientific 200 A) for Ca, Na, K, Mg, Fe, Zn, Cu, and Mn, whereas phosphorous was determined using Agilent UV/Vis Spectrophotometer.

3.9.4 Determination of Proteins

3.9.4.1 Procedure

Crude protein in the fish samples was determined using the Kjeldahl method as reported in AOAC (1995) with slight modifications. Where 2g of the homogenized fish sample was weighed on a weighing paper using analytical balance into a Kjeldahl digestion flask.

Then the sample was digested by heating at 370°C for 4 hours in 6 mL of nitrogen-free sulphuric acid, 3.5 mL H₂O₂, 3g of a hydrous nitrogen-free catalyst CuSO₄ and anhydrous nitrogen-free K₂SO₄. Soon after completion of digestion, the clear solution formed was cooled for 30 minutes and neutralized by the addition of 25 ml NaOH (40%) and diluted using 25 mLs of distilled water. Thereafter, 25 mL distilled water, 25mL Boric acid, and 3 drops of Methyl blue were then added to a receiving 250 mL capacity flask connected to the distiller by a tube. The distillation process was terminated when the volume of a receiving flask reached between 200 to 250 mLs. All reagents were added to the blank except the sample used as a control. Finally, the nitrogen content was determined by titration of the borate anion formed with 0.1N HCl. The amount of nitrogen percentage was calculated using the following formula:

$$\% N = \frac{N \text{ HCl} \times (\text{Vol HCl TS} - \text{Vol HCl TB}) \times 14 \text{ g}}{\text{Gram of sample mole}} \times 100 \dots \dots \dots \text{equation 4}$$

Where: TS = titration volume of the sample, TB = titration volume of the blank. Then the calculation of the percentage protein will be as follows:

% Protein = % Nitrogen x 6.25..... equation 5

Where: 6.25 is the protein-nitrogen conversion factor.

3.9.5 Determination of Crude fat content.

The determination of fat content was done by semi-continuous solvent extraction known as the Soxhlet method according to the procedure outlined in AOAC (1995). The fish samples were finely ground and homogenized using porcelain mortar and pestle, and blender, respectively. Then 5 grams of the sample was weighed using an analytical balance. Porous cellulose extraction thimbles were dried in an oven for 24 hours at 70 °C and placed in a desiccator to cool. Then thimbles were removed from the desiccator and labelled before weighing on an analytical balance (Nielsen & Carpenter, 2017). The samples were placed in the thimbles accordingly and covered with fat-free cotton and reweighed.

Then the thimble was placed in the Soxhlet extraction chamber which was suspended above a flask containing 50 mL of petroleum ether solvent below a condenser. Then the flask was dried in a drying oven at 105 °C before being placed inside the extraction chamber. Then boiling chips were placed inside a flask and heated at 55 °C. This was to allow the solvent to evaporate and be moved up into the condenser where it was converted to a liquid that trickles into the extraction chamber containing the sample. The extraction process lasted for 8-12 hours before the flask containing the solvent and lipid was removed. Finally, the solvent was evaporated in a drying assembly set at 100 °C and

the mass of lipid remaining was quantified gravimetrically and calculated from the difference in weight of the extraction flask before and after extraction as a percentage using the following formula.

$$\text{Fat content \%} = \frac{\text{Weight of fat} \times 100}{\text{Weight of sample}} \dots\dots\dots\text{equation}$$

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3.10 Determination of Iodine Value

3.10.1 Preparation of the reagents:

Wiji's method of iodine value determination was adopted with slight modifications. A sodium Thiosulfate Solution of 0.1N was prepared by dissolving 24.8 g of sodium thiosulfate in distilled water and diluting it to 1 L. Potassium iodide solution was prepared by dissolving 75 g in distilled water and making up to 500 mLs. The Wiji's solution was prepared by dissolving 13.0 g of iodine in 1 L of glacial acetic acid and heated gently to promote dissolution. Then the solution was cooled before removing a small quantity of 400 mLs and set aside in a cool place for future use. After that, 10 mL of excess chlorine was added, and the titration was resumed in Wiji's solution by adding some of the original iodine solution that had been removed at the beginning. The original iodine solution and the finished Wiji's solution were both titrated with Na₂S₂O₃ solution.

3.10.2 Soluble starch indicator of suitable sensitivity.

The starch solution indicator was prepared by making a homogeneous paste of 1g of soluble starch in 10 mL of cold distilled water and then the mixture was added to 90 mL of boiling distilled water with rapid stirring and heat for three minutes before allowing it to cool. Then the mixture was decanted as a clear supernatant. The starch sensitivity was tested by placing 5 mL of the prepared starch solution in 100 mL of water, then 0.05 mL of 0.1 N iodine solution was added to produce the deep blue colour which was discharged by 0.05 mL of 0.1 N sodium thiosulfate.

3.10.3 Standardization of the Thiosulfate

The standardization of $\text{Na}_2\text{S}_2\text{O}_3$ was done by pouring 25 mL of the standard dichromate solution into the Erlenmeyer flask. Then 5 mL of hydrochloric acid and 10 mL of potassium iodide solution were thoroughly mixed. Then the mixture was left to cool for 5 min and then 100 mL of distilled water was added. This was followed by titrating the mixture with sodium thiosulfate solution whilst shaking continuously until the yellow colour disappeared. Finally, 1 to 2 mL of the indicator was added with continual titration and slowly addition of the thiosulfate solution, until the blue colour has just disappeared.

3.10.4 Procedure

The frozen samples were melted and filtered through filter paper to remove any impurities and the last traces of water. The temperature for the sample melting point

during melting and filtering was maintained not to exceed 10° to 15°C to avoid absolute drying of the sample. Then 5 g of the sample was accurately weighed into a 500-mL flask to which 20 mL of CCl₄ was added. This was followed by pipetting 25 mL of the Wiji's solution into the flask containing the sample and swirling to ensure an intimate mixture. The blank was prepared along with the samples to be determined simultaneously and similar in all aspects. Then the incubation of the flasks containing samples in a dark place was done for 30 minutes at a temperature of 25 ±5°C. Then the samples were removed from the storage and 20 mL of KI solution and 100 mL of distilled water were added. Then titration of the solution with 0.1 N Na₂S₂O₃ solution was followed by gradual and constant shaking. The titration was continued until the yellow colour had almost disappeared. Then 1 to 2 mL of starch indicator solution was added and titration was continued until the blue colour has just disappeared. Finally, the calculation of IV was done as follows:

$$Iodine\ Value = \frac{(B-S) \times N \times 12.69}{Weight\ of\ Sample} \dots\dots\dots equation\ 7$$

Where: B = titration of blank, S = titration of sample and N = Normality of Na₂S₂O₃ solution.

3.11 Statistical Analysis

The data was analysed using one-way analysis of variance (ANOVA) to compare the means of the different parameters in different seasons using the SPSS statistical package program for Windows version 26.0 and the significant differences in proximate and IV of

fish samples in different seasons were determined using the turkey test (SPSS, 2020) at a significance level of 0.05. The means of different sexes were compared using a t-test. The results of the statistical analyses were presented as mean values \pm SD.

3.12 Ethical Approval

This research was approved by the University of Malawi Research Ethics Committee with the protocol number: P.11/22/202 (Appendix 1).

The chapter has provided the study's experimental design to evaluate the effects of season, sex, and processing methods on the proximate composition and oil quality of *L. gossei*. Fish samples were sourced from deep-water areas of Lake Malawi across three fishing seasons. It has also detailed the execution of processing methods, including smoking, solar drying, and boiling, and how the standard analytical techniques were applied to measure moisture, protein, ash, mineral, fat content, and iodine value. Data analysis involved one-way ANOVA for seasonal and processing variations, while a t-test was used to assess sex-based differences.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the findings and discussions on the nutritional composition of *L. gossei* from Lake Malawi. Seasonal variations significantly affect the fish's proximate composition, with the hot-dry season yielding higher protein, mineral content, and polyunsaturated fatty acids (PUFAs), while the rainy season leads to increased fat accumulation, especially in females. Processing techniques are crucial, as solar drying preserves ash and fat effectively while smoking optimizes protein retention. Sex variation also influences nutritional profiles, with females exhibiting richer PUFA content. Furthermore, the analysis of mineral composition highlights essential nutrients and the IV indicates that processing methods affect oil quality, underscoring the need for targeted harvesting and processing strategies to enhance the fish's nutritional value.

4.0 Influence of seasonal variation on the proximate composition of the *L. gossei* Fish.

Table 1 presents the results of proximate composition: moisture content, ash, protein, and fat content in various seasons; the rainy, cool-dry, and hot-dry seasons.

Table 1: Seasonal Variation on the Proximate Composition of *L. gossei* Fish

Season	Proximate composition and fat content (Mean \pm SD)			
	MC (%)	Ash (%)	Protein (%)	Fat (%)
Rainy	35.59 \pm 2.28 ^a	6.67 \pm 1.20 ^a	9.53 \pm 1.30 ^b	28.80 \pm 2.01 ^b
Cool-dry	58.01 \pm 0.30 ^b	17.20 \pm 0.41 ^b	6.87 \pm 0.11 ^a	12.17 \pm 2.02 ^a
Hot-dry	65.06 \pm 2.23 ^c	18.72 \pm 1.20 ^b	12.62 \pm 0.21 ^c	27.87 \pm 3.23 ^b

Means in the same column with different superscript letters are significantly different at p < 0.05.

The results show that the hot-dry season had the highest MC (65.06%) compared to the rest of the seasons with the rainy season reporting the lowest (35.59%) which was significantly different from the hot-dry and cool-dry seasons at $p < 0.05$. These findings are in line with (Pulido-Flores, et al., 2022; Siddique, et al., 2021) found in the freshwater demersal fish species. This is attributed to the rise of water temperatures in lakes with reduced humidity levels during this hot-dry season, causing fish dehydration and increased water absorption as a response to increased evaporation rates and increased metabolic demands (Pulido-Flores, et al., 2022). Further, studies conducted by (Adeyemo, Omitoyin, & Olaniyan, 2016; Ghosh, Pal, Das, & Barik, 2018) on the impact of seasonal variations on the nutrient composition of different demersal fish species, also reported similar observations. The high MC may lead to less fat content as described by (Adeyemo, Omitoyin, & Olaniyan, 2016). Moisture and fat of fish are inversely related due to their competition for space in the fish tissues. The possible reason for this study's findings could also be the feeding patterns of fish in this hot-dry season that influences their moisture and consequently fat content. During the rainy season, fish feed more actively on more energy-rich prey including zooplankton and small fish due to the abundance of nutrients input into the lake. This results in increased productivity and availability of other food nutrients apart from water. This potentially increases their fat content as explained earlier that feeding of fatty foods in the season influences the low

moisture and high-fat content, respectively (Zhang, et al., 2020; Ghosh, Pal, Das, & Barik, 2018).

Ash content was significantly higher in the hot-dry (18.72%) and cool-dry (17.20%) seasons compared to (6.67%) in the rainy seasons. There is an abundance of phytoplankton and other small organisms that are rich sources of minerals for fish in hot- and cool-dry seasons (Hossain, et al., 2017). It is such inclusion of animal-based components in fish feed that contributed to the increased ash content of the fish as they store these as minerals in their tissues (Ng, Chew, & Chong, 2015; Zemheri-Navruz, Yanar, Akyurt, Köseoglu, & Önalın, 2016). Similar findings were observed by (Alves, et al., 2016; Ng, Chew, & Chong, 2015), that the ash content of Nile *tilapia* fed with diets containing different levels of animal and plant by-products was significantly higher than those which were not exposed. The current study found that *L. gosseı* fish species exhibit high ash content not only during the hot-dry season. The average ash content observed in samples from all the seasons is higher (14.19 %) than the findings of (Gokoglu, Yerlikaya, & Cengiz, 2004), in rainbow trout with the range of ash values (1.35 - 1.66%). Similarly, the values reported by Akpambang (2015) for silver catfish (0.95–2.50%) and raw mince from five different Indian fish species (2.5–6.25%) were still lower. The observed variation could be attributed to differences in sex, species, and environment (Hossain, Al-Abdul-Elah, & Yaseen, 2019) and utilization of the whole fish body during sample analysis.

Protein content was significantly higher (12.62%) in fish samples collected from hot-dry, followed by cool-dry, and the lowest during the rainy season (6.87%) at $p < 0.05$. The high protein content during this season was because the species prefer high-protein shrimp and rockfish as food, so they retain the protein in their body tissues (Kocar, Suregil, Aktas, Pak, & Koca, 2023). Furthermore, the hot-dry and cool-dry seasons provide a conducive environment for fish to convert food more efficiently into body mass due to favourable environmental conditions such as increased water temperature and higher dissolved oxygen levels respectively (Adeyemo, Omitoyin, & Olaniyan, 2016). Similarly, the hot-dry season has reduced feed availability compared to the rainy season hence the *L. gossei* experiences a decrease in overall food intake. With this limited food supply, fish allocate more resources towards protein synthesis to maintain essential body functions, and support growth and reproduction, thereby increasing the protein content in the fish (Hossain, et al., 2017).

Crude fat content was highest (28.80 %) during rainy followed by hot-dry (27.87%), and cool-dry season (17.67 %). However, the hot-dry and rainy seasons had significantly ($p < 0.05$) higher fat content than the cold season. During the rainy season, this fish species undergoes significant physiological and metabolic changes to support the production of eggs and sperms, including the energy requirements of reproductive activities (Daurte, et al., 2022). As such, fat acts as an energy reservoir for such activities. This explains the reason why there is increased fat content in this season. These findings are attributed to the spawning and reproductive periods of the fish as Adeyemo, Omitoyin, and Olaniyan (2016) and Antonio (2020) established in their studies that there is a direct relationship

between the spawning or reproduction of fish and their fat content. In addition to that, warmer temperatures during the rainy and hot-dry seasons increase fish metabolic rates that triggers higher fat storage for the same, unlike during the cold season. Apart from these factors, the contribution of food availability to fat content of the fish in these seasons cannot be understated. The increased rainfall causes increased nutrient runoff from surrounding areas and rivers into freshwater lake bodies. As such, the lake is able to support the food chain by enriching the lake with nutrients. This result in demersal fish like *L. gosseii* benefits from the abundance of feed, such as zooplankton, benthic invertebrates, and other small organisms, contributing to a higher fat accumulation in the fish during this season (Lopes et al., 2021).

According to Taşbozan & Gökçe, (2017) fish are classified, based on their fat composition as lean (less than 5% fat), mid-fat fish (5–10% fat), and fatty fish (10–25% fat). Based on this classification, the results of this study (Table 1) show that *L. gosseii* is a fatty fish because its fat content ranges from 10-25% across the seasons. This high-fat content suggests the availability of polyunsaturated fatty acids that have been reported to have potential health benefits by (Petenuci, et al., 2021). Therefore, for fish harvest to extract oil, rainy and hot-dry seasons can be considered with emphasis on the hot-dry season. However, the rainy season is associated with spawning and reproduction activities of the fish, therefore, the fishing regulation has to be considered in this season for the species' sustainability despite of the revealed nutritional value and potential for oil extraction.

4.1 Impact of sex on proximate composition of *L. gossei* fish in different seasons.

The impact of sex on the proximate composition of *L. gossei* during rainy, cool-dry, and hot-dry seasons is presented in Table 2.

Table 2: Impact of sex on proximate composition of *L. gossei* fish in different seasons

Season	Proximate composition (Mean ± SD)				
	Sex	MC (%)	Ash (%)	Protein (%)	Fat (%)
Rainy	Male	33.43±0.11 ^a	8.34±0.10 ^a	10.93±0.00 ^a	21.52±0.21 ^a
	Female	37.76±0.10 ^b	5.00±0.21 ^b	8.13±0.10 ^b	36.08±0.20 ^b
Cool-dry	Male	57.40±0.40 ^a	17.56±0.10 ^a	6.83±0.21 ^a	10.32±0.21 ^a
	Female	58.62±0.10 ^b	16.83±0.10 ^b	6.90±0.10 ^a	14.02±0.10 ^b
Hot-dry	Male	67.43±0.21 ^a	17.62±0.21 ^a	12.71±0.20 ^a	18.54±0.11 ^a
	Female	62.68±0.30 ^b	19.83±0.00 ^a	12.53±0.10 ^a	37.21±0.11 ^b

Means in the same column of a particular season with different superscript letters are significantly different at $p < 0.05$.

The moisture content was significantly ($p < 0.05$) different from each sex across the seasons with increasing patterns from rainy through cool-dry to hot-dry season in ascending order. It ranged from 33.43 to 67.43% in males and from 37.76% to 62.68 in females, respectively. The MC trend is in the reverse direction with fat content during these two seasons except the cold-dry one. Female fish samples had significantly higher

fat content than males during rainy and hot-dry seasons at ($p < 0.05$). This is related to the accumulation of fat for breeding activities during these seasons. The increased crude fat content observed in both males and females during the rainy season has already been attributed to the food availability in the lake during these seasons. However, an increase in fat and protein content of female fish is related to the beginning of the spawning period as fish use fat and protein reserves during gonadal maturation and spawning. As such, fat and protein accumulate more in the female fish tissues than in male (Hossain, Al-Abdul-Elah, & Yaseen, 2019). Additionally, oestrogen promotes the accumulation of subcutaneous fat and protein synthesis in female fish species, resulting in their increased concentration in the fish bodies. Generally, both male and female *L. gosseii* fish are an excellent source of protein and fat since they are above what is reported to be a fatty fish thus 10-25% (Taşbozan & Gökçe, 2017). The accumulated fat during the rainy season extends to hot-dry because the lipids are metabolized gradually (Usydus, Szlifder-Richert, & Adamczyk, 2012). This applies to the *L. gosseii* species as they store fat during the period before spawning and during spawning that covers both hot-dry and rainy seasons respectively, before they quickly deplete it in the cold-dry season.

During the rainy season, ash and protein content were significantly higher in males ($8.34 \pm 0.10\%$ and $10.93 \pm 0.00\%$) than in females ($5.00 \pm 0.21\%$ and $8.13 \pm 0.10\%$), respectively. These findings agree with what was reported by (Ayas, et al., 2012) that male fish samples had significantly higher protein and ash than females. According to Andrew (2000), such a trend is linked to the fish reproduction season and hormonal activities, where male fish invest a significant amount of energy in reproductive processes,

regulating growth, development, and metabolic processes in fish (Fontaine & Cahu, 2012). Further to that, male fish produce higher levels of anabolic hormones such as testosterone which promotes protein synthesis in the rainy season (Jobling, 2010), this potentially results in higher protein content of the male fish. On the other hand, increased ash content of the male fish in rainy and cool-dry seasons could be a result of the more stress from the pollution and searching for their mates during these seasons and this results in the increased release of cortisol, a stress hormone that breaks down and lower proteins more quickly and consequently increases the ash content in males more than in females (Cahu, Le François, & Fontaine, 2004). During the cold season, males have increased moisture and ash content more than females. These findings are in agreement with what was reported by (Leal & Walker, 2019). This is because of the hormonal activities as testosterone in male fish samples stimulates the production of new bone cells and inhibits the breakdown of old bone cells and muscle growth hence the significant increase in bone density (Leal & Walker, 2019). As muscle mass and bone density increase in male fish samples, there is a corresponding rise in both moisture content and ash (Zhang, et al., 2016). According to (Volkoff & London, 2018), the energy-intensive nature of egg production in female fish, emphasizes the need for an increased food intake to produce enough eggs for successful reproduction. This phenomenon can be applied to female *L. gossei* fish, which possess a higher body fat content than male ones during the cold season (Table 2). Furthermore, cold water during this season causes a reduction in metabolic reaction rates in fish (Matthew, Ferrari, Hobson, & Stephen, 2006). Such conditions cause female *L. gossei* fish to increase their appetite, enabling them to

accumulate ample fat reserves to maintain their body temperature and realize sufficient eggs for reproduction (Volkoff & London, 2018). This explains why there is increased protein and fat content in this species during the cold season. In the hot-dry season, ash and protein content were not significantly different in males and females. In this season, male and female fish samples have similar metabolic rates and levels of hormones, because the lake is less stressful for hormonal release and it is the off-breeding season for extra protein mobilisation (de Graaf, van der Meeren, & van den Thillart., 2005). The slight differences in protein content between males and females could be attributed to the effects of both exogenous and endogenous factors (El, Chetoui, Darej, & Moujahed, 2019).

4.2 Impact of seasonal variations on oil quality (Iodine value)

The study also assessed the impact of seasonal variations on the *L. gossei* fish oil quality through IV determination during rainy, cool-dry, and hot-dry seasons. The results are presented in Table 3.

Table 3: Impact of season variations on *L. gossei* fish oil quality

Season	Iodine Value (gl₂/100 g)
Rainy	153.62±3.21 ^a
Cool-dry	165.01±2.30 ^a
Hot-dry	238.48±2.36 ^b

Means in the same column with different superscript letters are significantly different at $p < 0.05$.

The iodine value (IV) is used to measure the degree of unsaturation of lipids that defines the quality of the oil. The higher IV the more unsaturated the lipid is. In Table 3, the hot-dry season has a higher IV than the cool-dry and rainy seasons which are not statistically different. The findings in the current study are in agreement with what (Gomes, de M, & Cabral, 2008) found in their study on the seasonal variation of fatty acid composition in the oils from tropical freshwater fish, *Oreochromis mossambicus* during hot-dry season. The increased PUFAs which are directly related to high IV in this study were also reported in the season. This would be attributed to the type of feed that *L. gosseii* feeds on such as algae and planktons that have increased PUFAs during the hot-dry season as reported by (Lavrentyev, et al., 2010). Additionally, there is an increased availability of invertebrates, algae, and small fish full of PUFAs as feed for fish during this season, resulting in a high IV, which signifies the increase in PUFAs (Kaunda, Kassam, & Msukwa, 2011). It is for that reason that *L. gosseii* just like any other similar species in a freshwater lake, accumulates higher levels of PUFAs in its oil-rich tissues when they feed on these PUFA-rich feeds. This makes the hot-dry season ideal for fishing and fish oil extraction activities for PUFAs with its health-beneficial effects such as brain development and functionality and heart health as reported by (Kokubun, Nemoto, & Yamakawa, 2020). This is in contrast to what (Lopes et al., 2021; Petenuci, et al., 2021) found in their studies on seasonal variation in fat acid composition in specific fish organs such as muscle, liver, gonads and viscera from various fresh and salty water bodies. The probable reason for the disparity is that their studies focused on the different fish species of different sizes, sexes, reproductive cycles, geographical locations and on one particular

body tissue from different fresh and salty water bodies. According to (Všetičková, Suchy, & Straková, 2020) these are potential causes of nutritional variation even during the same season and that justifies why their results are different from what this study reported since our focus was on a demersal freshwater fish species *L. gossei* as a whole only.

There was no significant difference between IV during the rainy and cold seasons (153.62 ± 3.21 g_l/100 g and 165.01 ± 2.30 g_l/100g), respectively ($p > 0.05$). This is because of the accessibility and abundance of fatty prey that are rich in PUFAs in these seasons as reported earlier in this study. Similar observations were made in the study on the fatty acid composition of *Lepidopsetta gossei* fish from the rainy and cold seasons in Japan by (Sano, et al., 2022). Fish mobilise such PUFAs during the cold season to keep themselves warm hence contributing to the fish's higher IV content. Despite the comparatively lower IVs across the seasons, the species *L. gossei* has a higher content of unsaturated fatty acids. This is because in all the seasons IVs have gone above 130 g_l/100 g, the value that is the indicator of higher PUFAs in oils (Dehghani, Moradi, & Abbasi, 2018). Therefore *L. gossei* fish is a very good source of PUFAs that can render numerous health-beneficial effects. These results are consistent with the findings of (Dehghani, Moradi, & Abbasi, 2018; Alam, et al., 2020), who reported that fish oils with IV more than 150 g_l/100 g are a rich source of the PUFAs, including omega 3.

4.3 Impact of sex on oil quality (Iodine value) of fish in different seasons

The results presented in Table 4 examine the influence of sex on fish oil quality through IV determination across seasons. The data include IV of the *L. gossei* fish species during the rainy, cool-dry, and hot-dry seasons.

Table 4: Impact of sex on oil quality of fish in different seasons

Season		Iodine Value (gl ₂ /100 g)
	Sex	
	<i>Male</i>	126.02±0.10 ^a
Rainy	<i>Female</i>	181.22±0.00 ^b
	<i>Male</i>	146.04±0.21 ^a
Cool-dry	<i>Female</i>	183.98±0.10 ^b
	<i>Male</i>	217.05±0.20 ^a
Hot-dry	<i>Female</i>	259.91±0.10 ^b

Means in the same column of a particular season with different superscript letters are significantly different at $p < 0.05$.

The current study shows that IV was higher (259.91 gl₂/100g) in females during the hot-dry season than in males caught from the same season. The males from the rainy season had the lowest IV (126.02 gl₂/100g). These findings are consistent with the study conducted by Ross, Connor, and Cahu (2007), which reported that female fish typically exhibit higher levels of PUFAs compared to their male counterparts. This was observed

in Atlantic *salmon*, where females demonstrated significantly higher levels of EPA and DHA in their plasma and livers as compared to males. Notably, during the hot-dry season, female *salmon* exhibited increased egg production during spawning, leading to the reported increase in PUFAs. Similarly, Ng and Wang (2012) found that female *Tilapia* had a high concentration of EPA and DHA, as they necessitate higher levels of PUFAs for egg development, unlike males.

The observed trends in *L. gossei* may be attributed to the essential role of PUFAs in egg development, prompting female fish to store more PUFAs in their bodies, resulting in high PUFA levels (Ng & Wang, 2012; Ross, Connor, & Cahu, 2007).

On the other hand, the reported trend of PUFAs in this *L. gossei* is not in line with the reports from the works of (Vassallo-Agius, et al., 2007; Jørgensen & Nævdal, 2008) who reported inverse trend in male *rainbow trout* having a higher level of EPA and DHA in their livers than female ones. This was attributed to the production of sperm during the spawning season. Likewise, the study done by (Jørgensen & Nævdal, 2008) also reported that male Atlantic cod had higher levels of EPA and DHA in their muscle tissue than female Atlantic cod. The inconsistency of the results can be related to the differences in fish species, sizes and a particular tissue like fish muscles, liver and viscera which are different from the whole fish, the current study focused on. Further to that, factors such as the species of fish, the diet of the fish, and the environmental conditions also contributed (Hossain, Al-Abdul-Elah, & Yaseen, 2019). Therefore, female *L. gossei* fish species of the freshwater lake Malawi across the seasons, are a potential source of the PUFAs for

various purposes such as oil extraction and provision of these healthy fats in the diet. This is because they offer a wide range of health benefits such as protecting against a wide range of psychological disorders, particularly depression, attention deficit hyperactivity disorder (ADHD) and NCDs, through different mechanisms (Kaur, Chugh, & Gupta, 2012; AlAmmar, et al., 2021; Kokubun, Nemoto, & Yamakawa, 2020).

4.4 Impact of season variations on mineral composition of *L. gossei* fish.

The effect of seasonal changes on the mineral composition of *L. gossei* was determined. The transition from the rainy season to the cool-dry and hot-dry seasons influenced the mineral concentrations, as shown in Table 5.

Table 5: Impact of season variations on the mineral composition of *L. gossei* fish

Season	Mineral composition in mg/100 g (Mean \pm SD)								
	Zn	Fe	Cd	Mn	Na	K	Mg	Ca	P
Rainy	1.08 \pm 0.10 ^a	7.81 \pm 2.30 ^a	0.03 \pm 0.00 ^a	0.88 \pm 0.10 ^a	175.12 \pm 2.30 ^a	257.86 \pm 4.81 ^a	26.21 \pm 0.10 ^a	1812.94 \pm 4.40 ^a	16.95 \pm 1.10 ^a
Cool-dry	2.24 \pm 0.11 ^b	6.21 \pm 1.21 ^a	0.06 \pm 0.00 ^b	1.80 \pm 0.21 ^b	237.98 \pm 3.01 ^a	348.94 \pm 3.72 ^a	50.55 \pm 0.51 ^b	3037.41 \pm 3.62 ^b	17.49 \pm 0.72 ^b
Hot-dry	2.58 \pm 0.10 ^c	7.76 \pm 1.30 ^a	0.07 \pm 0.00 ^b	1.36 \pm 0.29 ^c	182.97 \pm 4.30 ^a	289.96 \pm 5.64 ^a	57.93 \pm 1.11 ^c	3524.33 \pm 5.61 ^c	18.12 \pm 0.12 ^b

Means in the same column with different superscript letters are significantly different at $p < 0.05$.

Zinc and Cd concentrations were increasing with significant differences at $p < 0.05$ from rainy through cool-dry to hot-dry season. Zinc content was within the ranges (0.23 -2.1 mg/100g) recommended by the (FAO/WHO, 2001) throughout the seasons. Although *L. gosseii* contains less, 1.96 mg/100g on average across the season than RDA of 8–11 mg/100 g of food for adults, the fish can still be considered as a potential source of zinc and may be incorporated in different foods for children with stunted growth and to reduce the zinc deficiency prevalences in Malawi being estimated to be 37% among the children (Kaudzu, 2021). Apart from that, it boosts immunity, and control inflammations, gene expression and cellular growth in the body (Mogobe, Mosepele, & Masamba, 2015). These findings are consistent with what (Alas, Ozcan, & Harmankaya, 2014) reported in their studies of various fish species. The observed variation in different seasons could be due to the seasonal changes that influence water temperature, feed composition and reproduction demand activity of the fish (Abdulkarim, Bwathondi, & Benno, 2015). The increase in Zn and Cd in the hot-dry season is in agreement with what (Phoungphet, Laohakul, & Phoungchan, 2019; Velcheva, 2018) reported on seasonal variation of trace element concentrations in freshwater fish species from the Lakes and rivers of Bulgaria and China, respectively. In our findings, this could be attributed to the feed composition in the hot-dry season that is more likely to be Zn-rich and their activeness with zinc-demanding processes such as growth and reproduction processes. Additionally, fish tend

to consume more food in this season, leading to increased absorption of large amounts of minerals via diffusion or active absorption (Velcheva, 2018; He, Wang, & Xie, 2006). Despite the presence of Cd in the samples during the hot-dry season, the *L. gossei* fish is safe for consumption because what the species contain as the highest concentration (0.007 mg/100g), is less than what is considered safe (0.2 mg/100g) in the international Codex Alimentarius Commission (He, et al., 2023).

There were no significant differences ($p < 0.05$) in terms of iron, sodium and potassium content across seasons. The findings are in agreement with what (Chen, Wang, & Chen, 2022; Phoungphet, Laohakul, & Phoungchan, 2019) reported that these minerals from different freshwater fish species are stable in all seasons. This is due to the fact that most of the fish species including *L. gossei* require these elements in small quantities, so any excess may not be absorbed, so long as the body has enough for the metabolic processes. Notably, the whole fish samples of this species had higher concentrations of Na and K in all seasons compared to other studies that used fillets or one particular body tissue. This implies that this fish could be used as a good source of minerals if consumed whole as it was studied. Differences in the rate at which these minerals are available in the lake and the fish's ability to absorb and convert them from their diet or the water bodies could be the reasons for the observed variations (Ahmed, et al., 2017). Furthermore, the use of whole fish samples in this study, contributed to these results, since fish bones and liver are naturally rich in these minerals, it is not surprising that this study reports higher contents than what is recommended by FAO recommends (30-134 mg/100g) and studies that focused on particular tissues like fillets only (Wang & Rainbow, 2010). This is

different from iron which was less than what FAO recommend, 24-27 mg/100g as a daily required intake in (2001). This could be linked to low levels of iron in the water, hence less trophic transfer and accumulation in the body tissues of *L. gosseii* fish. However, in a plate of 100 g of *L. gosseii* fish, for example, can be a source of the highly bioavailable Fe, Na and K regardless of the year. Therefore, it can provide essential nutrients for overall well-being and help combat a hidden hunger that is being faced by the country (FAO/WHO, 2001; Kaudzu, 2021). Whereas Mn, Mg, Ca and K are significantly different ($p < 0.05$) in each season, in order of increasing fashion from the rainy through cold to hot-dry season. However, these findings indicate that in all seasons, *L. gosseii* fish samples still have an appreciable concentration of these minerals suggesting that this fish could be used as a potential source of these minerals for various nutritional interventions.

The lowest concentrations of Mn, Mg, Ca and P were reported in the rainy season with the mean averages of 26.21, 1812.94, 26.21 and 16.95 mg/100g, respectively. The hot-dry season reported the highest concentrations of these minerals with 57.93, 57.93, 3524.33 and 18.12 mg/100g, respectively. The concentration ranges of Mn and Ca in all the seasons, was way higher than what FAO/WHO recommends (0.0003-25.2 mg/100g and 1000-1300 mg/100g) (FAO/WHO, 2001), respectively. Unlike Mg which was within the FAO (4.5-452 mg/100 g) and P was lower than the FAO/WHO recommendation range of 68-55mg/100g as a daily intake in all seasons. These findings are in agreement with what (Shija, Mihale, & Shilla, 2020) found in the hot-dry season, attributing it to the increased metabolic and physiological processes as a result of the elevated temperatures, hence bioaccumulation and utilization of these minerals (Shija, Mihale, & Shilla, 2020).

On the other hand, these findings are not in agreement with what is reported elsewhere by (Abdulkarim, Bwathondi, & Benno, 2015; Ndondo, Mwamfupe, Mvungi, & Mfinanga, 2016) who argued that P, Mn and Ca content of Lake Tanganyika's *Lates niloticus*, *Oreochromis niloticus*, and *Rastrineobola argentea* is not affected by the season. Nevertheless, *L. gosseii* fish are a better source of Mn, Mg, K and Ca (204 - 230 mg/100g) than terrestrial meats (176 mg/100 g). For instance, the recommended dietary intake (RDI) for Ca ranges from 400 to 500 mg/d for adults according to WHO/FAO, yet *L. gosseii* has more than these requirements in all seasons. Potassium together with Ca and Mg, acts as a major constituent of bones (Ahmed, et al., 2017; Alas, Ozcan, & Harmankaya, 2014). Therefore, consuming *L. gosseii* as a whole provides a potential source of a wide range of essential macro and micro minerals across seasons.

4.5 Influence of Sex on the Mineral Composition of *L. gosseii* Fish in Different Seasons

The mineral composition of male and female *L. gosseii* was also analysed in all the seasons to determine the sex that retains or loses more mineral content as presented in the Table 6.

Table 6: Impact of sex on the mineral composition of *L. gosseii* fish in different seasons

Season	Mineral composition in mg/100g (Mean ± SD)									
	Sex	Zn	Fe	Cd	Mn	Na	K	Mg	Ca	P
Rainy	Male	1.21±0.00 ^a	5.74±1.12 ^a	0.03±0.00 ^a	1.01±0.00 ^a	140.16±2.21 ^a	160.39±5.36 ^a	26.14±1.11 ^a	1890.91±3.30 ^a	15.95±2.21 ^a
	Female	0.95±0.00 ^b	9.88±1.10 ^b	0.03±0.00 ^a	0.76±0.00 ^b	210.08±1.10 ^b	355.32±3.00 ^b	26.27±2.20 ^a	1734.96±3.31 ^b	17.96±1.10 ^b
Cool-dry	Male	2.16±0.00 ^a	7.28±2.21 ^a	0.06±00 ^a	1.95±0.00 ^a	216.99±1.10 ^a	341.92±1.10 ^a	50.97±1.10 ^a	3070.84±3.30 ^a	18.08±2.21 ^a
	Female	2.31±0.00 ^b	5.14±1.10 ^b	0.06±00 ^b	1.65±1.11 ^b	258.97±2.21 ^b	355.96±1.10 ^b	50.14±2.21 ^b	3003.98±2.23 ^b	16.90±1.10 ^b
Hot-dry	Male	2.47±1.10 ^a	9.11±2.21 ^a	0.06±00 ^a	1.69±0.00 ^a	100.95±1.10 ^a	126.93±2.21 ^a	58.93±1.10 ^a	3641.76±2.21 ^a	18.11±1.11 ^a
	Female	2.69±0.00 ^b	6.40±1.10 ^b	0.07±00 ^b	1.02±0.00 ^b	265.00±1.10 ^b	452.98±2.21 ^b	56.93±2.21 ^b	3406.91±2.20 ^b	18.14±1.12 ^a

Means in the same column of the specific season with different superscripts letters are significantly different at $p < 0.05$.

The quantitative relationship of macro minerals (Ca, K, Na, Mg and P) in both male and female *L. gossei* is decreasing order during the rainy season, with a similar pattern observed for trace elements (Fe, Zn, and Mn). In this season, macro and microelement levels were significantly different between males and females ($p < 0.05$), except for Mg and Cd. A similar trend was seen during the cool-dry and hot-dry seasons for both macro and trace minerals, with significant differences between sexes, except that phosphorus levels remained stable in both males and females during the hot-dry season.

Phosphorus was highest in females (452.98 mg/100g) and lowest in males (126.93 mg/100g) during the hot-dry season. Na was highest in females (265.00 mg/100g) and lowest in males (100.95 mg/100g) during the hot-dry season. Mg concentration was highest in females (58.93 mg/100g) during the hot-dry season, with the lowest levels recorded during the rainy season. These findings align with those of Durmuş et al. (2017) and Kulcu (2017; 2014), who noted that sex and season impact mineral and proximate composition of red mullet (*Mullus barbatus Linnaeus 1758*) caught from the Middle Black Sea and North-eastern Mediterranean Sea, and calcium and phosphorus of roach (*Rutilus rutilus L.*) respectively.

The increased mineral content in the female samples might be attributed to the sex hormones like oestrogen during the pre-spawning period, which plays a role in bone

mineralization (Carvalho, et al., 2016). Lall & Kaushik, (2021) reported that calcium levels in females rise during reproductive seasons, as calcium is bound to vitellogenin, a key egg protein. This increased demand for Ca and P during the hot-dry season aids in building strong bones and supporting egg development (Lall & Kaushik, 2021). As a result, female *L. gosseii* fish is a better source of macro minerals in the hot-dry season, though male fish also contain adequate mineral levels for adult dietary intake. The study, therefore, concludes that female *L. gosseii* fish samples are the best source of essential macro minerals during the hot-dry season. However, males also can be considered since the concentration of the macro minerals in fish is within the recommended dietary intake for adults as reported earlier in this study.

In terms of trace elements, female *L. gosseii* fish species are a good source of Fe for physiological functions in the body, although our findings (9.88 mg/100g) differ from those of Mogobe et al (2015) who reported higher Fe levels (13 mg/100g) in different fish species from the Okavango Delta and Bangladesh. This variation could be due to the variations in environmental conditions, fish feed composition, water quality, and fish species studied as reported earlier in this study. Zinc content was higher in females (2.69 mg/100g) during the hot-dry season, exceeding FAO recommendations (0.23-2.1 mg/100g), although slightly lower than reported in other studies, likely due to competition in the absorption pathway in fish (Abelti, 2017). For Mn, male *L. gosseii* from the cool-dry season are richer sources than females from during the rainy season which had the lowest. In terms of toxicity levels of Cd, the *L. gosseii* fish species is safe for human consumption even though female ones in the hot-dry season have 0.07

mg/100g is still lower than what different international standards recommend (0.3mg/100g in the European Union, 0.25mg/100g in Australia and 0.2mg/100g in the international Codex Alimentarius Commission) for Cd exposure in the aquatic products (He, et al., 2023).

Most macro minerals (Ca, P, K, Mg) were higher in females, except Mn, Zn, and Fe, which varied between sexes and seasons, with the lowest levels recorded in the rainy season. The lowest in both males and females is found in the rainy season. Reproductive activity and mineral interactions likely contributed to the observed sex differences in Fe, Zn, and Mn (Carvalho, et al., 2016; Lall & Kaushik, 2021).

4.6 Impact of fish processing technique on the proximate composition of the *L. gossei* Fish

Given that fish consumption often involves exposure to various processing and preparation methods, this study further investigated the impact of boiling, smoking and solar drying techniques on proximate and mineral composition. The smoking and solar drying techniques are most commonly practiced during the hot-dry season when fish is susceptible to deteriorating conditions. Whereas boiling is the common method of preparation of fish for consumption as relish by the majority of Malawians. Table 7 presents the study's findings, showing how these processing techniques affect the proximate composition of the *L. gossei* fish.

Table 7: Impact of processing techniques on the proximate composition of the *L. gossei* fish

Processing technique	Proximate composition			
	MC (%)	Ash (%)	Protein (%)	Fat (%)
Fresh	65.06±2.63 ^c	18.72±1.21 ^{bc}	12.62±0.21 ^a	27.85±10.21 ^b
Boiling	59.68±0.41 ^b	9.36±1.12 ^a	10.35±1.10 ^a	12.81±4.00 ^a
Smoking	12.04±3.40 ^a	17.95±0.83 ^b	33.60±2.02 ^c	13.95±1.71 ^a
Solar drying	9.89±0.91 ^a	20.98±2.81 ^c	19.36±4.41 ^b	27.50±8.62 ^b

Means in the same column with different superscript letters are significantly different at $p < 0.05$.

Results in Table 7, show that moisture contents of both smoked and solar-dried fish were not significantly different because the processes involve heat that aids in the removal of

the via evaporation (Likongwe, et al., 2017). Even though there are observable differences between smoking and solar drying, such differences are not statistically significant ($P > 0.05$) as indicated in table 7. The observable increase in MC of the boiled samples is related to the absorption of water by the samples during the boiling process. However, the moisture content of the boiled fish was lower than the control. This may be attributed to the heat application during the boiling process which leads to the denaturation of proteins and the breakdown of cell structures within the fish. As a consequence, water is released from the fish tissues in the form of steam, contributing to the reduction in moisture content (Abraha B. , et al., 2018; Akintola, 2014; Likongwe, Kapute, Mtethiwa, & Sikawa, 2017). The comparable decrease in moisture content in processed *L. gosseii* fish is within the acceptable limit of 15% to prevent spoilage microbial contamination (Tenyang, Ponka, Tiencheu, & Djikeng, 2020). This limit is very important because it reduces the fish's susceptibility to microbial spoilage and oxidative degradation of PUFAs, which consequently improves the quality of the fish and extends its shelf life (Ünal, et al., 2013).

The ash content of the fish was significantly different from one processing technique to another. Unlike the ash contents of the smoked and solar-dried fish which were not significantly different from the control sample. This means that smoking and solar drying do not lead to the loss of most of the minerals present in fish. However, the slight increase of the ash content in solar-dried *L. gosseii* fish can be explained by the loss of moisture during processing through evaporation, which causes the minerals to become more concentrated as a result of water dehydration (Tenyang, et al., 2020). Additionally,

the study reports high ash content (16.75%) than the mean average of 3.46% reported by (Tenyang, et al., 2022; Abraha B. , et al., 2018; Tenyang, et al., 2020) in the similar hot-dry season. This huge difference could be attributed to the inclusion of bones and scales as a whole *L. gossei* fish sample was used in this study contributing to the high ash content found in this study. The boiling technique reduced ash content by half when compared to the control sample. This is in line with the findings of (Abraha, et al., 2018; Holma, Ayinsa, & Maalekuu, 2013; Goswami & Manna, 2020) in their studies on the effects of different processing methods in various fish species on the proximate composition of fish. Boiling led to the loss of the mineral components of the *L. gossei* fish because the process led to leaching out of the water-soluble minerals from the fish into the processing water which was discarded (Goswami & Manna, 2020).

The protein content of the samples was significantly different ($p < 0.05$) from one processing technique to another. Protein contents were high in smoked fish (33.60%), and then solar-dried fish (19.36%) and lowest in boiled fish (10.35%). These findings are within the range of 16.4 -36.0% which was reported by (Tenyang, et al., 2022; Holma, Ayinsa, & Maalekuu, 2013). The increased crude protein content of solar-dried and smoked fish samples in this study could be a result of the loss of moisture content from the samples via evaporation due to heat that led to the protein concentration, hence the increase (Holma & Maalekuu, 2013). In addition, this indicates that these two processing techniques retain more nitrogen content as a component of protein than boiling. This is because these techniques involve less heat application for a prolonged drying period, hence preserving the structural integrity of proteins, thereby reducing the likelihood of

protein denaturation and subsequent nitrogen loss (Pathania, Parmar, & Tiwari, 2019). The boiled fish protein content was not significantly ($P > 0.05$) different from the control. However, some of the proteins decrease as a result of the loss of more soluble proteins that are found in muscle tissues like myofibrillar and sarcoplasmic contents of the fish muscle (Abraha, et al., 2018).

The highest fat content was recorded on solar-dried fish followed by the smoked fish and finally the boiled as indicated in Table 7. This huge difference between the solar-dried fish and the other samples is due to the oozing out of the oils from the fish and losses of oils into boiling water because of heat generated from the smoking and boiling processes respectively. This study's findings are in line with what (Golpolipour, Khodanazary, & Ghanemik, 2019; Tenyang, et al., 2020), reported in their studies that lipid content changes in fish during different cooking methods, such as frying, boiling, drying and steaming. Some fish processing techniques, such as smoking and boiling, significantly reduce oil content due to exposure to high temperatures. Boiling leads to fat leaching into the cooking water, while smoking causes fat to melt and drip away, as well as promoting oxidation of the lipids. Consequently, both methods physically decrease the fat content in the fish.

Additionally, smoking was shown to reduce most of the nutrients like proteins in the *L. gosseii* fish, this can be attributed to the fact that the smoke particles reacted with the nutrients in the fish leading to the formation of pyrene and benzo compounds that affect its nutritional quality (Kiczorowska, Samolińska, & Grela, 2019). However, these

compounds have a safety issue due to their potential carcinogenic properties (Fronthea, Titi, Augustini, & Ryard, 2015). Therefore, it is important to consider the effect of each processing technique on the nutritional composition and safety of the fish during and after processing since the different processing techniques influence their chemical and nutritional composition and the health of the consumer at large (Abraha et al., 2018).

4.7 Impact of sex on proximate composition of the processed *L. gossei* Fish

The investigation further evaluated the effects of boiling, solar-drying and smoking techniques on male and female *L. gossei*, with the findings detailed in Table 8.

Table 8: Impact of sex on proximate composition of the processed *L. gossei* fish

Processing technique	Proximate composition (Mean ± SD)				
	Sex	MC (%)	Ash (%)	Protein (%)	Fat (%)
Fresh	<i>Male</i>	67.44±0.23 ^a	17.62±0.21 ^a	12.71±0.23 ^a	18.49±0.00 ^a
	<i>Female</i>	62.68±0.30 ^b	19.83±0.01 ^b	12.54±0.11 ^a	37.20±0.11 ^b
Boiling	<i>Male</i>	59.42±0.22 ^a	10.33±0.20 ^a	11.38±0.20 ^a	9.19±0.01 ^a
	<i>Female</i>	59.94±0.41 ^a	8.39±0.31 ^b	9.32±0.10 ^b	16.43±0.30 ^b
Smoking	<i>Male</i>	10.70±0.30 ^a	23.53±0.10 ^a	15.41±0.32 ^a	19.69±0.13 ^a
	<i>Female</i>	9.08±0.00 ^b	18.43±0.00 ^b	23.36±0.14 ^b	35.30±0.10 ^b
Solar drying	<i>Male</i>	10.70±0.31 ^a	23.53±0.11 ^a	15.41±0.30 ^a	19.69±0.11 ^a
	<i>Female</i>	9.08±0.00 ^b	18.43±0.02 ^b	23.36±0.10 ^b	35.30±0.13 ^b

Means in the same column for a specific processing technique, marked with different superscript letters, are significantly different at $p < 0.05$.

The impact of sex on the proximate composition of boiled, smoked and solar-dried *L. gossei* fish is presented in Table 8. The sex variation of *L. gossei* in different processing techniques affected some of the proximate composition of the fish. Interestingly, the boiling process slightly lowered the MC compared to the control, the male had significantly higher MC than female samples. This can be attributed to the fact that the boiling process causes proteins to denature and breaks down cell structures in the fish. Consequently, moisture is released from the fish tissues in the form of steam, resulting in a decrease in moisture content as explained earlier. However, of all the processing techniques, at least boiled female samples retained MC (59.94%) and the lowest were found in the smoked (9.08%) and solar-dried (9.08%) female samples. These findings are consistent with what was reported by (Rukshana, Majeed, & Asmath, 2021; Noel, et al., 2022) in *Skipjack Tuna (Katsuwonus pelamis Linnaeus, 1758)* and *polypterus bichir* fish species. The observed trends of MC in boiled fish could be attributed to the prolonged fish contact with both boiling water and steam during the boiling process. Whereas the evaporation of fish and water during smoking and solar drying explains the lowest moisture content registered, as reported by (Likongwe, et al., 2017)

Sex variation is reported to have a significant difference in the ash content in all the processing techniques whereby all the male fish had on average a higher (18.75%) ash content compared to 16.27% of their female counterparts. The fresh samples exhibited a

higher ash content than the boiled ones. However, this relationship was reversed when comparing them with the smoked and solar-dried samples. The highest ash content was (23.53%) in solar-dried male fish and the lowest was in boiled female samples (8.39%). This finding is in line with the results reported by (El, et al., 2019) who found that the ash content of male fish was higher than the females even in *Scomber scombrus* (L. 1758) fillets from the Middle East Coast of Tunisia. Similarly, (Pereira, et al., 2013; Ayas, Ozogul, Ozogul, & Ucar, 2012), in their study of assessing the proximate composition of male and female fish species in the southern Gulf of Lake Tana in Ethiopia, reported increased ash in male fish samples than females. The possible explanation could be linked to the increased demand for minerals for reproduction and hormonal activities that play an important role in regulating growth and bone development in fish hence reflected in ash content (Fontaine & Cahu, 2012). This means that processing the male fish does not lead to a significant loss of the total mineral content of the fish but rather a slight increase more especially in the solar-dried samples because of the loss of water that led to the mineral concentrations in the fish sample.

The protein content of the processed fish ranged from 9.32% to 23.36% and the highest levels for both males and females were recorded in solar-dried samples. The results indicates that there is a significant difference ($P < 0.05$) between male and female fish regardless of the processing technique. Smoked and solar-dried female fish had the highest protein content of 23.36% than the control and male samples, unlike the boiled female fish which significantly lowered the protein to 9.32%. The possible explanation behind the increased protein in the smoked and solar-dried female fish could be due to

the increased concentration of insoluble proteins in the solar-dried samples (Abraha, et al., 2018). The study shows that the sex of the fish affected the fat content of the processed fish as reported by (El, et al., 2019). Processing male fish samples returned fat content except the boiled one which was lowest (9.19%). Likewise, the smoked and solar-dried females maintained fat content except the boiled which reported the lowest (16.43%). Generally, female samples had significantly higher fat content than male samples while smoking and solar drying techniques maintaining the level. However, these fat contents in females are higher than what (Chetoui, Darej, & Moujahed, 2019; Ross, Connor, & Cahu, 2007) reported in their studies. The probable reason for such findings is that *L. gossei* stores more fat before and during the spawning period that covers both hot-dry and rainy seasons before they quickly depleted in the cold-dry season (Usydus, Szlifder-Richert, & Adamczyk, 2012). The observed slight difference is related to the physiological differences between the male and female fish as reported earlier in this study.

4.8 Impact of Processing Technique on the Iodine Value

The evaluation of the influence of processing techniques on the degree of saturation of *L. gossei* fish samples' oil has been conducted. Table 9 presents the findings, illustrating the effects of boiling, solar-drying, and smoking on the Iodine Value of the fish samples.

Table 9: Effects of processing technique on Iodine Value

Processing technique	Iodine Value (gl ₂ /100g)
Fresh	238.71±4.32 ^c

Boiling	182.67±3.90 ^b
Smoking	144.95±2.01 ^a
Solar-drying	164.32±3.50 ^{ab}

Means in the same column with different superscript letters are significantly different at $p < 0.05$.

The iodine value (IV) is used to measure the degree of unsaturation of lipids. The higher the IV, the more unsaturated the lipids are and vice versa. In the instances where there was a higher iodine value and with time the value decreased, it could indicate the degree of occurrence of the oxidation process of the oil, the double bonds which would otherwise be covered by the iodine have been occupied with oxygen (Prabhakar, et al., 2020). The results in Table 9, show a significant difference ($p < 0.05$) between the fresh sample and the three processed samples. Boiled *L. gossei* fish samples retained IV which was not significantly different from the solar dried ones about the control and smoked samples. The smoked samples had the lowest IV of 144.95 gI₂/100g. The fact that processing lowers the IV of the fish is in agreement with what (Tenyang, et al., 2020; Tenyang, et al., 2022) reported in raw *Polypterus bichir bichir* oil, although he reported slightly higher values. However, the IV of *L. gossei* oil ranged from 144.95 to 238.71 gI₂/100 g oil, with raw samples having the highest. This signifies that *L. gossei* fish has high PUFAs such that it can be considered as a potential source of EPA and DHA which have been reported to have health-beneficial effects earlier in this study. Our study values are higher than 53.54 gI₂/100 g reported by (Djopnang, Francois, Eyango, & Womeni, 2018) in raw *menhaden and aji-aji*, and the Oil Quality of a Commercially Important

Freshwater Fish (*Chrysichthys nigrodigitatus*) oils from Malaysia. Probably the differences could be attributed to the differences of the fish species. However, the results reported in this study are slightly lower than 260 gI₂/100 g reported by (Tenyang, et al., 2022). The decrease in IV in the smoked fish samples is consistent with the findings of Rai et al., (2010) and (Tenyang, et al., 2017), who also reported a significant decrease in IV in smoked *Clupea harengus*. This decrease could be attributed to differences in fatty acids that occur when fish is exposed to heat from boiling, hot smoking, and solar drying due to the deactivated lipoxygenase enzymes that are responsible for the fat deterioration reactions (Wang, et al., 2013).

According to Tenyang, et al. (2017), high temperatures cause lipid oxidation in oils, which is why the raw fish sample had the highest IV. The combination of heat and smoke during smoking further oxidized the lipids and increased the susceptibility of unsaturated fatty acids (UFAs) to be attacked by free radicals (Tenyang, et al., 2022). This resulted in the reduction of the number of double bonds in the fatty acids, which led to a decrease in IV in the smoked fish samples. However, based on the findings, despite the observed decrease in the IV, *L gossei* is still a potential source of PUFAs in the diet that can be considered for various purposes.

4.9 Effect of sex on the Iodine Value of the fish in different processing techniques

The study revealed that the sex of the processed fish impacts their iodine value. The results of different processing techniques such as boiling, solar drying, and smoking on the IV of both male and female *L. gosseii* are presented in Table 10.

Table 10: Impact of sex on the Iodine Value of the fish in different processing techniques

Processing technique	Sex	Iodine Value (gI₂/100 g)
Fresh	<i>Male</i>	217.47±0.14 ^a
	<i>Female</i>	259.95±0.43 ^b
Boiling	<i>Male</i>	172.68±0.31 ^a
	<i>Female</i>	192.66±0.42 ^b
Smoking	<i>Male</i>	137.40±0.53 ^a
	<i>Female</i>	191.23±0.31 ^b
Solar-drying	<i>Male</i>	137.40±0.54 ^a
	<i>Female</i>	191.23±0.31 ^b

The means in the same column for a specific processing technique marked with different superscript letters are significantly different at $p < 0.05$.

The processing techniques affected the oil quality for both male and female fish differently. For the fresh samples, the IV was higher in female fish than the male ones. After processing the fish under the various techniques (Boiling, Smoking, and solar-drying), there was a significant ($p < 0.05$) decrease of IV in both sexes. The lowest IV (137.40±0.54 gI₂/100 g) was found in males from solar-dried and smoked and it was

more consistent than those from the boiled fish samples. However, the female fish samples were reported to conserve the IV ($192.66 \pm 0.42 \text{ gI}_2/100 \text{ g}$) from the boiled samples but not as well as unprocessed samples.

The findings of this study are consistent with those of Ross et al. (2007), who found that female Atlantic salmon have significantly higher levels of EPA and DHA in their plasma and livers than male ones. This is similar to what has been found in this study even after processing, the accumulation of PUFAs in female fish is still higher than their male counterparts. The reason for this difference may be related to the different reproductive roles of male and female fish that have been reflected in the processed samples. This is because the PUFAs are essential for the development of eggs in fish. As a result, female fish need to store more PUFAs in their bodies to produce healthy eggs. This is supported by the findings of Ng and Wang (2012) and Ross et al. (2007), who found that female fish have significantly higher levels of PUFAs in their eggs than male fish. This means that exposing fat degrading factors to oil from male or female *L. gossei* can only oxidise the PUFAs equivalent to their number leaving the excess, hence increased IV in the female simply means that more UFAs were not oxidised. Therefore, oils from the fish female samples have a higher degree of unsaturation hence a greater instability against rancidity (Ng & Wang, 2012).

4.10 Effect of Processing Technique on the Mineral Composition of *L. gossei* Fish

The mineral composition of the processed *L. gossei* was also determined after solar drying, boiling, and smoking to find out which techniques retain more or less mineral

composition. The results of the mineral composition of the processed *L. gossei* are presented in Table 11.

Table 11: Impact of processing technique on the mineral composition of *L. gossei* fish

Processing technique	Mineral composition in mg/100g (Mean ± SD)								
	Zn	Fe	Cd	Mn	Na	K	Mg	Ca	P
Control	2.50±0.3 ^b	7.81±1.5 ^a	0.07±0.0 ^c	1.36±0.4 ^a	183.46±90.4 ^a	290.21±178.6 ^b	57.78±1.0 ^{bc}	3535.05±100.4 ^c	18.41±0.2 ^a
Boiled	1.44±0.3 ^a	7.94±3.4 ^a	0.04±0.0 ^a	0.95±0.0 ^{ab}	160.07±26.9 ^a	127.52±3.5 ^a	25.65±2.9 ^a	1651.92±319.8 ^a	18.51±0.2 ^a
Smoked	2.89±0.4 ^b	26.06±16.3 ^b	0.07±0.0 ^c	1.72±0.4 ^b	210.36±22.2 ^a	388.84±23.0 ^b	58.67±4.7 ^c	3454.41±54.8 ^{bc}	17.86±1.1 ^a
Solar-dried	2.50±0.3 ^b	29.42±8.1 ^b	0.06±0.0 ^b	2.24±0.1 ^c	218.24±6.5 ^a	338.31±55.0 ^b	52.59±3.3 ^b	3203.41±226.9 ^b	17.72±0.6 ^a

Means in the same column with different superscript letters are significantly different at $p < 0.05$

The concentrations of minerals in the fish varied with the processing technique as shown in table 11. The values of the minerals present in the processed fish ranged between 0.04 to 3454.41 mg/100g. The mean Ca content of fresh *L. gossei* was $3,535.05 \pm 100.4$ mg/100 g. This was not significantly different from the 3454.42 mg/100 g content of the smoked samples. However, the values reported in this study are lower than 5,171 mg/100 g, which was reported by (Tenyang, Ponka, Tiencheu, & Djikeng, 2020) in raw *C. nigrodigitatus*. This may be due to differences in species' physiology or the inclusion of bones in our study. Boiling and solar drying significantly decreased the Ca content from 3,535.05 mg/100 g to 1,651.92 and 3203.41 mg/100 g for boiling and solar drying, respectively. These findings are consistent with the study by (Tiwo, Womeni, Tchoumboungang, Ndomou, & Linder, 2016), who determined the Ca content of boiled *Clarias Gariepinus* and *Cyprinus carpio* and observed a decrease from 205.40 for fresh to 141.00 mg/100g in Ca content of the processed. However, (Tenyang, et al., 2020) noted an increase in Ca content in smoked *C. nigrodigitatus*, which contradicts the findings of this study.

The potassium (K) content of unprocessed *L. gossei* ranged from 17-18 mg/100 g, and this remained the same in all the different processing techniques. This finding is in agreement with the findings of (Ackurt, 1991) who reported that some fish processing and cooking methods have little or no effect on their K content. However, it is

inconsistent with the rest of the minerals reported in this study which is in agreement with the findings of (Jim, Garamumhango, & Musara, 2017) and (Tenyang, et al., 2022) who together reported a decrease in K content in three ecosystem fish from Zimbabwe and far-north region of Cameroon, respectively. Potassium plays a crucial role in protein synthesis, control of heartbeat, muscle contraction, synthesis of nucleic acids and nerve conduction (Soetan et al., 2010). Therefore, the consumption of this species could potentially provide the reported health benefits.

Sodium (Na) as a macro element is essential for muscle functioning. The study revealed that the raw *L. gossei* had a Na content of 183.47 mg/100 g. Sodium was significantly higher ($p < 0.05$) in both the smoked and solar-dried samples compared to the fresh sample, with mean values of 210.36 mg/100 g and 218.24 mg/100 g, respectively. During processing, all treatments except boiling resulted in a significant increase in the Na content of *L. gossei*. The boiled samples had the lowest (160.07 mg/100 g) which is consistent with the findings of (Tenyang, et al., 2022) in boiled *Polypterus bichir bichir*. This is because the boiling results in the leaching out of the sodium ions into the cooking water as reported earlier in this study.

The magnesium (Mg) content of *L. gossei* ranged from 26 to 59 mg/100 g. Where the highest content was in smoked samples (57.93 mg/100 g) which was significantly different from other treatments but not the fresh sample. Boiling significantly ($p < 0.05$) decreased the Mg content of these fish samples, yet the levels are within the FAO range

of 4.5 to 452 mg/100 g (FAO/WHO, 2001). Sodium plays an important role in the blood plasma and aid in the normal functioning of the nervous system (Adeyemi, et al., 1013a).

The phosphorus (P) content of raw *L. gosseii* was 18.41 mg/100 g. This remained constant in all processed samples. This is consistent with what (Ackurt, 1991) reported that preservation techniques and methods of cooking do not significantly affect the mineral content of the fish, especially P. However, recent studies by (Kiczorowska, et al., 2019; Tenyang, et al., 2022) report that minerals including P are affected by boiling, smoking, and solar drying, contradicting our findings. This could be attributed to the variations in terms of fish species, methods of sample preparation and the part of the sample used. In our case, we used the whole fish sample.

The iron (Fe) content of solar-dried *L. gosseii* was 29.42 mg/100 g, which is significantly ($p < 0.05$) higher than the 21 mg/100g and 15.2 mg/100g reported in *rainbow trout* and smoked *Polypterus bichir bichir* by (Gokoglu, Yerlikaya, & Cengiz, 2004; Tenyang, et al., 2022), respectively. Boiling did not affect the iron content of *L. gosseii*, just like what (Ackurt, 1991) reported. The increased mineral content including Fe in *L. gosseii*, is in line with what (Tenyang, et al., 2020) reported, that there is an increase in Fe content in some smoked fish. The high Fe content of *L. gosseii* is of importance as it is an essential micronutrient that helps transport oxygen around the body. Therefore, consuming *L. gosseii* can help minimise the reported Fe deficiency, a public health concern, especially in the areas where this species is being consumed regularly.

The zinc (Zn) content of this species decreased significantly ($p < 0.05$) after boiling, while the content remained the same in the raw, smoked, and solar-dried samples. The lowest Zn content (1.44 mg/100 g) was found in the boiled samples. These findings are consistent with the findings of (Tenyang, et al., 2022) who reported a decrease in Zn content in fresh fish from 5.65 mg/100 g to 4.30 mg/100 g after boiling.

Manganese (Mn) was the least abundant microelement in *L. gossei* which was significantly higher in the solar-dried samples than in the other treatments, refer to table 11. Manganese functions better when combined with calcium and phosphorus in regulating enzyme activity in the body for various vital processes, contributing to bone formation and acting as a major constituent of bones. Therefore, *L. gossei* can be considered as a potential source of a wide range of essential macro- and micro minerals.

Cadmium was the least abundant trace element in *L. gossei*. Its concentration was significantly reduced in the boiled samples, followed by the solar-dried whereas smoked fish samples maintained the concentration. This means that *L. gossei* is safe for consumption with cooking methods like boiling, the levels are almost undetectable since boiling has reduced the Cd levels from 0.07mg/100g to 0.04.0 mg/100g. These levels are not very far from what is recommended by different standards on Cd exposure in aquatic products worldwide. The food limits of Cd are 0.0005–0.3mg/100g in the European Union, 0.005–0.25mg/100g in Australia, and 0.0003–0.2mg/100g in the international Codex Alimentarius Commission (CAC), respectively (He, et al., 2023).

This study has revealed that boiling significantly reduces most of the minerals compared to the other treatments like smoking and solar-drying which have significantly increased the concentrations of most of the determined minerals. The observed variation in mineral content in this study may be attributed to the changes caused by the thermal treatments of boiling, smoking, and solar drying. The loss of some minerals, such as Na, K, and Mg during the boiling process, could be related to their water-soluble property (Djopnang, et al., 2018). These minerals leached out during boiling from the broken cell walls of the fish, resulting in their release into the cooking water, which was discarded. This resulted in their loss which is reflected in table 11. The observed increase in most of the minerals in the smoked and solar-dried samples can be linked to the loss of water in the fish samples due to heat (Likongwe, et al., 2017). The loss of water in samples via evaporation led to the concentration and consequently increased the mineral content of the samples as determined in this study (Tenyang, et al., 2020). The study also revealed that all the macro- and microelements except Cd in *L. gosseii* are within 30-134 mg/100g, 19-502 mg/100g, 19-881 mg/100g, 4.5-452 mg/100g, 68-550,1-5.6 mg/100g, 0.23-2.1 mg/100g and 0.0003-25.2 mg/100g for Na, K, Ca, Mg, Fe, Zn and Mn, respectively. These ranges are within the recommended levels by the (FAO/WHO, 2001). As such, *L. gosseii* can potentially contribute to the minimization of the hidden hunger problem especially when processed using smoking and solar-drying techniques. Where boiling has been used, people should be encouraged to consume the fish together with the soup because it has the essential water-soluble and other minerals that have leached out of the fish during the boiling process.

In conclusion, this chapter has discussed the findings on the nutritional composition of *L. gosseii* from Lake Malawi. Seasonal variations significantly influence proximate composition, with the hot-dry season yielding higher protein, mineral content, and PUFAs, while the rainy season results in increased fat accumulation, especially in females. Effective processing techniques like solar drying and smoking are vital for maintaining nutritional quality. Additionally, sex variation affects PUFA content, and mineral composition analysis reveals essential nutrients. The iodine value highlights how processing methods impact oil quality emphasizing the need for targeted harvesting and processing strategies to enhance the fish's nutritional value.

CHAPTER 5

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

This chapter summarizes the findings of the study, focusing on the three key objectives. The determination of the proximate and mineral composition, as well as the iodine value of raw *L. gossei* in different seasons; analyzing these parameters in processed fish using various techniques; and comparing the nutritional profiles of male and female fish caught in different seasons. The results indicate that seasonal variations and processing methods significantly influence the nutritional quality of the fish, with notable differences observed between sexes.

5.0 Concluding objective one

The study determined that seasonal variations significantly affect the proximate and mineral composition of *L. gossei*. The hot-dry season emerged as optimal for harvesting, yielding fish with superior protein, mineral content, and PUFAs. In contrast, the rainy season resulted in higher fat accumulation, particularly in females, highlighting the importance of seasonal timing in fish harvesting for nutrient density.

5.1 Concluding objective two

The analysis of processed *L. gossei* revealed that processing techniques substantially influence the nutritional quality of the fish. Solar drying proved to be the most effective method for preserving ash and fat content, while smoking was identified as the best technique for retaining protein. These findings give a call for a proper choice of processing methods to maximize nutritional benefits.

5.2 Concluding objective three

The comparison of proximate and mineral composition between male and female *L. gossei* indicated that females exhibited richer PUFA content, particularly during the rainy season, while males generally presented different nutrient profiles. This information is crucial for optimizing harvesting strategies based on sex variation to enhance the nutritional value of the fish.

5.3 General Conclusion

In general, this study has provided critical insights into the nutritional composition of *L. gossei* from Lake Malawi, showing that seasonal variations, sex, and processing techniques significantly influence the fish's proximate, mineral, and lipid quality. The hot-dry season is the optimal season for harvesting, with fish displaying superior protein, mineral content, and polyunsaturated fatty acids (PUFAs) in both males and females. The rainy season, on the other hand, has the highest fat accumulation, while fish harvested during this period, especially females, are rich in PUFAs, making it an ideal time for

nutrient-dense consumption. Additionally, processing techniques have an impact, with solar drying being the most effective at preserving ash and fat content, while smoking was identified as the best method for retaining protein. These findings are highly relevant for guiding fish harvesting and processing practices.

By targeting specific seasons and processing techniques, fishermen, processors, and consumers can maximize the nutritional benefits of *L. gossei*. Moreover, policymakers in the fisheries industry can use this information to set quotas that balance the sustainable harvesting of this species with its nutritional and commercial value. Ultimately, the study highlights the need for seasonally optimized harvesting strategies and precise processing methods to meet both the health and economic demands in regions reliant on *L. gossei*.

5.4 Strengths and limitations of the study

5.4.1 Strength of the Study

The sampling of *L. gossei* was conducted at the right place where over 60% of the annual fish landings from the entire Lake Malawi occur. The use of the fisheries experts helped to identify the exact *L. gossei* fish, their sex, and the fishing vessel to help catch the fish from their deeper habitat of the lake. All these factors including the technical expertise of the team involved, have made the findings of the study a true reflection of the nutritional composition of the *L. gossei*.

5.4.2 Limitations of the study

This research focussed on the proximate and mineral composition, and IV as an indicator of fat quality only. The proposed fatty acid profiling was not conducted because of financial constraints. The study did not sample and analyse the nutritional composition of water sediment because of the lack of sampling equipment that could help us capture them from the depth where this fish species is found. Nevertheless, the efforts we managed to sample out the fish within the period that is considered the rainy, cool-dry and hot-dry season of the year according to the fisheries calendar.

5.5 Study implications

This study offers new insights into the proximate, mineral composition, and lipid quality of *L. gossei* from Lake Malawi, demonstrating that processing methods, sex, and seasonal variations significantly influence the fish's nutritional profile. The study implies that fishermen should focus on harvesting *L. gossei* during the rainy and hot-dry seasons to maximize nutritional and commercial benefits. This information is crucial for guiding public policy and decision-making on optimal fishing and processing practices to ensure both economic sustainability and improved nutritional outcomes in developing countries like Malawi. Additionally, the high-fat content throughout the seasons indicates *L. gossei*'s potential for oil extraction, making it a viable source for fish oil production year-round. The study further reveals that unprocessed, smoked, and solar-dried female *L. gossei* generally display superior nutritional quality, particularly in terms of fat content

and iodine values, compared to males, signifying their higher nutritional value across all seasons.

5.6 Recommendations for further studies

1. Future studies should focus on the characterization of fatty acids and amino acids in *L. gossei* across different seasons and after applying various processing techniques. This will help identify the season with optimal nutritional quality and processing methods that retain the nutritional quality of *L. gossei* for oil extraction and provide insights for dietary interventions aimed at managing non-communicable diseases (NCDs).
2. Further research is necessary to explore how storage conditions affect the quality of *L. gossei* fish oil across different seasons, providing insights that could optimize storage practices for its use as a dietary supplement and functional food ingredient.
3. Additionally, research on fish feed formulations that enhance the nutrient composition of *L. gossei*, particularly its fatty acids and amino acids, could play a crucial role in improving food security and economic development in regions dependent on fisheries.

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APPENDICES:

APPENDIX 1: SELECTED DATA OUTPUTS FROM ONE-WAY ANOVA AND -T-TEST

Appendix 1.1: One-way ANOVA output: Impact of the season on proximate composition of the processed L. gossei Fish

		Descriptives							
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Moisture content in %	Rainy	3	35.5900	2.28274	1.05685	32.8233	38.2567	32.73	38.15
	Cool dry	3	58.1033	.30225	.34385	57.2194	58.9872	57.06	59.18
	Hot dry	3	65.0683	2.23099	.96795	62.2401	67.2165	62.31	67.63
	Total	9	52.7906	13.00468	3.06523	46.3235	59.2576	32.73	67.63

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Moisture content in %	Rainy	Cool dry	-22.56333*	1.20336	.000	-25.6890	-19.4377
		Hot dry	-29.18833*	1.20336	.000	-32.3140	-26.0627
	Cool dry	Rainy	22.56333*	1.20336	.000	19.4377	25.6890
		Hot dry	-6.62500*	1.20336	.000	-9.7507	-3.4993
	Hot dry	Rainy	29.18833*	1.20336	.000	26.0627	32.3140
		Cool dry	6.62500*	1.20336	.000	3.4993	9.7507
Total ash content in%	Rainy	Cool dry	-10.07583*	.73154	.000	-11.9760	-8.1757
		Hot dry	-11.30383*	.73154	.000	-13.2040	-9.4037
	Cool dry	Rainy	10.07583*	.73154	.000	8.1757	11.9760
		Hot dry	-1.22800	.73154	.245	-3.1281	.6721
	Hot dry	Rainy	11.30383*	.73154	.000	9.4037	13.2040

Appendix
way
output:
processing
on the
composition
gossei fish

		Cool dry	1.22800	.73154	.245	-.6721	3.1281
Crude protein in %	Rainy	Cool dry	2.46500*	.55626	.001	1.0201	3.9099
		Hot dry	-3.19283*	.55626	.000	-4.6377	-1.7480
	Cool dry	Rainy	-2.46500*	.55626	.001	-3.9099	-1.0201
		Hot dry	-5.65783*	.55626	.000	-7.1027	-4.2130
	Hot dry	Rainy	3.19283*	.55626	.000	1.7480	4.6377
		Cool dry	5.65783*	.55626	.000	4.2130	7.1027
Crude fat in %	Rainy	Cool dry	18.17167*	4.39435	.002	6.7575	29.5859
		Hot dry	2.51000	4.39435	.837	-8.9042	13.9242
	Cool dry	Rainy	-18.17167*	4.39435	.002	-29.5859	-6.7575
		Hot dry	-15.66167*	4.39435	.007	-27.0759	-4.2475
	Hot dry	Rainy	-2.51000	4.39435	.837	-13.9242	8.9042
		Cool dry	15.66167*	4.39435	.007	4.2475	27.0759

1.2: One-
ANOVA
Impact of
techniques
proximate
of the L.

*. The mean difference is significant at the 0.05 level.

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Moisture content %	Control	3	65.0583	2.63099	.96795	62.2401	67.2165	62.31	67.63
	Boiled	3	59.6810	0.41449	.96121	57.0191	61.9609	55.47	62.76
	Smoked	3	12.0450	3.30437	1.33717	8.5477	15.4223	8.83	15.35
	Solar dried	3	9.8933	.91358	.40481	8.8727	10.9539	8.93	11.00
	Total	12	36.5292	26.30395	5.36927	25.4220	47.6364	8.83	67.63
Total ash content %	Control	3	18.7213	1.21088	.42045	17.4905	19.6521	17.45	19.86
	Boiled	3	9.7640	1.12837	.53822	8.1415	10.9085	8.21	11.33
	Smoked	3	17.6850	1.23992	.50619	16.3838	18.9862	15.63	18.92
	Solar dried	3	20.9750	2.59165	1.05804	18.2552	23.6948	18.40	23.58
	Total	12	16.6891	4.66547	.95233	14.7190	18.6591	8.21	23.58
Crude protein %	Control	3	12.6247	.20897	.10164	12.4454	12.9679	12.46	13.05
	Boiled	3	10.3537	1.10630	.50880	8.9588	11.5746	8.81	11.62
	Smoked	3	33.6033	2.02826	.79537	31.6288	35.7179	31.74	35.62

	Solar dried	3	19.3583	4.40567	1.74553	14.8213	23.7954	15.06	23.47
	Total	12	18.9888	9.56927	1.95332	14.9480	23.0295	8.81	35.62
Crude fat %	Control	3	27.8543	10.21422	4.20668	16.8047	38.4319	17.54	37.27
	Boiled	3	12.8650	4.00632	1.75805	8.3558	17.3942	8.66	17.97
	Smoked	3	13.9517	1.74671	.63144	12.5385	15.7848	12.17	15.82
	Solar dried	3	27.5017	8.65021	3.41917	18.6724	36.2509	19.63	35.37
	Total	12	20.5292	9.71546	1.98316	16.4267	24.6316	8.66	37.27

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Processing technique	(J) Processing technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Moisture content %	Control	Boiled	5.23833*	1.38072	.006	1.3738	9.1029
		Smoked	52.74333*	1.38072	.000	48.8788	56.6079
		Solar dried	54.81500*	1.38072	.000	50.9505	58.6795
	Boiled	Control	-5.23833*	1.38072	.006	-9.1029	-1.3738
		Smoked	47.50500*	1.38072	.000	43.6405	51.3695
		Solar dried	49.57667*	1.38072	.000	45.7121	53.4412
	Smoked	Control	-52.74333*	1.38072	.000	-56.6079	-48.8788
		Boiled	-47.50500*	1.38072	.000	-51.3695	-43.6405
		Solar dried	2.07167	1.38072	.456	-1.7929	5.9362
	Solar dried	Control	-54.81500*	1.38072	.000	-58.6795	-50.9505
		Boiled	-49.57667*	1.38072	.000	-53.4412	-45.7121
		Smoked	-2.07167	1.38072	.456	-5.9362	1.7929
Total ash content %	Control	Boiled	9.04633*	.95972	.000	6.3601	11.7325
		Smoked	.88633	.95972	.793	-1.7999	3.5725

		Solar dried	-2.40367	.95972	.090	-5.0899	.2825
Boiled		Control	-9.04633*	.95972	.000	-11.7325	-6.3601
		Smoked	-8.16000*	.95972	.000	-10.8462	-5.4738
		Solar dried	-11.45000*	.95972	.000	-14.1362	-8.7638
Smoked		Control	-.88633	.95972	.793	-3.5725	1.7999
		Boiled	8.16000*	.95972	.000	5.4738	10.8462
		Solar dried	-3.29000*	.95972	.013	-5.9762	-.6038
Solar dried		Control	2.40367	.95972	.090	-.2825	5.0899
		Boiled	11.45000*	.95972	.000	8.7638	14.1362
		Smoked	3.29000*	.95972	.013	.6038	5.9762
Crude protein %	Control	Boiled	2.44000	1.40512	.332	-1.4928	6.3728
		Smoked	-20.96667*	1.40512	.000	-24.8995	-17.0338
		Solar dried	-6.60167*	1.40512	.001	-10.5345	-2.6688
	Boiled	Control	-2.44000	1.40512	.332	-6.3728	1.4928
		Smoked	-23.40667*	1.40512	.000	-27.3395	-19.4738

		Solar dried	-9.04167*	1.40512	.000	-12.9745	-5.1088
	Smoked	Control	20.96667*	1.40512	.000	17.0338	24.8995
		Boiled	23.40667*	1.40512	.000	19.4738	27.3395
		Solar dried	14.36500*	1.40512	.000	10.4322	18.2978
	Solar dried	Control	6.60167*	1.40512	.001	2.6688	10.5345
		Boiled	9.04167*	1.40512	.000	5.1088	12.9745
		Smoked	-14.36500*	1.40512	.000	-18.2978	-10.4322
Crude fat %	Control	Boiled	14.74333*	4.05440	.008	3.3953	26.0913
		Smoked	13.45667*	4.05440	.017	2.1087	24.8047
		Solar dried	.15667	4.05440	1.000	-11.1913	11.5047
	Boiled	Control	-14.74333*	4.05440	.008	-26.0913	-3.3953
		Smoked	-1.28667	4.05440	.989	-12.6347	10.0613
		Solar dried	-14.58667*	4.05440	.009	-25.9347	-3.2387
	Smoked	Control	-13.45667*	4.05440	.017	-24.8047	-2.1087
		Boiled	1.28667	4.05440	.989	-10.0613	12.6347

	Solar dried	-13.30000*	4.05440	.018	-24.6480	-1.9520
Solar dried	Control	-.15667	4.05440	1.000	-11.5047	11.1913
	Boiled	14.58667*	4.05440	.009	3.2387	25.9347
	Smoked	13.30000*	4.05440	.018	1.9520	24.6480

*. The mean difference is significant at the 0.05 level.

Appendix 1.3: One-way ANOVA output: Impact of Season on Mineral Composition of the Processed L. gossei Fish

		Descriptives							
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
mg/100g									
Zn	Rainy	3	1.1117	.13805	.05636	.9668	1.2565	.91	1.21
	Cool dry	3	2.2367	.08595	.03509	2.1465	2.3269	2.14	2.32
	Hot dry	3	2.5033	.25232	.10301	2.2385	2.7681	2.05	2.71

	Total	9	1.9506	.64157	.15122	1.6315	2.2696	.91	2.71
Fe	Rainy	3	7.8467	2.30656	.94165	5.4261	10.2673	5.64	10.06
	Cool dry	3	6.2600	1.13733	.46431	5.0664	7.4536	5.01	7.48
	Hot dry	3	7.7583	1.49245	.60929	6.1921	9.3246	6.32	9.37
	Total	9	7.2883	1.77808	.41910	6.4041	8.1725	5.01	10.06
Cd	Rainy	3	.0317	.00983	.00401	.0213	.0420	.02	.05
	Cool dry	3	.0650	.00837	.00342	.0562	.0738	.06	.08
	Hot dry	3	.0633	.00816	.00333	.0548	.0719	.05	.07
	Total	9	.0533	.01782	.00420	.0445	.0622	.02	.08
Mn	Rainy	3	.8630	.16468	.06723	.6902	1.0358	.65	1.04
	Cool dry	3	1.8133	.18522	.07562	1.6190	2.0077	1.57	2.02
	Hot dry	3	1.3083	.37070	.15134	.9193	1.6974	.90	1.70
	Total	9	1.3282	.46698	.11007	1.0960	1.5604	.65	2.02
Na	Rainy	3	171.3800	36.32315	14.82886	133.2612	209.4988	137.72	216.97

	Cool dry	3	235.4467	23.70777	9.67866	210.5669	260.3264	215.09	268.23
	Hot dry	3	185.1283	92.68848	37.83991	87.8577	282.3989	99.89	277.05
	Total	9	197.3183	62.31509	14.68781	166.3298	228.3069	99.89	277.05
K	Rainy	3	256.6000	105.47142	43.05853	145.9145	367.2855	159.15	357.11
	Cool dry	3	348.5233	7.44907	3.04107	340.7060	356.3406	341.02	356.59
	Hot dry	3	289.2033	177.94992	72.64775	102.4563	475.9503	126.25	453.81
	Total	9	298.1089	118.89018	28.02269	238.9862	357.2316	126.25	453.81
Mg	Rainy	3	25.7227	1.33138	.54353	24.3255	27.1199	23.09	26.78
	Cool dry	3	50.6417	.60734	.24794	50.0043	51.2790	49.96	51.50
	Hot dry	3	58.2967	1.84144	.75177	56.3642	60.2291	56.73	61.58
	Total	9	44.8870	14.36684	3.38630	37.7425	52.0315	23.09	61.58
Ca	Rainy	3	1841.520 0	64.58669	26.36741	1773.7404	1909.2996	1734.66	1891.46
	Cool dry	3	2989.113 3	52.99121	21.63357	2933.5025	3044.7242	2919.26	3070.56

	Hot dry	3	3520.170 0	120.04573	49.00846	3394.1897	3646.1503	3372.90	3641.56
	Total	9	2783.601 1	725.20453	170.93235	2422.9654	3144.2368	1734.66	3641.56
P	Rainy	3	16.9200	1.15566	.47180	15.7072	18.1328	15.54	18.07
	Cool dry	3	17.4900	.65745	.26840	16.8000	18.1800	16.78	18.20
	Hot dry	3	18.2517	.31896	.13022	17.9169	18.5864	17.83	18.68
	Total	9	17.5539	.93004	.21921	17.0914	18.0164	15.54	18.68

Multiple Comparisons

Tukey HSD

Dependent Variable (mg/100g)	(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Zn	Rainy	Cool dry	-1.12500*	.10006	.000	-1.3849	-.8651
		Hot dry	-1.39167*	.10006	.000	-1.6516	-1.1318
	Cool dry	Rainy	1.12500*	.10006	.000	.8651	1.3849

		Hot dry	-0.26667*	.10006	.044	-.5266	-.0068
	Hot dry	Rainy	1.39167*	.10006	.000	1.1318	1.6516
		Cool dry	.26667*	.10006	.044	.0068	.5266
Fe	Rainy	Cool dry	1.58667	.99114	.276	-.9878	4.1611
		Hot dry	.08833	.99114	.996	-2.4861	2.6628
	Cool dry	Rainy	-1.58667	.99114	.276	-4.1611	.9878
		Hot dry	-1.49833	.99114	.314	-4.0728	1.0761
	Hot dry	Rainy	-.08833	.99114	.996	-2.6628	2.4861
		Cool dry	1.49833	.99114	.314	-1.0761	4.0728
Cd	Rainy	Cool dry	-.03333*	.00509	.000	-.0466	-.0201
		Hot dry	-.03167*	.00509	.000	-.0449	-.0184
	Cool dry	Rainy	.03333*	.00509	.000	.0201	.0466
		Hot dry	.00167	.00509	.943	-.0116	.0149
	Hot dry	Rainy	.03167*	.00509	.000	.0184	.0449

		Cool dry	-.00167	.00509	.943	-.0149	.0116
Mn	Rainy	Cool dry	-.95033*	.14864	.000	-1.3364	-.5642
		Hot dry	-.44533*	.14864	.023	-.8314	-.0592
	Cool dry	Rainy	.95033*	.14864	.000	.5642	1.3364
		Hot dry	.50500*	.14864	.010	.1189	.8911
	Hot dry	Rainy	.44533*	.14864	.023	.0592	.8314
		Cool dry	-.50500*	.14864	.010	-.8911	-.1189
Na	Rainy	Cool dry	-64.06667	34.11188	.179	-152.6713	24.5379
		Hot dry	-13.74833	34.11188	.915	-102.3529	74.8563
	Cool dry	Rainy	64.06667	34.11188	.179	-24.5379	152.6713
		Hot dry	50.31833	34.11188	.330	-38.2863	138.9229
	Hot dry	Rainy	13.74833	34.11188	.915	-74.8563	102.3529
		Cool dry	-50.31833	34.11188	.330	-138.9229	38.2863
K	Rainy	Cool dry	-91.92333	68.99749	.400	-271.1423	87.2956

		Hot dry	-32.60333	68.99749	.885	-211.8223	146.6156
	Cool dry	Rainy	91.92333	68.99749	.400	-87.2956	271.1423
		Hot dry	59.32000	68.99749	.673	-119.8989	238.5389
	Hot dry	Rainy	32.60333	68.99749	.885	-146.6156	211.8223
		Cool dry	-59.32000	68.99749	.673	-238.5389	119.8989
Mg	Rainy	Cool dry	-24.91900*	.78403	.000	-26.9555	-22.8825
		Hot dry	-32.57400*	.78403	.000	-34.6105	-30.5375
	Cool dry	Rainy	24.91900*	.78403	.000	22.8825	26.9555
		Hot dry	-7.65500*	.78403	.000	-9.6915	-5.6185
	Hot dry	Rainy	32.57400*	.78403	.000	30.5375	34.6105
		Cool dry	7.65500*	.78403	.000	5.6185	9.6915
Ca	Rainy	Cool dry	-1147.59333*	48.75162	.000	-1274.2242	-1020.9624
		Hot dry	-1678.65000*	48.75162	.000	-1805.2809	-1552.0191
	Cool dry	Rainy	1147.59333*	48.75162	.000	1020.9624	1274.2242

		Hot dry	-531.05667*	48.75162	.000	-657.6876	-404.4258
	Hot dry	Rainy	1678.65000*	48.75162	.000	1552.0191	1805.2809
		Cool dry	531.05667*	48.75162	.000	404.4258	657.6876
P	Rainy	Cool dry	-.57000	.45577	.443	-1.7538	.6138
		Hot dry	-1.33167*	.45577	.027	-2.5155	-.1478
	Cool dry	Rainy	.57000	.45577	.443	-.6138	1.7538
		Hot dry	-.76167	.45577	.248	-1.9455	.4222
	Hot dry	Rainy	1.33167*	.45577	.027	.1478	2.5155
		Cool dry	.76167	.45577	.248	-.4222	1.9455

*. The mean difference is significant at the 0.05 level.

Appendix 1.4: One-way ANOVA output: Impact of seasonal variation on oil quality (Iodine Value)

Descriptives

Iodine Value in gI2/100g

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Rainy	3	153.8350	3.21322	12.27734	122.2751	185.3949	125.88	181.43
Cool dry	3	165.0067	2.30138	8.60644	142.8831	187.1302	144.92	186.93
Hot dry	3	237.5150	2.36059	9.16764	213.9488	261.0812	216.47	260.37
Total	9	185.4522	7.87519	10.54630	163.2015	207.7030	125.88	260.37

Multiple Comparisons

Dependent Variable: Iodine Value in gI2/100g

Tukey HSD

(I) Season	(J) Season	Mean	Std. Error	Sig.	95% Confidence Interval
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		Difference (I-J)			Lower Bound	Upper Bound
Rainy	Cool dry	-11.17167	14.34920	.721	-48.4433	26.1000
	Hot dry	-83.68000*	14.34920	.000	-120.9516	-46.4084
Cool dry	Rainy	11.17167	14.34920	.721	-26.1000	48.4433
	Hot dry	-72.50833*	14.34920	.000	-109.7800	-35.2367
Hot dry	Rainy	83.68000*	14.34920	.000	46.4084	120.9516
	Cool dry	72.50833*	14.34920	.000	35.2367	109.7800

*. The mean difference is significant at the 0.05 level.

Appendix 1.5: One-way ANOVA output: Impact of processing techniques on oil quality (Iodine Value)

Descriptives

Iodine Value (gI2/100g)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Control	3	238.7050	4.31605	9.16764	213.9488	261.0812	216.47	260.37
Boiled	3	182.6733	3.90100	4.15735	172.1365	193.5102	172.42	193.04
Smoked	3	144.9483	2.01175	4.71190	129.0260	153.2507	125.29	156.63
Solar dried	3	164.3233	3.50231	14.31013	133.2380	206.8087	136.93	211.43
Total	12	182.6625	13.73111	8.42757	165.4412	200.3088	125.29	260.37

Multiple Comparisons

Dependent Variable: Iodine Value (gI2/100g)

Tukey HSD

(I) Processing technique	(J) Processing technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Control	Boiled	54.69167*	12.81232	.002	18.8308	90.5525
	Smoked	96.37667*	12.81232	.000	60.5158	132.2375
	Solar dried	67.49167*	12.81232	.000	31.6308	103.3525
Boiled	Control	-54.69167*	12.81232	.002	-90.5525	-18.8308
	Smoked	41.68500*	12.81232	.019	5.8241	77.5459
	Solar dried	12.80000	12.81232	.752	-23.0609	48.6609
Smoked	Control	-96.37667*	12.81232	.000	-132.2375	-60.5158
	Boiled	-41.68500*	12.81232	.019	-77.5459	-5.8241
	Solar dried	-28.88500	12.81232	.143	-64.7459	6.9759

Solar dried	Control	-67.49167*	12.81232	.000	-103.3525	-31.6308
	Boiled	-12.80000	12.81232	.752	-48.6609	23.0609
	Smoked	28.88500	12.81232	.143	-6.9759	64.7459

*. The mean difference is significant at the 0.05 level.

Appendix 1.6: Independent samples-t-test: Impact of sex on proximate composition in the rainy season

Group Statistics

	Sex (male or female)	N	Mean	Std. Deviation	Std. Error Mean
Moisture content	Male	3	33.4331	.11241	.24099
	Female	3	37.7637	.10338	.14051
Total ash content	Male	3	8.3410	.10407	.27082
	Female	3	5.0020	.21275	1.46806
Crude protein	Male	3	10.9320	.00381	.06802

	Female	3	8.1347	.10188	.08653
Crude fat	Male	3	21.5163	.20525	1.60229
	Female	3	36.0833	.20447	.97830

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Moisture content	Equal variances assumed	1.209	.333	-16.824	4	.000	-4.69333	.27897	-5.46787	-3.91880
	Equal variances not assumed			-16.824	3.219	.000	-4.69333	.27897	-5.54792	-3.83875
Total ash content	Equal variances assumed	9.910	.035	1.074	4	.343	1.60300	1.49283	-2.54175	5.74775

	Equal variances not assumed			1.074	2.136	.389	1.60300	1.49283	-4.44379	7.64979
Crude protein	Equal variances assumed	.140	.727	26.860	4	.000	2.95633	.11007	2.65074	3.26192
	Equal variances not assumed			26.860	3.789	.000	2.95633	.11007	2.64390	3.26877
Crude fat	Equal variances assumed	1.634	.270	-7.473	4	.002	-14.03000	1.87734	-19.24234	-8.81766
	Equal variances not assumed			-7.473	3.309	.004	-14.03000	1.87734	-19.70081	-8.35919

Appendix 1.7: Independent samples-t-test: Impact of sex on proximate composition in the cool dry season

		Group Statistics			
Sex (male or female)		N	Mean	Std. Deviation	Std. Error Mean
Moisture content	Male	3	57.4033	.44049	.25432
	Female	3	58.8033	.33081	.19099
Total ash content	Male	3	17.7870	.39695	.22918

	Female	3	16.8997	.16808	.09704
Crude protein	Male	3	7.0423	.40337	.23288
	Female	3	7.0553	.22997	.13277

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Moisture content	Equal variances assumed	.432	.547	-4.402	4	.012	-1.40000	.31805	-2.28305	-.51695
	Equal variances not assumed			-4.402	3.712	.014	-1.40000	.31805	-2.31078	-.48922

Total ash content	Equal variances assumed	3.669	.128	3.565	4	.023	.88733	.24888	.19635	1.57832
	Equal variances not assumed			3.565	2.695	.045	.88733	.24888	.04206	1.73261
Crude protein	Equal variances assumed	.853	.408	-.048	4	.964	-.01300	.26807	-.75729	.73129
	Equal variances not assumed			-.048	3.176	.964	-.01300	.26807	-.84001	.81401
Crude fat	Equal variances assumed	2.367	.199	-13.504	4	.000	-3.76000	.27843	-4.53304	-2.98696
	Equal variances not assumed			-13.504	3.129	.001	-3.76000	.27843	-4.62577	-2.89423

Appendix 1.8: Impact of sex on proximate composition of boiled L. gossei fish sample

		Group Statistics			
Sex (male or female)		N	Mean	Std. Deviation	Std. Error Mean
Moisture content	Male	3	60.5300	1.93915	1.11957
	Female	3	58.4500	2.61800	1.51150

Total ash content	Male	3	10.6633	.60781	.35092
	Female	3	8.3867	.29738	.17169
Crude protein	Male	3	11.3833	.23502	.13569
	Female	3	9.1500	.29513	.17039
Crude fat	Male	3	9.0100	.30414	.17559
	Female	3	16.7400	1.20578	.69616

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Moisture content	Equal variances assumed	.544	.502	1.106	4	.331	2.08000	1.88097	-3.14242	7.30242

		Equal variances assumed			1.106	3.687	.336	2.08000	1.88097	-3.32212	7.48212
Total ash content		Equal variances assumed	1.680	.265	5.828	4	.004	2.27667	.39067	1.19200	3.36134
		Equal variances not assumed			5.828	2.906	.011	2.27667	.39067	1.01022	3.54311
Crude protein		Equal variances assumed	.510	.515	10.253	4	.001	2.23333	.21782	1.62858	2.83809
		Equal variances not assumed			10.253	3.809	.001	2.23333	.21782	1.61643	2.85024
Crude fat		Equal variances assumed	2.264	.207	-10.767	4	.000	-7.73000	.71796	-9.72338	-5.73662
		Equal variances not assumed			-10.767	2.253	.006	-7.73000	.71796	-10.50893	-4.95107

Appendix 1.9: Independent samples-t-test: Impact of sex on proximate composition of solar-dried L. gossei fish sample

Group Statistics

	Sex (male or female)	N	Mean	Std. Deviation	Std. Error Mean
Moisture content	Male	3	10.8000	.30414	.17559
	Female	3	9.0267	.08386	.04842
Total ash content	Male	3	23.3233	.35360	.20415
	Female	3	18.6267	.35019	.20218
Crude protein	Male	3	15.4133	.32868	.18977
	Female	3	23.2033	.28676	.16556
Crude fat	Male	3	19.8200	.23302	.13454
	Female	3	35.1033	.34775	.20078

Independent Samples Test

Levene's Test for
Equality of
Variances

t-test for Equality of Means

			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
										Lower	Upper
Moisture content	Equal variances assumed		7.353	.053	9.736	4	.001	1.77333	.18215	1.26761	2.27906
	Equal variances not assumed				9.736	2.302	.006	1.77333	.18215	1.08044	2.46622
Total ash content	Equal variances assumed		.000	1.000	16.346	4	.000	4.69667	.28732	3.89893	5.49441
	Equal variances not assumed				16.346	4.000	.000	4.69667	.28732	3.89890	5.49444
Crude protein	Equal variances assumed		.073	.800	-30.933	4	.000	-7.79000	.25184	-8.48921	-7.09079
	Equal variances not assumed				-30.933	3.928	.000	-7.79000	.25184	-8.49431	-7.08569
Crude fat	Equal variances assumed		.877	.402	-63.237	4	.000	-15.28333	.24168	-15.95436	-14.61231
	Equal variances not assumed				-63.237	3.495	.000	-15.28333	.24168	-15.99441	-14.57226

APPENDIX 2: ETHICAL CLEARANCE



VICE-CHANCELLOR
Prof. Samson Sajidu, BSc Mtw, MPhil Cantab, PhD Mtw

Our Ref: P.11/22/202.

Your Ref.:

24th February, 2023

Mr Mayeso Kachingwe
Masters in Food Science Student
Human Ecology Department
University of Malawi
P.O. Box 280
Zomba

Email: mayesokachingwe@gmail.com

Dear Mr Kachingwe

**RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT
FOR PROTOCOL NO. P.11/22/202. ASSESSMENT OF PROXIMATE
AND FATTY ACID COMPOSITION OF RAW AND PROCESSED
LETHRINOPS GOSSEI FISH FROM LAKE MALAWI**

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above-referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for **one year** from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be

required to be sought from the University of Malawi Research Ethics Committee (UNIMAREC) in a format that is available at the Secretariat.

Once the study is finalized, you are required to furnish the Committee and the Vice Chancellor with a final report of the study. The committee reserves the right to carry out a compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

UNIMAREC wishes you a successful implementation of your study.

Yours Sincerely,



Dr Symon Winiko
VICE CHAIRPERSON OF UNIMAREC



CC: Vice Chancellor
The University Registrar
Acting Director of Finance and Investments
Acting Head of Research
Chairperson UNIMAREC
UNIMAREC Compliance Officer