Sensory analysis, consumer preference and meat quality of wild versus farmed tilapia on the Malawian market

by

Vincent Mlotha

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Supervisor: Dr Khalid Salie

Co-supervisors: Dr Jeannine Marais

Dr Annelin Molotsi

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Declaration

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Summary

Fish is a healthy food and contribute significantly to global food security, nutrition, and trade. Tilapia from both wild and farmed sources is a popular fish and contributes to global fish supply. There is lack of published information on tilapia supply, quality, consumption patterns and consumer preference for tilapia in Southern Africa. The aim of this study was to review tilapia consumption trends, assess consumer preference, analyse sensory profile, identify tilapia species, and determine the proximate composition, fatty acid profile and heavy metal concentration of wild versus farmed tilapia on the Malawian market. The objectives of this study were 1)to review literature on tilapia consumption in Southern Africa focusing on supply, quality, and consumer preference for wild versus farmed tilapia for a 20-year period (2000 to 2019); 2)to assess consumer preference for wild versus farmed tilapia found on the Malawian market; 3) to identify wild and farmed tilapia species on the Malawian market using deoxyribonucleic acid (DNA) analysis; 4) to assess the sensory profile of tilapia by descriptive sensory analysis; 5) to analyse the chemical composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia. The tilapia were from five sources namely: 1) wild tilapia from Malawi; 2) farmed tilapia from Malawi; and farmed tilapia imported from 3) China; 4)Zambia and; 5) Zimbabwe. The review covered 10 countries, namely, Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. The 10 countries were selected because of the significant contribution of tilapia towards economics and food security in the respective countries. FAO time series data on tilapia production and annual per capita fish supply were used for the review and covered a 20-year period from 2000 to 2019. In the consumer preference study, tilapia consumers (n=200) in Lilongwe Malawi were interviewed in a quantitative survey. Four qualitative focus group discussions (FGDs), with eight participants per group, were conducted to gain a deeper understanding of consumer preference for wild versus farmed tilapia. In the tilapia species identification study, deoxyribonucleic acid (DNA) analysis was used to identify the tilapia species while descriptive sensory analysis (by a trained panel of eight members) was used to assess the descriptive sensory quality of the tilapia. Proximate composition (moisture, crude protein, total crude fat and ash) of the tilapia was determined following standard official methods, fatty acids were analysed by gas chromatography and flame-ionization detector (GC-FID) method while inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the concentrations of heavy metals in the tilapia samples. The review of tilapia consumption data showed that wild tilapia declined while farmed tilapia and tilapia imports, particularly from China, contributed to fish supply in Southern Africa. Tilapia capture data for Malawi showed a declining trend from the year 2007 to 2019, although a few peaks were observed in some years (2005 to 2010). Among the 10 countries, Zambia was the leading producer of farmed tilapia. In 2000, Zambia produced 4020 tonnes of farmed tilapia, and this grew to 38390 tonnes in 2019. In 2019, Zambia produced over half of the total farmed tilapia in Southern Africa. The increases in farmed tilapia imports demonstrated the potential acceptability of farmed tilapia. The consumer preference study showed that consumers (98%, n=197) were aware of the various types and sources of tilapia sold on the Malawian market (wild versus farmed and locally produced versus imported tilapia). Sixty five percent (n = 130) of the consumers preferred wild tilapia from Malawi due to its quality (appearance, aroma, taste, and texture) even though they perceived the price of the wild tilapia to be higher than that of farmed tilapia. Forty two percent (n = 84) of the consumers often purchased wild tilapia while 34% (n = 67) purchased farmed tilapia. Correspondence analysis (CA) revealed that consumers from high tilapia consumption frequency (1-2 times tilapia consumption per week) were more likely to purchase frozen farmed tilapia than consumers from medium (1-2 times tilapia consumption per month) and low tilapia consumption frequency (5-6 times tilapia consumption per year). DNA analysis revealed that all the wild and farmed tilapia analysed showed over 98% similarity with *Oreochromis niloticus* in a search in GenBank and they were identified as *Oreochromis niloticus*. The sensory analysis experiment showed that there were statistical differences in only three sensory attributes of the fish evaluated in this study (musty mouldy aroma, earthy flavour, and musty mouldy flavour). The chemical analyses showed that farmed tilapia from Malawi had the highest total fatty acid concentration (115.62 mg/g) and all specific fatty acids except C22:0 and C20:5n3 only while wild tilapia from Malawi had the lowest total fatty acid concentration (23.06 mg/g). All the tilapia analysed in this study contained relatively high amounts of essential minerals particularly potassium (K), phosphorus (P), sodium (Na), magnesium (Mg), and calcium (Ca). Potassium was higher than Na in all the tilapia analysed. All non-essential heavy metals in all the tilapia were below the maximum recommended limits according to Food and Agriculture Organisation (FAO) and World Health Organisation (WHO) standards. The study provides valuable insights for policy analysis and development of strategies to upscale sustainable aquaculture and fisheries and facilitate fish trade by demonstrating demand and supply gaps, elucidating consumer preference, and purchasing behaviour, and providing updated information on the chemical composition of tilapia on the Malawian market.

Opsomming

This dissertation is dedicated to all tilapia consumers in Malawi.

Biographical sketch

Vincent completed his undergraduate studies and received a bachelor's degree in Nutrition and Food Science from Bunda College, University of Malawi in July of 2010. He then worked briefly for Valid International as a Research Manager in Lilongwe, Malawi. Vincent joined Lilongwe University of Agriculture and Natural Resources (LUANAR) as a Research Associate under the McKnight Foundation Collaborative Research Program in 2011. Later in 2012, he was awarded a USAID funded scholarship to study for a Master of Science degree in Food Science and Human Nutrition at Bunda College, University of Malawi under the mentorship of Dr Agnes Mbachi Mwangwela. His MSc research focused on assessing the glycaemic response to maize flour stiff porridges prepared using local recipes in Malawi. He successfully completed the program, and the research was published in Food Science and Nutrition journal where it received wide readership (https://onlinelibrary.wiley.com/doi/10.1002/fsn3.293). Vincent was appointed as a Staff Associate in 2013 and in 2015, he was promoted to Lecturer position in Food Science and Technology (Meat Products) in the Faculty of Food and Human Sciences at LUANAR. He contributed to the development and management of several research programs at LUANAR including the following: Africa Centre of Excellence in Aquaculture and Fisheries project; Peanut and Mycotoxin Innovation Lab (PMIL) project in Malawi, Zambia and Mozambique; Trilateral Dairy Value Chain Project led by Michigan State University (MSU) in collaboration with Tamil Nadu Veterinary and Animal Sciences University (TANUVAS) in India and LUANAR in Malawi; and the Nutrition-Diversified Agriculture for a balanced nutrition in Sub-Saharan Africa. In January of 2019, he enrolled for a PhD (Aquaculture) at Stellenbosch University, Department of Animal Sciences, Faculty of AgriSciences in South Africa. His research focused on analysing the sensory profile, consumer preference and meat quality of wild versus farmed tilapia in retail distribution in Malawi. Vincent did this research under the direction and supervision of Dr Khalid Salie (Aquaculture), Dr Jeanine Marais (Food Science) and Dr Annelin Molotsi (Animal Sciences).

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Preface

This dissertation is presented in the format prescribed by the Faculty of AgriSciences, Stellenbosch University. The dissertation is presented as a compilation of six chapters. Each chapter is introduced separately and is written according to the style of the journal to which it is envisaged to be submitted for publication. In this regard, some repetitions in introduction, methods, results, and discussions between chapters were unavoidable. Chapter one and six were presented in the format proposed by the Faculty of AgriSciences, Stellenbosch University. Chapter two was prepared according to author guidelines for Global Food Security journal. Chapter three was prepared according to author guidelines for Appetite journal. Chapter four was prepared according to author guidelines for Food Research International journal while chapter five was prepared according to author guidelines for Food Chemistry journal.

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List of Acronyms

ACE	Africa Centre of Excellence
AfCFTA	African Continental Free Trade Area
AHA	American Heart Association
ALA	Alpha-linolenic acid
AMSA	American Meat Science Association
ANOVA	Analysis of variance
AquaFish	Aquaculture and Fisheries project
BCLME	Benguela Current Large Marine Ecosystem
BOLD	Barcode of Life Database
CA	Correspondence analysis
COI	Cytochrome c oxidase I gene
CRD	Completely randomised design
CVD	Cardiovascular diseases
DHA	Docosahexaenoic acid
DNA	Deoxyribonucleic acid
DSA	Descriptive sensory analysis
EIA	Environmental impact assessment
EPA	Eicosapentaenoic acid
EU	European Union
FAO	Food and Agriculture Organisation
FDA	Food and Drug Administration
FGD	Focus group discussion
GLA	Gamma-linolenic acid
GLM	General linear model
ICP-MS	Inductively coupled plasma mass spectrometry
LMIC	Low- and middle-income countries
LOQ	Limit of quantification
LSD	Least significant difference
LUANAR	Lilongwe University of Agriculture and Natural Resources
MLs	Maximum limits
MUFA	Monounsaturated fatty acid
MWK	Malawi Kwacha
NCDs	Non-communicable diseases
NCST	National Commission for Science and Technology
NFE	Nitrogen free extract
PCA	Principal component analysis

PCR	Polymerase chain reaction
PRD	Pearl River Delta
PUFA	Polyunsaturated Fatty Acid
QAAFI	Queensland Alliance for Agriculture and Food Innovation
SBER	Social, Behavioural and Education Research
SD	Standard deviation
SEM	Standard error of means
SUFA	Saturated fatty acid
TBT	Technical barriers to trade
USA	United States of America
USD	United States dollar
WHO	World Health Organisation

CHAPTER 1: General introduction and project aim

1.1 Background

Fish is a healthy food and contributes significantly to global food security, nutrition, and trade (Belton & Thilsted, 2014; Chan et al., 2019; Obiero et al., 2019). In 2018 global fish production was 179 million tonnes and valued at 401 billion United States dollars (USD), while the total global export revenue was USD 7.8 billion (FAO, 2020). Several countries rely on fish exports for forex earnings (FAO, 2020). Fish contributes to 17% of the global animal protein intake and is crucial in the provision of lipids especially essential fatty acids which cannot be synthesized in the human body (Belton & Thilsted, 2014; Chan et al., 2019). Regular fish consumption (227 g per week) is recommended for improved health outcomes (Nishida et al., 2004; Miller et al., 2014; Tur et al., 2001). World per capita fish consumption more than doubled from 9.7 kg in 1961 to 20.5 kg in 2018, with a global fish consumption record of 140 million tonnes reported in 2018 (FAO, 2020). The latter can be attributed to the increased promotion and consumer awareness on the health benefits linked to fish consumption coupled with increased availability of fish on the global food market (Bogard et al., 2019; Mohanty et al., 2019; Ragasa et al., 2020).

Wild fish from oceans, seas, lakes, and rivers has been the main source of fish for human consumption (FAO, 2020). However, a combination of factors like overfishing, habitat destruction due to mineral resource extraction and industrialization, pollution, climate change as well as the introduction of invasive species in some ecosystems have led to declining fish stocks to below minimum sustainable levels (Banda et al., 2005; Bell et al., 2012; FAO, 2020). Therefore, fish supply from wild sources is stagnating and may not sustainably support future global fish demand (Bell et al., 2012; Blasco et al., 2020; FAO, 2020). Nonetheless, an increasing global consumer demand for fish has resulted in a significant growth of the fish market through aquaculture (Naylor et al., 2021). Aquaculture is the fastest growing animal food production industry in the world with a growth rate of 7% per year since 1970 (FAO, 2020). In 2018 aquaculture contributed 82.1 million tonnes of fish representing 46% of the total global fish supply (FAO, 2020).

One of the emerging fish species that is widely and successfully farmed in different aquaculture systems is tilapia (Day et al., 2016). Tilapia is the second most popular farmed fish globally, after the carp (*Ctenopharyngodon idellus* and *Hypophthalmichthys molitrix*) (FAO, 2020). In the United States of America (USA) tilapia has been listed among the top four highly consumed fish species along with Atlantic salmon, catfish, and trout (Weaver et al., 2008). In Africa, tilapia is a favourable farmed fish along with catfish (El-Sayed, 2019). More specifically in Malawi, tilapia is a popular fish among consumers and tops fish-based menus in consumer diets, hotels, and restaurants (Chikowi et al., 2021). There are different species of tilapia, including, *Oreochromis niloticus, Oreochromis mossambicus*, *and Oreochromis shiranus* (FAO, 2020). However, *Oreochromis niloticus* (Nile Tilapia) is the most widely farmed tilapia worldwide because of its higher growth rate and easiness to raise in aquaculture (Day et al., 2016).

China is the largest producer of farmed tilapia globally (FAO, 2020). In 2015 China produced 1.78 million metric tonnes of tilapia while in 2016 China produced 1.78 million metric tonnes of tilapia (FAO, 2020). Tilapia from China is exported and has gained good market share particularly in the USA as well as European Union (FAO, 2020). China exports tilapia to several African countries, such as South Africa, Nigeria, Zambia, and Malawi (FAO, 2020). Egypt is the largest tilapia producer in Africa, although almost of the tilapia produced is consumed locally in the country (El-Sayed, 2019). Other countries with significant farmed tilapia production in Africa include Ghana, Kenya, Nigeria, and Zambia (Moyo & Rapatsa, 2021). Despite the increasing importance of farmed fish (including farmed tilapia) in sustaining global fish supply, wild fish is preferred over farmed fish and it (wild fish) is regarded as the reference point in terms of sensory quality of the fish (Claret et al., 2014). However, objective sensory studies produce inconsistent results and sometimes show no differences in the sensory quality of wild versus farmed fish of the same species (Claret et al., 2014)

The globalised nature of food trade (including fish) in recent years due to improvements in food supply chain systems means that fish produced in one country is transported and can be accessible in several countries globally (Cawthorn et al., 2018; FAO, 2020). Increasing demand for fish, consumer preference for wild fish and the globalised nature of food trade bring challenges of fish misclassification and fish fraud on the global food market (Cawthorn et al., 2018; FAO, 2020). Fraud in the fish sector includes mislabelling of products with regards to geographical region of origin, wild versus farmed fish, misrepresentation of fish species, as well as misclassification of fresh versus frozen and thawed fish (Cawthorn et al., 2018). The problem is compounded using generic names of fish such as “tilapia” or “snapper” which includes hundreds of different species within such groups (Cawthorn et al., 2018). In addition to this, fish processing techniques such as filleting makes it difficult for consumers to verify fish species at the point of sell or consumption (Cawthorn et al., 2018).

The problem of fish misclassification resulted in the development and application of fish authentication methods both in scientific research as well as the food industry (Khaksar et al., 2015; Warner et al., 2013). There are well developed laboratory-based methods that are used to identify and authenticate fish with regards to species classification, provenance of region of origin as well as discrimination of fresh from frozen then thawed fish. Fish identification methods include morphometric techniques, DNA analysis, stable isotope analysis, elemental profiling, chemical analysis particularly use of fatty acid profiling, descriptive sensory analysis, and application of near infrared reflectance spectroscopy (NIRS) (Mariani et al., 2015). Among the different fish authentication methods, DNA analysis is a specialised and well-standardised procedure capable of unambiguously identifying fish to the species level (Mariani et al., 2015).

Fish plays a significant role to Malawi’s economy and food security (Banda et al., 2005; Bell et al., 2012). In 2005 fish contributed 4% to the country’s Gross Domestic Product (GDP) (Banda et al., 2005; Bell et al., 2012). The major fishing grounds in Malawi are in Lake Malawi, Lake Chirwa, Lake Chiuta, and the Shire River (Banda et al., 2005). The sector is largely artisanal in nature with a few semi-commercial and commercial fisheries, made up of pair trawlers and larger stern trawlers respectively on Lake Malawi (Banda et al., 2005). The small-scale sector produces 90% of the annual fish production while the rest is landed by the commercial or industrial sector (Banda et al., 2005). The beach value of fish was estimated at 15 million USD on an annual basis (Banda et al., 2005). In 2015, Malawi produced 144315 tonnes of fish, generating USD 162.26 million (FAO, 2020). Malawi's annual fish production increased by eight percent at 157268 tonnes, providing USD 172.74 million in 2017 (FAO, 2020). Between the years 2000 and 2017 the total fish supply in Malawi was 12.05 kg/capita/annum and the average fish supply over this period was 6.5 kg/capita/annum (FAO, 2020).

In Malawi, tilapia is an important fish for the fisheries industry, aquaculture as well as consumers (Banda et al., 2005). Wild tilapia is made up of *Oreochromis* spp., such as *O. karongae*, *O. lidole*, and *O. squamipinnis*, caught by fishermen from lakes and rivers. Farmed tilapia is defined as the tilapia that is raised in cages in Lake Malawi as well as in ponds by both small scale (pond aquaculture farmers) and large-scale (cage aquaculture in lakes) farmers while imported tilapia species are the ones sourced from other countries mainly China, Zambia, and Zimbabwe. There is a steady growth of the aquaculture sector to complement the capture fisheries for tilapia in Malawi (FAO, 2020). Aquaculture production in Malawi consists of 93% tilapia (*Oreochromis shiranus, Oreochromis karongae and Tilapia rendalli*), 5% catfish (*Ictalurus spp*.) and 2% exotic species such as common carp (*Cyprinus carpio*), black bass (*Micropterus salmoides*) and trout (*Oncorhynchus spp*.) (FAO, 2020). Annual tilapia production from aquaculture increased from 800 tonnes in 2006 to 3600 tonnes in 2015 (FAO, 2020). In 2019 the total annual landings of wild tilapia were 7277 tonnes while farmed tilapia were 7742 tonnes (FAO, 2020). In addition to the wild and farmed tilapia produced in the country, Malawi imports tilapia from countries such as China, Zambia, and Zimbabwe. Malawi imported 954 tonnes of tilapia in 2019 to meet consumer demand and fill the supply gap in tilapia (FAO, 2020). However, there is lack of published information on the genetic identity, consumer preference, proximate composition, fatty acid profile, heavy metal concentrations, and sensory quality of the wild versus farmed tilapia from Malawi as well as farmed tilapia imported from other countries.

1.2 Problem statement

Farmed fish (including farmed tilapia) has always received a negative image from consumers, despite the significant contribution of farmed fish to the global fish supply (Claret et al., 2014). Consumers rate wild fish products as tastier, safer, and healthier than farmed fish (Claret et al., 2012). Aquaculture products are chosen because of their relatively lower cost and increasing availability in the global fish market (Claret et al., 2012; Freitas et al., 2020). The low consumer rating for farmed fish is partly due to a lack of correct and updated information about farmed fish and aquaculture in general, and insufficient promotion and awareness campaigns of the quality of farmed fish (Calanche et al., 2020). Consumer perception of farmed fish and aquaculture is influenced by several factors. These factors include personal experiences, preconceptions, and consumer demographics such as age, gender, education, and income level. In addition to these factors, the regional context of consumers also influences their evaluation of different farmed fish compared to wild fish (Polymeros et al., 2015).

Tilapia is a generic name, and it includes over a hundred types of Tilapiine species which are endemic to African freshwater bodies (Cawthorn et al., 2018). In the USA a compendium on names of fish from the USA, Canada, and Mexico showed nine different species of *Oreochromis* all falling under the same generic name “tilapia” (Page et al., 2013). However, without proper labelling it is not easy for consumers to distinguish the different types of fish species as well as their country of origin or whether they are wild or farmed (Cawthorn et al., 2012). The use of common names such as “tilapia” and “snapper” leads to misrepresentation of fish particularly of lower value for high value ones within such bracket names (Cawthorn et al., 2018; O’Brien et al., 2013). Misclassification of fish is a growing food trade and food safety challenge globally (Cawthorn et al., 2018). This is of particular concern in the globalised food supply chain with increasing international trade, rising demand for fish and fish products and declining levels of supply from wild catches (FAO, 2020). Efforts to monitor the situation through fish identification market surveys using DNA analysis have unravelled the gravity of the problem in recent years (Barendse et al., 2019). Fish authentication research coupled with consumer awareness may result in reduced trends of the fish fraud problem (Mariani et al., 2015). In the USA mislabelling dropped from 33% in 2012 to 16.3% in 2015 after authentication studies and consumer awareness (Khaksar et al., 2015; Warner et al., 2013). The health benefits of fish can also be compromised due to the presence of toxins and contaminants in the fish (Simukoko et al., 2022). Some of the hazardous chemicals that can contaminate fish are mercury (Hg), lead (Pb), aluminium (Al) and cadmium (Cd) (Bosch et al., 2016). Fish raised in water which is contaminated with heavy metals can accumulate the toxins in the tissue muscle and act like a carrier of such contaminants to the human diet (Simukoko et al., 2022).

In Malawi, wild tilapia is famous among consumers and has a high market demand in the country (Chikowi et al., 2021). However, there is a decline in wild tilapia from the natural sources. High consumer demand for tilapia and the decline in wild tilapia has resulted in the production of tilapia through aquaculture in Malawi and imports from China, Zambia, and Zimbabwe to close the supply gap (Bell et al., 2012; Chikowi et al., 2021). The introduction of farmed tilapia and tilapia imports being traded under a generic name (“*Chambo*” the local name for Tilapia) resulted in conflicts over the original definition of Chambo and what it constitutes as well as who should use the name (https://www.businessmalawi.com/row-over-foreign-chambo-branding/). Of particular concern is that consumers looking for the wild tilapia may buy the farmed or imported tilapia and there are complaints of unsatisfactory quality or deviation of the farmed and imported tilapia as compared to wild tilapia. However, there is limited published scientific information in highly regarded journals on trends in wild and farmed tilapia versus famed and imported tilapia in Malawi covering the past two decades from 2000 to 2020. There is limited scientific information to back the claims that wild tilapia is superior to farmed and imported tilapia in aspects such as sensory characteristics and nutrition or chemical composition.

1.3 Justification

This study will help to characterise the tilapia and investigate on the claims of mislabelling. The study will identify commercial tilapia species on the Malawian market to the species level. The research findings will also add to the body of research information on the nutritional value and safety of tilapia by analysis the proximate, fatty acid and heavy metal concentrations in tilapia in retail distribution in Malawi. This research will provide consumers with current knowledge on the different sources of tilapia found on the Malawi market. Sensory qualities of the fish as well as consumer preferences will also be established. This information will help consumers to make informed decisions when purchasing tilapia fish from the Malawi market. Traders will also benefit from the results of the consumer beliefs and attitudes towards tilapia from different sources and make necessary adjustments in their tilapia fish trade. Similarly, tilapia fish farmers will benefit from the sensory and consumer preference information to make necessary improvements in the aquaculture production systems.

1.4 Objectives of the study

1.4.1 General objective

The aim of this study was to review tilapia consumption trends, assess consumer preference, analyse sensory profile, identify tilapia species, and determine the proximate composition, fatty acid profile and heavy meatal concentrations of wild versus farmed tilapia on the Malawian market.

1.4.2 Specific objectives

1. To review trends in tilapia consumption in Southern Africa focusing on supply, quality, and consumer preference for wild and farmed tilapia.
2. To investigate consumer preference for wild versus farmed tilapia from Malawi and farmed tilapia imported from other countries.
3. To identify species of wild and farmed tilapia in retail distribution in Malawi by DNA analysis.
4. To assess the descriptive sensory profile of wild versus farmed tilapia in retail distribution in Malawi using descriptive sensory analysis.
5. To determine and compare proximate composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia from Malawi, Zambia, Zimbabwe, and China.

1.5 Research questions

The following specific research equations guided the study.

1. What are the production and consumption trends of wild and farmed tilapia in Southern Africa?
2. What is the preference of tilapia consumers in Malawi regarding wild versus farmed tilapia?
3. What are the common commercial species of tilapia traded in Malawi?
4. What is the descriptive sensory profile of tilapia, and does it differ between different sources as traded in Malawi?
5. What is the proximate composition, fatty acid profile and heavy metal concentrations in tilapia from different sources and traded in Malawi?

1.6 Significance

This research will provide consumers with current knowledge on the different sources of tilapia found on the Malawi market. A detailed profile of the chemical (proximate, mineral, fatty acid and DNA) and sensory properties of tilapia on the Malawi market will be established. Sensory profile of the fish as well as consumer preferences will also be established. This information will help consumers to make informed decisions when purchasing tilapia fish from the Malawi market. Similarly, tilapia fish farmers will benefit from the sensory and consumer preference information to make necessary improvements in the aquaculture production systems. Findings from the sensory research will contribute to resolving a long-standing debate on the sensory quality and preference of tilapia from Malawi (wild) in comparison with the farmed as well imported tilapia from other countries. This will also provide a background for further research on the factors affecting the quality of tilapia as well as how farmed tilapia would be improved if there will be any differences perceived.

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CHAPTER 2: Tilapia consumption in Southern Africa: A review of tilapia supply, quality, and consumer preference

Abstract

Fish and related products are important sources of income, food and nutrition and contribute significantly to global food security. Tilapia is an important species for fisheries and aquaculture, and it is a preferred fish in most countries in Africa. This review aims to examine trends in tilapia consumption in Southern Africa focusing on supply, quality, and consumer preference. The analysis covered 10 countries, namely, Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. The 10 countries were selected because of the significant contribution of tilapia towards economics and food security in the respective countries. There is also lack of published information on tilapia production, supply, and consumption trends for the region for the past two decades from 2000 to 2019. FAO time series data on tilapia production and annual per capita fish supply were used to review tilapia production, supply, and consumption trends over a 20-year period from 2000 to 2019. There were accessed through the FishStatJ statistics software version 4.01.7. The data were filtered by selecting the 10 countries and specifying all tilapia species. Graphs and tables were constructed in Microsoft Excel to depict tilapia production, supply, and consumption trends for the region. Wild tilapia production data were available for three countries only (Botswana, Malawi, and Zimbabwe) and showed a declining trend over the 20-year period. Zambia showed outstanding growth in tilapia aquaculture and produced 4020 tonnes of farmed tilapia in the year 2000, and this grew to 38390 tonnes in 2019. Increases in farmed tilapia imports particularly from China demonstrated the potential acceptability of farmed tilapia in the region. The review adds to the body of knowledge on tilapia consumption trends and provides evidence for reviewing current policies and strategies to upscale sustainable aquaculture, facilitate fish trade and ensure consumer protection against fish fraud.

Keywords: Aquaculture; Consumer preference; Food security; *Oreochromis* spp.; Sub-Saharan Africa; Wild caught fish

2.1 Introduction

Fish and related products are important sources of income, food and nutrition and contribute significantly to global food security. Fish accounts for 17% of the global animal protein intake, and it is the main animal-derived food in many low- and middle-income countries particularly in Africa (Belton et al., 2018; FAO, 2020). Furthermore, fish is crucial in the provision of vitamins, minerals and lipids in the human diet, especially fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Harris and Zotor, 2019). Therefore, fish consumption is considered as part of a healthy and balanced dietary regime for optimal human nutrition (Bogard et al., 2019).

Diets high in fish products (about 227 g per week) are recommended because they associated with improved health outcomes such as reduced risk of heart diseases (Nishida et al., 2004; Miller et al., 2014; Tur et al., 2001). In South Africa, the Food-Based Dietary Guidelines advocates for daily consumption of fish (Phillips, 2021). The world per capita fish consumption doubled from 9.7 kg in 1961 to 20.5 kg in 2018. Furthermore, a global fish consumption record of 140 million tonnes was reported for 2018 (FAO, 2020). This is due to the health recommendations on fish consumption, improved consumer awareness, availability of fish on the global food market, population growth and emerging middle-income classes (Desiere et al., 2018; Ragasa et al., 2020).

In Africa, fish contributes significantly to the economy of many countries as well as food and nutrition security of millions of people due to its prominence in the African food basket (Chan et al., 2019). The fish sector in Africa, both capture fisheries and aquaculture, is mainly inland (lakes, rivers, and dams) and is integral to the economies as well as development efforts of many countries (Avadí et al., 2022). Two hundred million people in Africa derive high-quality proteins (containing essential amino acids and is digestible) from fish particularly from small pelagic species (Mohanty et al., 2019). Such species pelagic include tilapia, daaga (*Rastrineobola argentea*), kapenta (*Limnothrissa moidon*), pilchards (*Sardinops sagax*) and usipa (*Engraulicypris sardella*) (FAO, 2020). Tilapia is an important species for fisheries and aquaculture, and it is a preferred fish in most countries in Africa (FAO, 2020).However, most of the research in Africa on fish is on the production with limited attention given to consumption trends and consumer preferences (Chan et al., 2019). This review aims to examine trends in tilapia consumption in Southern Africa focusing on supply, quality, and consumer preference for wild and farmed tilapia. The analysis covered 10 countries, namely, Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. The countries were selected because of the economic and food security significance of tilapia and due to a lack of published information on the subject for the region.

2.2 Methods

FAO time series data on tilapia production and annual per capita fish supply were used covering a 20-year period from 2000 to 2019. The FAO data was selected because it is the most comprehensive database on fish statistics despite the shortcomings that exist such lack of data for some countries and for some specific species. FAO relies on voluntary submission of annual landings of wild and farmed fish from national correspondents from the participating countries and the process is not easy since capture fisheries and small-scale farmed fish data are difficult to compile in the selected countries (Blasco et al., 2020). The data was accessed through the FishStatJ statistics software version 4.01.7.

2.3 Findings

2.3.1 Tilapia production in Southern Africa

Tilapia has traditionally been caught from freshwater ecosystems including lakes, rivers, and dams in Southern Africa (Belton et al., 2018). However, a combination of factors like overfishing, habitat destruction, pollution as well as climate change has led to declining fish stocks and catch (Banda et al., 2005; FAO, 2020; Thilsted et al., 2016). Increasing demand for tilapia has resulted in significant growth of alternative and innovative tilapia production systems through aquaculture. Tilapia imports, particularly from China, are also common and contribute to tilapia supply (FAO, 2020).

2.3.2 Tilapia production from capture fisheries in Southern Africa

Important inland ecosystems for tilapia production include, not exclusively, Lake Kariba, Lake Malawi, Zambezi River and Kavango River. These sources contribute to the supply of tilapia particularly among rural fishing communities (Belton et al., 2018). Selected tilapia strains are endemic to theses ecosystems such as *Oreochromis mozambicus, Oreochromis andersonii* and *Oreochromis karongae* while others are exotic, including, *Oreochromis niloticus* (Day et al., 2016). Capture fisheries are dominated by artisanal small-scale fishing communities. For this reason, documentation of the quantities of wild fish has been a challenge (Youn et al., 2014). The artisanal fisheries setup has limited capacity to report fish harvests since most of the fish captured are consumed or sold in fish value chains with weak data capturing systems (Blasco et al., 2020; Desiere et al., 2018).

Figure 2.1 shows trends in wild tilapia production for three countries (Botswana, Malawi, and Zimbabwe) over a 20-year period, from 2000 to 2019. Tilapia capture data for the other seven countries were not available in the FAO database. Wild tilapia capture volumes declined over the 20-year period in the three countries. Tilapia capture data for Malawi showed a declining trend from the year 2007 to 2019, although a few peaks were observed in some years (2005 to 2010). In fact, the observed peaks were reported to be due to increasing fishing effort rather than improvements in fish biomass in the ecosystems (Banda et al., 2005; Bell et al., 2012; Torell et al., 2020). Similarly, in Botswana and Zimbabwe tilapia capture fisheries dropped from the year 2015 to 2019 (FAO, 2020). The declining fish supply in Malawi was attributed to overfishing to meet the increasing demand for wild tilapia in the country (Torell et al., 2020). Other factors that have contributed to the decline of wild tilapia biomass in Malawi and similar countries include, pollution, climate change, illegal fishing, habitat destruction, violation of closed seasons, catchments damage and destruction of protected areas along the lake (Bell et al., 2012; Torell et al., 2020).

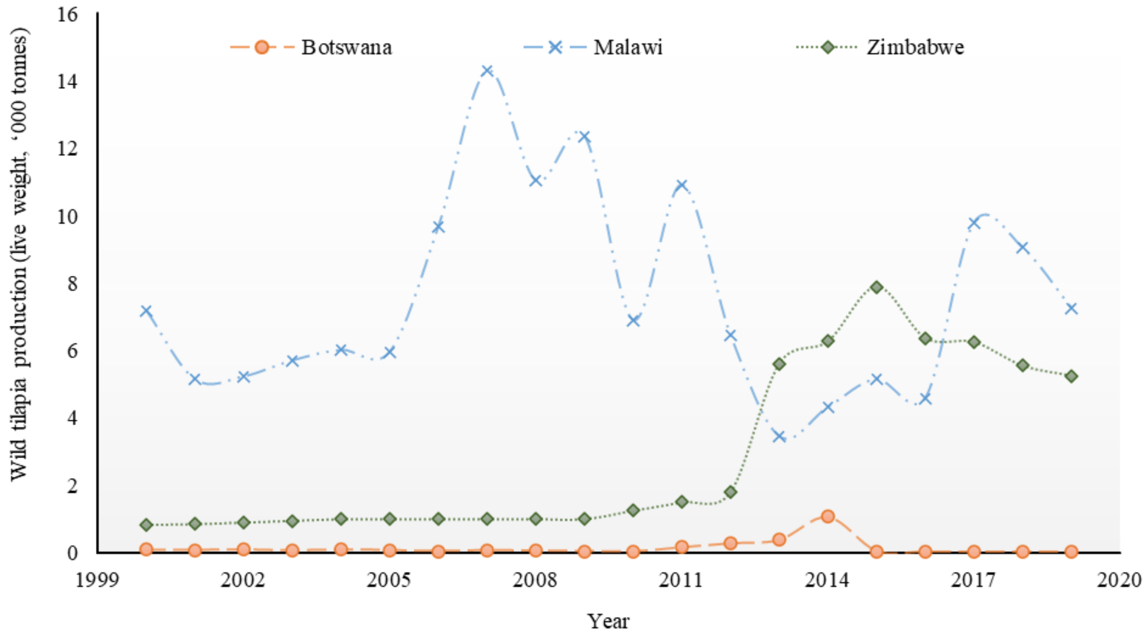

Figure 2.1 Wild tilapia production in Southern Africa (live weight, '000 tonnes).
Production method: Capture (capture fisheries from dams, lakes, and rivers)
Species: *Blue tilapia; Sabaki tilapia; Longfin tilapia; Mango tilapia; Blackchin tilapia; Redbelly tilapia; Redbreast tilapia; Tilapias nei; Nile tilapia; Three spotted tilapia; Tilapia shiranus; Blue-Nile tilapia hybrid*.
Source: FAO. 2021. Fishery and Aquaculture Statistics. Global production by production source 1950-2019 (FishstatJ). In: FAO Fisheries Division [online]. Rome. Updated 2021.
www.fao.org/fishery/statistics/software/fishstatj/en

2.3.3 Tilapia production from aquaculture in Southern Africa

Declining wild tilapia stocks resulted in growth of tilapia aquaculture to meet consumer demand. Although the contribution of farmed tilapia from Southern Africa to the global fish supply is still considered minimal, there is potential for tilapia aquaculture in this region (El-Sayed, 2019). There has been growing interest in commercial tilapia aquaculture in the major lakes and rivers in Southern Africa (Hasimuna et al., 2019). There were several commercial cage aquaculture companies on Lake Kariba. Cage aquaculture companies located on the Zimbabwean side of the lake are Kariba Bream Farm and Lake Supplies-Fish Farm (Hasimuna et al., 2019; Kaminski et al., 2018; Nyikahadzoi et al., 2017). On the Zambian side there was Yalelo Limited, FirstWave Group and Kariba Harvest Limited Fish Farm. Lake Harvest Limited operates on both the Zambian and Zimbabwean sides of the lake (Kaminski et al., 2018). In Malawi, The Foods Company (Maldeco) operates tilapia cages on Lake Malawi (Torell et al., 2020).

Figure 2.2 shows farmed tilapia production for the 10 countries under investigation from 2000 to 2019. There was a general trend of increasing production despite low reported volumes. Angola reported 5 tonnes of farmed tilapia in the year 2000 with steady increases up to 1,898 tonnes in 2019. Similarly, Malawi reported 500 tonnes of farmed tilapia in 2000 and continued to report increasing annual tilapia aquaculture output up to 7742 tonnes in 2019. Higher volumes of farmed tilapia production were reported from Zambia and Zimbabwe.

Tilapia production in Zambia and Zimbabwe was mainly from cage tilapia aquaculture on Lake Kariba, while Nile tilapia (*Oreochromis niloticus*) was the main tilapia species produced (Nyikahadzoi et al., 2017). In 2000, Zambia produced 4020 tonnes of farmed tilapia, and this grew to 38390 tonnes in 2019. In 2019, Zambia produced over half of the total farmed tilapia in Southern Africa (Hasimuna et al., 2019). It was the sixth largest producer of farmed tilapia in Africa after Kenya, Ghana, Uganda, Nigeria, and Egypt (Tran et al., 2019). Some of the enabling factors for the increased aquaculture production in Zambia include availability of freshwater for cage aquaculture, interest in aquaculture from commercial companies, availability of fingerlings (juvenile fish), and availability of fish feed (Hasimuna et al., 2019). Aquaculture companies in Zambia were Lake Harvest Ltd, Yalelo Ltd, Hechikay Aquaculture Ltd, Dimus Aquaculture Ltd and Phindol Fisheries Ltd (Hasimuna et al., 2019). Some fingerlings suppliers were Yalelo Ltd and Chirundu Bream Farm Ltd. Some fish feed processors were Aller-Aqua Ltd and Skretting Ltd (Hasimuna et al., 2019).

Most of the aquaculture farmers (over 90%) are small-scale producers in inland freshwater ecosystems (Adeleke et al., 2020; Nyikahadzoi et al., 2017). The fish are raised in earthen ponds and the culture of indigenous species such as *Oreochromis shiranus* is common practice (Adeleke et al., 2020). Earthen ponds are excavated earth resulting in a water-holding depression (Adeleke et al., 2020). Tilapia from earthen ponds is often associated with an earthy flavour (Abd El-Hack et al., 2022). Two chemical compounds associated with earthy taints in fish are geosmin and 2-methylisoborneol (2-MIB). The former compound renders an earthy pond-bottom flavours, whilst the latter one is associated with a musty flavour (Abd El-Hack et al., 2022). These are bicyclic tertiary alcohols produced by microorganisms, namely actinomycetes and cyanobacteria (Abd El-Hack et al., 2022). Geosmin and 2-MIB enter through fish gills and accumulate in the fish adipose tissues. The compounds are detected at low odour thresholds (4 ng/l) and are the most widespread off-flavour metabolites in aquaculture products and can cause a deterioration in the quality of fish, affecting the market demand and price (Abd El-Hack et al., 2022).

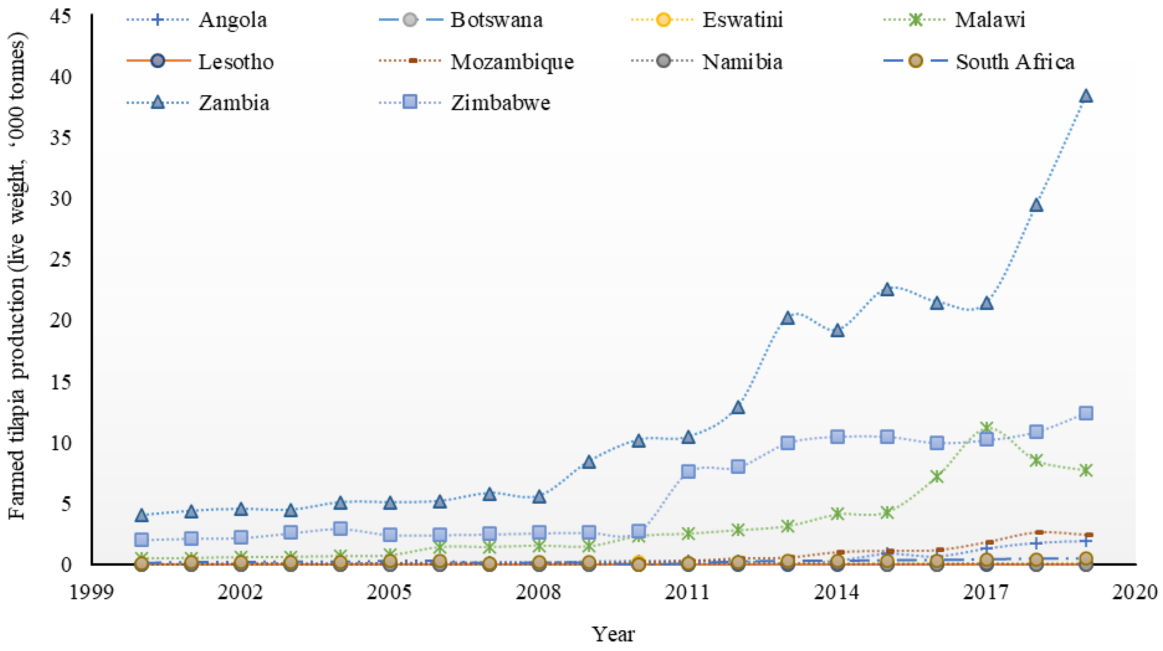

Figure 2.2 Farmed tilapia production in Southern Africa (live weight, '000 tonnes).
Production method: Farmed (aquaculture from freshwater and brackish water)
Species: *Blue tilapia; Sabaki tilapia; Longfin tilapia; Mango tilapia; Blackchin tilapia; Redbelly tilapia; Redbreast tilapia; Tilapias nei; Nile tilapia; Three spotted tilapia; Tilapia shiranus; Blue-Nile tilapia hybrid*.
Source: FAO. 2021. Fishery and Aquaculture Statistics. Global production by production source 1950-2019 (FishstatJ). In: FAO Fisheries Division [online]. Rome. Updated 2021.
www.fao.org/fishery/statistics/software/fishstatj/en

2.3.4 Challenges impeding aquaculture development in Southern Africa

All the 10 countries in Southern Africa support aquaculture and are committed to develop it despite the low productivity (Moyo and Rapatsa, 2021). Several factors have led to limited growth in the aquaculture sector, such as the high cost of imported fish feed and low quality of locally processed feed, use of low performing local tilapia species, poor quality of fingerlings, occurrence of tilapia fish diseases and limited human resource capacity (Adeleke et al., 2020; Hasimuna et al., 2019; Kaminski et al., 2018; Moyo and Rapatsa, 2021). Tilapia farming is also negatively affected by competition from wild tilapia from the region and imported tilapia from China (Tran et al., 2019).

For start-ups on large scale commercial aquaculture operations, the cost for environmental impact assessment (EIA) was also reported to be prohibitive in some countries (Hasimuna et al., 2019). There is a need for government policies to address these challenges. Commercial operations should be planned and supported to lead future growth in aquaculture (Moyo and Rapatsa, 2021). Contemporary aquaculture business approaches focusing on small and medium-scale private enterprises should be pursued (Hasimuna et al., 2019; Kaminski et al., 2018). Governments should create enabling environments for aquaculture investment through easing regulations and fast-tracking the process of issuing permits and licences for aquaculture operations (Day et al., 2016; Kaminski et al., 2018).

2.3.5 Tilapia imports and exports in Southern Africa

Declining wild tilapia coupled with low supply of farmed tilapia necessitated alternative sources to meet the growing demand for fish. Consequently, tilapia imports increased to meet rising demand for fish in most countries (Tran et al., 2019). In Zambia, reports showed that over the period of 2004 to 2014, total fish imports (all fish species and products including tilapia) grew 14 times and played an important role in increasing fish supply. In 2014, total fish supply in Zambia was 10.6 kg/capita/annum (FAO, 2020). Reports for the 2000 to 2019 period showed that without fish imports, fish supply would decrease by 3.9 kg/capita/annum (Kaminski et al., 2018).

Figure 2.3 shows the trend for pooled quantities of tilapia imports and exports over an eight-year period from 2012 to 2019. The corresponding values (USD) for the imports and exports are presented in Figure 2.4. Data on tilapia imports and exports for 12 years, between 2000 and 2011, were meagre and were not used in the present review. The eight-year trend showed that imports dominated tilapia trade flow while exports were nominal. There were also some disparities in the share of individual countries on the cumulative volume of tilapia imports. Countries which reported more tilapia imports were Angola, Namibia, South Africa, and Zambia (FAO, 2020). For instance, in 2014 when the aggregate tilapia imports were 66520 tonnes for the 10 countries valued at USD 33 million, Angola imported 47562 tonnes. In 2019, when the combined tilapia imports were 47258 tonnes, the share for Zambia was 13775 tonnes.

The Chinese farmed tilapia industry is the largest in the world. China continues to export significant quantities of tilapia to Africa including Southern Africa (FAO, 2020). Africa is an important market for the Chinese tilapia since the other market in United States of America (USA) imposed some tariffs on the product (Tran et al., 2019). A notable impact of tilapia imports from China is on the price of tilapia on the local market. Imported tilapia from China is cheaper than locally produced farmed and wild tilapia (Tran et al., 2019). The Chinese tilapia industry is competitive due to relatively low cost of feed, seed (fingerlings) and labour which are important production inputs in tilapia farming (Gu et al., 2019). The production of tilapia using a polyculture system was also reported as an important factor in driving the economic profitability of tilapia farming in China (Gu et al., 2019; Wang and Lu, 2016). Tilapia polyculture improves feed utilization, enhances water quality, increases total yield and profit (Wang and Lu, 2016). Therefore, affordable tilapia imports from China continues to moderate tilapia prices making the product affordable to consumers (Tran et al., 2019). In 2015 Namibia imported 3670 tonnes of frozen tilapia from China (FAO, 2020). Imports and exports between Southern Africa countries were also reported. In 2015, Namibia exported 76 tonnes of fresh tilapia to Zambia along with 2651 tonnes of frozen tilapia (FAO, 2020).

There were specialised cold chain and logistics companies that import/export, distribute and market tilapia in Southern Africa (Hasimuna et al., 2019). In Zambia there was Capital Fisheries Ltd which is a major importer and distributor of farmed tilapia (Kaminski et al., 2018). In South

Africa and Malawi, Boss Fisheries Ltd imports tilapia and plays a key role in distribution and marketing of the product (Kaminski et al., 2018). The companies had cold chain systems and transport networks that deliver tilapia products in the respective countries. They had cold rooms, refrigerated trucks and display freezers in their distribution and retail shops. A working cold chain system is important to ensure that fresh tilapia is delivered in good quality as well as that frozen tilapia maintains a temperature of -18°C or less to guarantee food safety (Xiao, 2021).

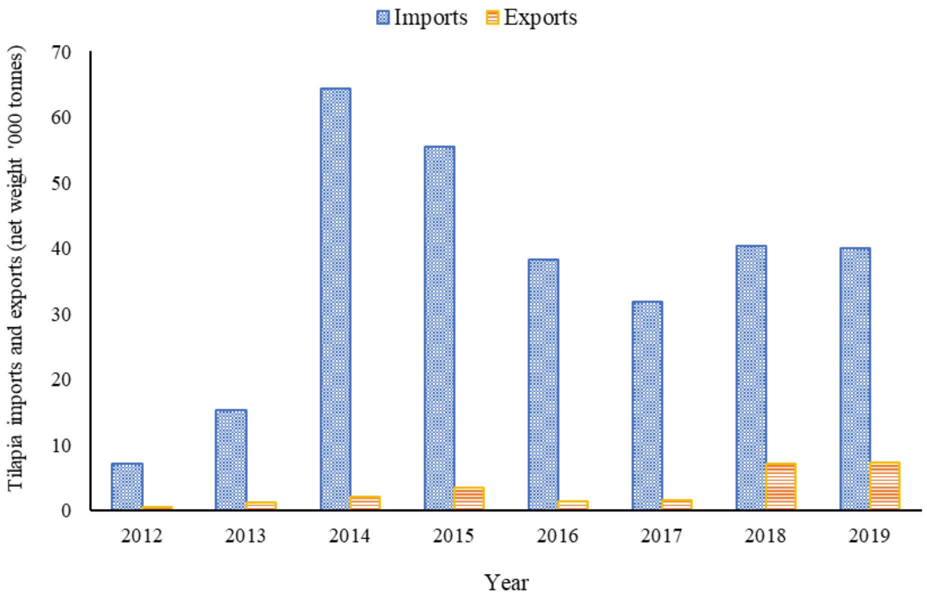

Figure 2.3 Pooled quantities of tilapia imports and exports in Southern Africa.

Countries**:** Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe

Species: *Blue tilapia; Sabaki tilapia; Longfin tilapia; Mango tilapia; Blackchin tilapia; Redbelly tilapia; Redbreast tilapia; Tilapias nei; Nile tilapia; Three spotted tilapia; Tilapia shiranus; Blue-Nile tilapia hybrid*.

Source: FAO. 2021. Fishery and Aquaculture Statistics. Global production by production source 1950-2019 (FishstatJ). In: FAO Fisheries Division [online]. Rome. Updated 2021. www.fao.org/fishery/statistics/software/fishstatj/en

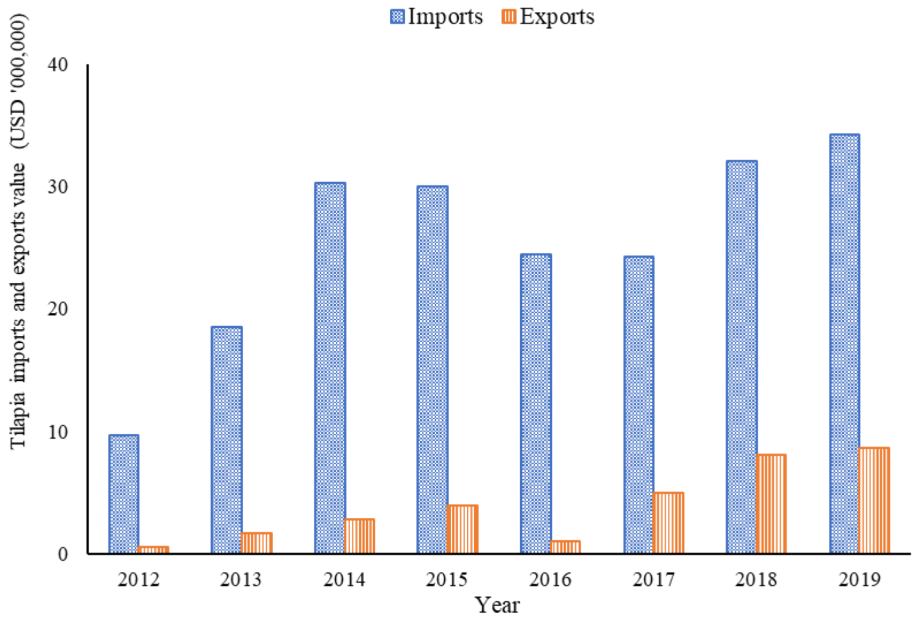

Figure 2.4 Total value for tilapia imports and exports in Southern Africa.

Countries**:** Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe
Species: *Blue tilapia; Sabaki tilapia; Longfin tilapia; Mango tilapia; Blackchin tilapia; Redbelly tilapia; Redbreast tilapia; Tilapias nei; Nile tilapia; Three spotted tilapia; Tilapia shiranus; Blue-Nile tilapia hybrid*.
Source: FAO. 2021. Fishery and Aquaculture Statistics. Global production by production source 1950-2019 (FishstatJ). In: FAO Fisheries Division [online]. Rome. Updated 2021.
www.fao.org/fishery/statistics/software/fishstatj/en

2.3.6 Tilapia consumption in Southern Africa

Tilapia consumption dates to centuries (over 3000 years ago) and it is a favourite dish in almost all countries in Africa (Belton et al., 2018). Tilapia is consumed as an affordable source of protein in rural areas, particularly among fishing communities along the major inland fishing grounds (Chikowi et al., 2021). Contrarily, tilapia is also a premium product for the affluent in urban centres and features on the menus of hotels and restaurants in most countries (Chikowi et al., 2021; Kaminski et al., 2018). Some of the qualities that make tilapia a favourite fish to many consumers include good visual appearance, easiness to clean and prepare, as well as the taste and flavour of the fish when cooked (Darko et al., 2016; Uddin et al., 2019). Tilapia is affordable due to its medium size (FAO, 2020). It is also uncommon for tilapia to be negatively associated with religious and cultural beliefs (Darko et al., 2016; Uddin et al., 2019). The increasing tilapia imports to Southern Africa also indicates high demand for the product (Chikowi et al., 2021; Tran et al., 2019). Southern Africa is an important market for tilapia due to a combination of factors including rapid population growth, urbanization, and the rise of a middle economic class (Chikowi et al., 2021; FAO, 2020; Moyo and Rapatsa, 2021; Tran et al., 2019).

Time series data on fish prices and demand did not exist in many countries in Southern Africa for the period between 2000 and 2019 (Blasco et al., 2020; Chikowi et al., 2021; Desiere et al., 2018). Therefore, demand for fish was estimated from data on per capita fish supply, as well as consumer incomes and preferences (Chikowi et al., 2021). Total fish supply was used as a proxy for tilapia consumption, albeit with caution since other fish species especially small pelagic fish, dominate fish supply and consumption in many parts of the region (FAO, 2020).

2.3.7 Total fish supply in Southern Africa

Figure 2.5 shows trends in total fish supply (kg/capita/annum) from 2000 to 2017. Total fish supply was calculated by dividing available fish quantities by the total population for a country (FAO, 2020). The overall average annual fish supply for all the 10 countries was 6.96 kg/capita/annum for the period between 2000 and 2017. There were some disparities in the average annual per capita fish supply among the 10 countries. Angola recorded the highest fish supply of 16.70 kg/capita/annum while Lesotho recorded the lowest fish supply of 1.2 kg/capita/annum.

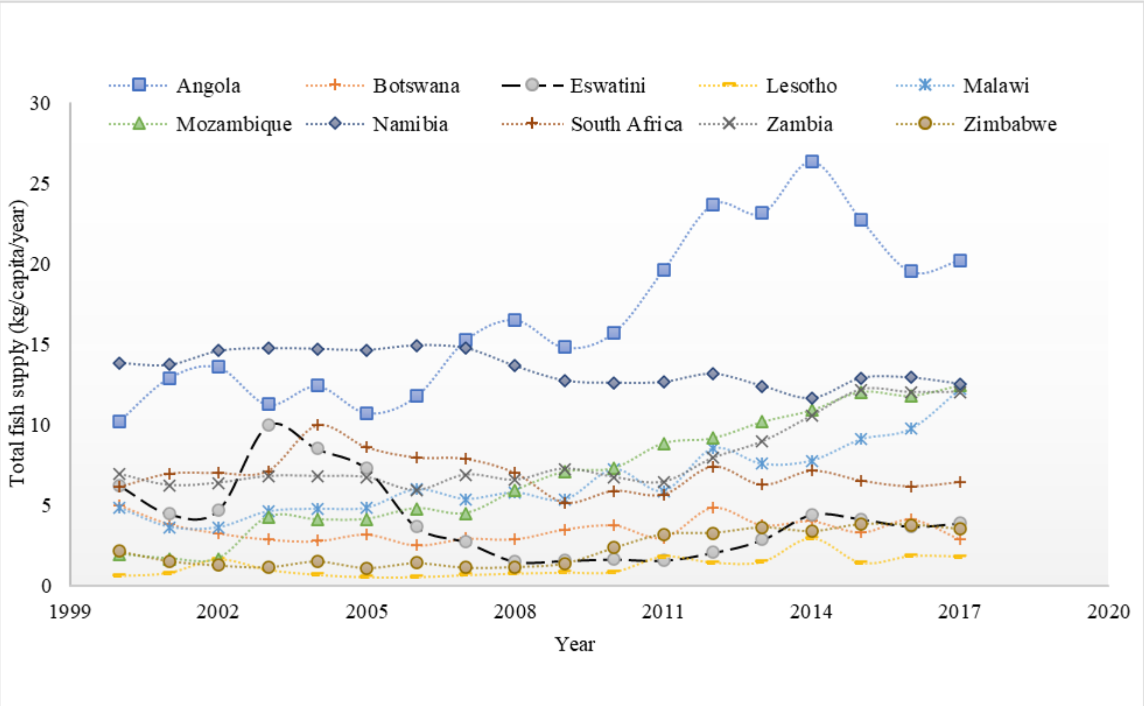

Figure 2.5 Total fish supply in Southern Africa (kg/capita/annum).
Species: *Blue tilapia; Sabaki tilapia; Longfin tilapia; Mango tilapia; Blackchin tilapia; Redbelly tilapia; Redbreast tilapia; Tilapias nei; Nile tilapia; Three spotted tilapia; Tilapia shiranus; Blue-Nile tilapia hybrid*.
Source: FAO. 2021. FAO food balance sheet 1950-2019 (FishstatJ). In: FAO Fisheries Division [online]. Rome. Updated 2021. www.fao.org/fishery/statistics/software/fishstatj/en

Angola lies within the Benguela Current Large Marine Ecosystem (BCLME), one of the most productive large marine ecosystems in the world. It has a continental coastline of 1,600 km that supports marine fisheries accounting for more than 70% of fish production in the country (Sowman and Cardoso, 2010). There is also high demand for fishery products in Angola due to traditional patterns of fish consumption and fishery products account for over 25% of total animal protein supply. However, small pelagic fish dominates domestic fish supply and represents 39% of the total declared catches (FAO, 2020).

2.3.8 Common forms of tilapia consumed in Southern Africa

Tilapia in Southern Africa is found in three forms, namely, fresh whole, frozen whole or smoked whole (Genschick et al., 2018). Other forms of tilapia are frozen fillets with or without the skin. Fresh whole tilapia, particularly wild tilapia, is consumed within the fishing communities as well as urban cities through a short and less developed fish value chain (Chikowi et al., 2021; Genschick et al., 2018). Farmed tilapia, raised mostly in earthen ponds by small-scale fish farmers, is also consumed fresh locally (Chikowi et al., 2021; Torell et al., 2020). Smoked tilapia from capture fisheries is consumed by a large majority of tilapia consumers in distant places away from the fishing grounds. Smoked tilapia is shelf stable and therefore easy to transport (Torell et al., 2020). It is also more affordable as compared to fresh whole tilapia due to its longer shelf life and easiness to transport. The product is particularly useful as it significantly reduces post-harvest losses and contributes to food security in resource constrained areas where cold chain systems are poorly developed (Torell et al., 2020).

2.3.9 Food safety concerns for farmed tilapia

One of the food safety concerns for fish is the level of heavy metal contamination in the fish muscle (Kong et al., 2005). Heavy metals are classified as essential metals and non-essential metals. Essential metals, such as, magnesium (Mg) and iron (Fe) are required for normal biological functions in the human body but can be harmful when levels exceed thresholds for toxicity (tolerable upper intake levels, UL). Non-essential metals such as mercury (Hg) and lead (Pb) are not needed for normal biological functions in the human body and are toxic even in small amounts (Bosch et al., 2016; Kong et al., 2005). Heavy metals can cause cancer (carcinogens), can disrupt endocrine function, and can cause kidney and lung damage just to mention a few effects (Simukoko et al., 2021). Fish is a potential carrier of heavy metals from polluted environments to the human diet. Therefore, monitoring of toxic metals in fish is important to safeguard both the environment and human health (Simukoko et al., 2021).

There are maximum limits (ML), set by the Word Health Organisation (WHO), the Food and Agriculture Organization (FAO), the European Union (EU) and the Food and Drug Administration of the United States (FDA) for various heavy metals in fish for human consumption (Simukoko et al., 2021). However, limited studies have been done on heavy contamination in tilapia from different sources in Southern Africa. One study reported on the assessment of heavy metals in wild and farmed tilapia (*Oreochromis niloticus*) on Lake Kariba (Zambia side) and showed that tilapia from the lake is safe for human consumption (Simukoko et al., 2021). In China, studies on heavy metal contamination in tilapia showed concern on the problem in tilapia from some of the major tilapia producing regions.

Table 2.1 presents results of assessment of heavy metals in tilapia from Zambia and China (Simukoko et al., 2021). The table also shows maximum limits (MLs) set by WHO/FAO, European Union (EU) and the Food and Drug Administration (FDA). The data in Table 2.1 are from a study on heavy metal contaminants in tilapia collected from mainland China. The study showed that the fish were polluted by lead (Pb) (Kong et al., 2005; Leung et al., 2014). Another study on assessment of heavy metals concentrations in fish in the Pearl River Delta (PRD), China, showed that significant levels of Pb were found in tilapia at all locations where the fish were sampled (Kong et al., 2005; Leung et al., 2014). PRD is the low-lying area surrounding the Pearl River estuary, where the Pearl River flows into the South China Sea. It is in Guangdong, the province that produces over 40% of all tilapia in China (Kong et al., 2005). It was recommended from the studies that heavy metal concentrations in different fish species should be monitored to safeguard food safety and reduce the impending consequences on human health.

2.3.10 Nutritional quality of tilapia from different sources in Southern Africa

Comparative data on the nutritional quality of tilapia from different sources in Southern Africa was scanty. Table 2.2 shows a general overview of the nutrient profile of tilapia from some sources in the region. The data are not representative and exhaustive of all tilapia production types (wild versus farmed and for pond and cage systems), production regions or species of tilapia. The table presents proximate composition (dry matter proportion, protein, fat, and ash), mineral and selected vitamin composition, as well as fatty acid profile of tilapia (Jim et al., 2017; Nölle et al., 2020). The proximate composition data shows that tilapia is an important source of animal protein as the fish contains 17.1% protein. This is a crucial aspect of the contribution of tilapia to food and nutrition security.

Fatty acid profile data showed higher amounts of unsaturated fatty acids (total monounsaturated, MUFA and total polyunsaturated, PUFA) than saturated fatty acids (SFA). Tilapia is a good source of health friendly essential fatty acids, such as, omega-3 polyunsaturated fatty acids (n-3 PUFA) which are important because of their anti-inflammatory effect as well as their protective role against chronic non communicable diseases (NCDs), such as cardiovascular diseases (CVD) (Harris and Zotor, 2019; Kuusipalo and Käkelä, 2000).

Table 2.1 Heavy metal concentrations (mg/kg, ww) in tilapia from Zambia (Lake Kariba) and China.

Heavy metals	**Tilapia from Zambia[1]**		**Tilapia from China**		**Maximum limits[4]**		
	Wild	**Farmed**	**Fishpond and local markets[2]**	**Pearl River Delta[3]**	**WHO/FAO**	**EU**	**FDA**
Essential metals							
Magnesium (Mg)	248.00	252.00					
Iron (Fe)	6.24	7.58			45		
Zinc (Zn)	6.00	7.03		29.5	30		
Copper (Cu)	0.91	3.04		1.38	30		
Selenium (Se)	0.157	0.165					
Cobalt (Co)	0.038	0.055					
Molybdenum (Mo)	0.023	0.054					
Chromium (Cr)	0.044	0.029	<0.001 – 0.884	0.51			8
Nickel (Ni)	0.015	0.011		3.50			1
Non-essential metals							
Vanadium (V)	0.023	0.011					
Aluminium (Al)	3.29	1.47					
Arsenic (As)	0.029	0.036					
Mercury (Hg)	0.013	0.005			0.5	0.5	1
Lead (Pb)	0.007	0.008	0.507 – 3.519	8.62	0.3	0.3	
Lithium (Li)	0.007	0.007					
Cadmium (Cd)	0.001	0.001	<0.001 – 0.298	0.03	0.1	0.05	
Silver (Ag)	0.001	0.001		0.03			

[1]Wild tilapia was sampled from three sites on Lake Kariba while farmed tilapia was sampled from two farms on the lake in Zambia. The results were presented separately in the original study. However, the values were averaged to provide an overview of the heavy metal concentrations in Table 2.1 in the present review.
[2]Thirty fish (*Tilapia mossambicus*) collected from fishponds and local markets in Hong Kong and China
[3]Fish samples were collected from estuaries area located in Pearl River Delta in Guangdong province China
[4]Maximum limits (MLs) are from different organisations (WHO/FAO, EU, FDA). However, some metals like Magnesium (Mg) did not have MLs specifically for fish muscle in these guidelines.
Ww means on wet weight basis

Table 2.2 Nutrient composition of tilapia from different sources in Southern Africa.

Composition	**Quantity**	**Species**	**Origin**	**Reference**
Proximate composition (g /100 g, ww, mean, SE)		*Oreochromis niloticus*	Lake Kariba, Zimbabwe	(Jim et al., 2017)[a]
Dry matter	24.7 (0.7)			
Protein	17.1 (0.5)			
Ash	3.3 (0.3)			
Fat	1.7 (0.3)			
Minerals (mg /100 g, dw)		*Oreochromis niloticus*	Lake Kariba, Zimbabwe	(Jim et al., 2017)[a]
Iron (Fe)	4.50			
Zinc (Zn)	0.95			
Copper (Cu)	0.71			
Magnesium (Mn)	24.17			
Sodium (Na)	18.33			
Potassium (K)	387.17			
Calcium (Ca)	59.00			
Phosphorus (P)	175.00			
Vitamins (mean ± SD)		*Oreochromis niloticus*	Lake Kariba, Zambia	(Nölle et al., 2020)[b]
Riboflavin (mg /100 g)	0.17 ± 0.027			
Niacin (mg /100 g)	4.01			
Folate (µg /100 g)	13.02			
Vitamin B12 (µg /100 g)	1.31			
Fatty acid (wt %, mean ± SD)				
∑SFA	40.2 ± 3.00	*Oreochromis lidole*	Lake Malawi, Malawi	(Kuusipalo & Käkelä, 2000)[c]
∑MUFA	21.8 ± 2.41			
∑PUFA	30.0 ± 2.53			
∑n-3 PUFA	19.9 ± 2.71			
∑n-6 PUFA	9.7 ± 1.17			

SE: Standard error; SD: Standard deviation; ww means on wet weight basis; wt % means percent weight
SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; ∑ - total
[a]The data were from a study on comparative analysis of nutritional value of *Oreochromis niloticus* (Linnaeus), Nile Tilapia, from three different ecosystems in Zimbabwe. The sample for this dataset comprised of 10 fresh tilapia caught using the seine netting and gill netting method from Lake Kariba in Zimbabwe.
[b]This was part of a study on nutrient analysis of different fish in Zambia. The samples were four fresh tilapia (*Oreochromis niloticus*) from cage aquaculture Lake Kariba in Zambia. The fish were scaled and filleted,
[c]The fish sampled for this study were collected from trawl catches in Mangochi District, in the southeast arm of Lake Malawi in Malawi.

2.3.11 Consumer preference for wild and farmed tilapia

Consumer preference is a process of choice and rank by consumers when they are presented with a range of similar products (Uddin et al., 2019). People choose or rank different goods because of the levels of utility, or the total satisfaction realised after consuming each product (Chikowi et al., 2021). Consumers have individual preferences, and their choices reflect such preferences (Darko et al., 2016). One of the dimensions of preference towards fish quality is the production method of fish in terms of wild versus farmed sources. Given similar prices, consumers would choose one product over the other (wild or farmed tilapia) based on their preference (Darko et al., 2016; Uddin et al., 2019). However, this preference may not always lead to predictable purchasing and consumption patterns due to prices and availability differences for wild versus farmed tilapia on the market (Chikowi et al., 2021). Consumer preference for different fish can be measured through consumer surveys (using questionnaires with Likert scales), choice experiments and sensory analysis techniques (Chikowi et al., 2021; Uddin et al., 2019).

Globally, consumer preference studies have shown that farmed fish receives a less positive image by consumers, as consumers rate wild fish products as tastier, safer and healthier compared to farmed fish (Claret et al., 2014). Farmed fish products are chosen due to their relatively lower cost and because of their increasing availability on the fish market. In Europe, research showed that consumers had different beliefs regarding farmed versus wild fish, and a clear preference for wild fish was demonstrated (Claret et al., 2014).

The low rating of farmed fish among consumers in general is partly due to a lack of correct and updated information about the fish and aquaculture (Claret et al., 2014; Freitas et al., 2020). Personal experience, preconceived ideas, demographics (such as age, sex, education, and income level) and regional context of consumers strongly influence perceptions of farmed fish (Claret et al., 2014). Nevertheless, there are emerging changing trends in consumer perceptions on farmed fish globally, particularly among younger generations as observed in some countries in Europe (Freitas et al., 2020). There is a segment of high potential aquaculture consumers with overall positive rating for farmed fish and a contrasting segment of low potential aquaculture consumers with negative perceptions for farmed fish products (Freitas et al., 2020).

In some countries in Africa findings showed that some consumers rate wild tilapia favourably over farmed tilapia (Chikowi et al., 2021). In Tanzania, research showed that consumers were willing to pay less for farmed tilapia than for wild tilapia because of their preference for the better taste of wild tilapia (Darko et al., 2016). However, in the same study it was found that consumers were heterogeneous in their preferences for other tilapia attributes such as size, and form. In Southern Africa reports indicate favourable rating of wild over farmed tilapia among consumers, despite the dearth of specific research on the subject (Chikowi et al., 2021; Genschick et al., 2018). This is partly the case because some consumers are used to the taste and qualities of wild caught fresh tilapia and they regard wild tilapia quality as the reference (Chikowi et al., 2021; Claret et al., 2014; Genschick et al., 2018).

However, there might be changing trends in consumer perceptions to have positive rating for farmed fish in Southern Africa. The uptake of farmed tilapia imported from China indicated changing dynamics of the overall image of farmed tilapia in the region (Tran et al., 2019). Factors such as availability and lower price of farmed tilapia have been reported to be mediating factors for the market potential of farmed tilapia in Southern Africa (Tran et al., 2019). Similar findings, where consumers prefer cheaper farmed tilapia that is readily available, have were reported in Tanzania and Bangladesh (Genschick et al., 2018).

2.4 Discussion

The review has highlighted trends in tilapia consumption in Southern Africa focusing on supply, quality, and consumer preference for wild and farmed tilapia using a 20-year (2000-2019) time series data by the FAO. Wild tilapia production from the region declined over the 20-year reporting period (FAO, 2020). The data supported the trend in literature which shows that wild fish stocks in Southern Africa were exhausted and could no longer support current and future demand for fish (Belton and Thilsted, 2014; Blasco et al., 2020; FAO, 2020; Freitas et al., 2020). The decline in fish supply was due to overfishing to meet increasing demand for tilapia because of population growth and emerging middle-income classes (Bell et al., 2012; FAO, 2020). Other factors such as pollution, climate change, illegal fishing, habitat destruction, violation of closed seasons (for breading) also exacerbate the problem (Bell et al., 2012; FAO, 2020).

Declining wild tilapia poses a threat to the food and nutrition security of millions of people who depend on fisheries for food and income (Belton et al., 2018; Torell et al., 2020). Therefore, there is a need to make tilapia fisheries more sustainable to continue supporting communities that depend on wild tilapia. Freshwater ecosystems such as Lake Malawi, Lake Kariba and Zambezi River should be protected so that vulnerable local fishing communities can continue to benefit from the fish resources from such sources. Governments should enforce regulations that help to reduce pollution of the freshwater bodies by controlling anthropogenic activities close to these areas (Makwinja et al., 2021; Nyikahadzoi et al., 2017; Torell et al., 2020). Some of the specific strategies for sustainable fisheries management include gear licensing, gear and mesh size regulations, implementation of closed seasons for tilapia breeding, fisheries co-management, and ecosystem-based management approach to fisheries (Bell et al., 2012; Makwinja et al., 2021). However, there is a need for more research on the effectiveness of these strategies in improving fish biomass in the respective tilapia fishing grounds. Data reporting systems for wild tilapia should be strengthened so that databases such as the FAO database could be complete for ecosystems monitoring, biodiversity conservation and research (Blasco et al., 2020; Desiere et al., 2018; FAO, 2020).

Tilapia production from aquaculture operations from the 10 countries investigated in this review showed growth in the sector over the 20-year period notwithstanding low volumes from most of the countries. Zambia demonstrated to be a model for successful cage aquaculture. There is biophysical potential in the other countries such as presence of lakes, rivers and dams that can successfully support aquaculture in Southern Africa (Moyo and Rapatsa, 2021). These countries should emulate the Zambian model by encouraging private sector involvement in large-scale commercial cage aquaculture, researching, and legalising the use of high performing tilapia strains such as *Oreochromis niloticus*, and supporting entrepreneurship in feed processing and fingerlings production (Hasimuna et al., 2019; Kaminski et al., 2018; Tran et al., 2019). Governments should put in place systems to fast-track the process of issuing permits and licences for commercial aquaculture start-ups and ensure that the process is synchronised to avoid a back-and-forth scenario that lengthens the process.

Most of the tilapia famers (over 90%) in Southern Africa are small-scale farmers who raise the fish in earthen ponds (Adeleke et al., 2020). However, aquaculture contributes to the livelihoods of the farmers and boosts household fish consumption particularly in resource constrained settings (Adeleke et al., 2020). However, small-scale tilapia farmers face challenges to raise good quality fish and have limited access to formal tilapia markets (Mussa et al., 2020). Therefore, there is a need to support these farmers by assisting them to be organised in cooperatives and providing them with access to training, capital, and inputs such as commercial feed and fingerlings (Moyo and Rapatsa, 2021; Mussa et al., 2020). Use of high performing tilapia strains such as *Oreochromis niloticus* should be researched and promoted among these small-scale farmers to boost productivity and efficiency (Mussa et al., 2020).

Earthy flavours in farmed tilapia should be controlled by following good aquaculture practices to reduce the growth of cyanobacteria and actinomycetes and the production of geosmin (Abd El-Hack et al., 2022). This can be achieved by maintaining good water quality in the ponds and by avoiding over-feeding which results in the formation of excess feed in the bottom of the pond resulting in the growth of the above-mentioned microorganisms (Abd El-Hack et al., 2022). In addition, the use of pelleted fish feed should also be encouraged (Abd El-Hack et al., 2022). Governments should facilitate the provision of expertise on fish disease management, cold chain transport systems as well as group marketing for fresh tilapia (Abd El-Hack et al., 2022). Farmers should be encouraged to keep records of tilapia harvests and should report the harvests through a working data tracking system to the respective governments. More comprehensive data would be helpful for research, evidence-based policy analysis, and programmes development (Blasco et al., 2020).

Tilapia imports to Southern Africa increased over the eight years from 2012 to 2019. The rise in imports was due to higher demands for tilapia considering the dwindling wild fish supply coupled with slow growth of the aquaculture sector. Tilapia imports from China played an important role of addressing fish supply deficits, meeting consumer demand for fish and moderating the price of tilapia on the local market. Supporting international and regional fish trade in Southern Africa has a potential of reducing poverty and improving food security. Fish trade can benefit from initiatives such as the African Continental Free Trade Area (AfCFTA) and efforts aimed at reducing tariff and non-tariff technical barriers to trade (TBT) (Mussa et al., 2017). This would also reduce the prevalence of informal fish trade between countries and enhance the process of compiling fish trade statistics (Mussa et al., 2017). Tilapia trade in Southern Africa presents an entrepreneurship opportunity for importing, refrigerated transport for frozen tilapia as well as marketing of the product in the 10 countries included in this review (Chan et al., 2019).

Average fish supply (for all fish species and fish products including tilapia) for the region was 6.96 kg/capita/annum between 2000 to 2017. This was less than the average fish supply for Africa which was reported at 10.1 kg/capita/annum (FAO, 2020). Despite the low aggregate fish supply, Angola showed the highest record of 16.70 kg/capita/annum (FAO, 2020). The total fish supply trend can be used as a crude indicator for tilapia supply and demand even though other fish species may dominate fish consumption. Interestingly, Angola also reported the highest figures for tilapia imports over the same period signifying that the aggregate fish supply was relevant in this context. There are several factors that explain fish supply such as availability (from fish production and trade), accessibility (physical or economic access), utilisation and individual preferences (Chan et al., 2019). In Angola, access to fish and an established tradition of including fish in the diet contributes to high fish consumption (Sowman and Cardoso, 2010). On the other hand, in other countries like Lesotho, Eswatini and Botswana, limited fish availability may explain the low per capita fish supply. There is a need to increase fish availability through sustainable aquaculture and fish trade and raise consumer awareness on the health benefits of fish consumption.

Reports showed favourable rating of wild tilapia over farmed tilapia among consumers in some countries in Southern Africa. However, this is partly due to a long-established tradition of consuming fresh wild tilapia from freshwater ecosystems. An increase in farmed tilapia imports from other countries, particularly farmed tilapia from China to most countries in Southern Africa, demonstrated the potential acceptability of farmed tilapia in the region. There is a need for consumer studies and sensory analysis research to conclusively demonstrate consumer preference for locally produced wild tilapia versus farmed tilapia as well as imported farmed tilapia in Southern Africa (Chan et al., 2019). There is also a need for research on the nutritional quality, fatty acid profile and heavy metal concentration of locally produced farmed and will tilapia in Southern Africa in comparison with imported tilapia. This important since nutritional profile and presence of heavy metal contaminants in tilapia depends on feed quality and as well as water quality in which the fish is raised (Simukoko et al., 2021). Policies and strategies to upscale sustainable aquaculture, facilitate fish trade and ensure consumer protection should be strengthened.

2.5 Conclusions

Tilapia plays an important role in food security and livelihoods in Southern Africa despite low supply of wild tilapia and slow growth in the aquaculture sector. Zambia is a model for successful cage aquaculture in Southern Africa. Other countries should encourage private sector involvement in aquaculture, researching and legalising the use of high performing tilapia strains, supporting feed processing and fingerlings production, and synchronising the process for issuing permits and licences. Tilapia imports particularly from China play a critical role of sustaining fish supply to meet increasing demand with countries like Angola, Namibia and South Africa being the major tilapia importers. Preference for wild tilapia over farmed tilapia is still reported in the region. However, an increase in farmed tilapia imports demonstrates the potential acceptability of farmed tilapia in some countries. Policies and strategies to upscale sustainable aquaculture, facilitate fish trade and ensure consumer protection should be strengthened.

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CHAPTER 3: Consumer preference for wild versus farmed tilapia in retail distribution in Malawi

Abstract

Farmed fish (including farmed tilapia) have always received a less positive image from consumers. Consumers rate wild fish products as tastier, safer, and healthier as compared to farmed fish. However, objective sensory analysis of wild versus farmed fish of the same species often show comparable results on the sensory characteristics of the fish. The objective of this study was to examine consumer preference for wild versus farmed tilapia from Malawi and farmed tilapia imported from other countries. Tilapia consumers (n = 200) in Lilongwe Malawi were interviewed in a quantitative survey. Data were collected on tilapia consumption patterns, knowledge, beliefs, attitudes, perceptions of consumers towards tilapia as well as main demographic aspects including age categories and income. Four qualitative focus group discussions (FGDs), with eight participants per group, were conducted to gain a deeper understanding of consumer preference for wild versus farmed tilapia. Quantitative survey data were analysed using χ^2 test and correspondence analysis (CA) while qualitative data were analysed by thematic analysis using ATLAS.ti 22. Consumers (98%, n = 197) were aware of the different types and sources of tilapia sold on the Malawian market (wild versus farmed and locally produced versus imported tilapia). Sixty five percent (n = 130) of the consumers preferred wild tilapia from Malawi due to its perceived quality (appearance, aroma, test, and texture) even though they perceived the price of wild tilapia to be higher than that of farmed tilapia. Forty two percent (n = 84) of the consumers purchased wild tilapia most of the times while 34% (n = 67) purchased farmed tilapia. However, CA revealed that consumers with a high tilapia consumption frequency (1-2 times tilapia consumption per week) were more likely to purchase frozen farmed tilapia than consumers from medium (1 - 2 times tilapia consumption per month) and low tilapia consumption frequencies (5 - 6 times tilapia consumption per year). The study provides valuable information on consumer preference with relevance for consideration to improve the quality of tilapia from aquaculture. It demonstrates the potential demand for farmed tilapia from Malawi and farmed tilapia sourced from other countries. This is because of the proportion of consumers (34%) which reported that they often purchased farmed tilapia.

Keywords

Aquaculture; Consumer choice; Correspondence analysis; *Oreochromis* spp.; Southern Africa

3.1 Introduction

The World Health Organisation (WHO), United States Department of Health and Human Services (HHS) as well as the American Heart Association (AHA) recommend regular consumption of fish, of at least two servings per week (227 g per week) as part of a healthy dietary regime (Nishida et al., 2004; Miller et al., 2014; Phillips, 2021; Tur et al., 2001). World per capita fish consumption more than doubled from an average of 9.7 kg/capita/annum in 1961 to 20.5 kg/capita/annum in 2018 (FAO, 2020). Furthermore, a global aggregate fish consumption record of 140 million tonnes was reported for 2018 (FAO, 2020). It is estimated that the global population will increase to 9 billion by 2050 with a corresponding increase in the demand for food (100% increase) (FAO, 2020). Fish is a healthy food and is an important source of proteins, minerals, vitamins, and omega-3 fatty acids (Mohanty et al., 2019). As a result of the recognition of fish as a healthy food in the diet, the demand for fish can also increase with an increase in the global population. Another factor that will contribute to the increase in demand for fish is a rise in a middle-class population that can afford fish purchases especially in low- and middle-income countries (LMIC) (Desiere et al., 2018; Ragasa et al., 2020).

The increase in demand for fish exerts pressure on wild fish stocks leading to overfishing and unsustainable fisheries (FAO, 2020). Other factors like fish habitat destruction, pollution, climate change and the introduction of invasive species in some natural ecosystems also contribute to the decline of wild fish stocks (FAO, 2020; Hecky et al., 2003; Vollmer et al., 2005). Wild fish from natural sources can no longer meet the demand for fish from the global population. Fish from aquaculture complements wild fisheries to meet the demand for fish (FAO, 2020). Aquaculture is the fastest growing animal food production industry in the world with estimates showing an average growth rate of 7.5% per annum since 1970 (FAO, 2020; Fiorella et al., 2021). In 2018 aquaculture contributed 82.1 million tonnes of fish representing 46% of the total global fish supply (Freitas et al., 2020).

Tilapia is a strategic fish species that is important for aquaculture development due to its fast growth and tolerance to varying aquatic conditions (Day et al., 2016; FAO, 2020; Freitas et al., 2020). Tilapia is the second most popular farmed fish globally, after the carp (*Cyprinus carpio*) (FAO, 2020). Additionally, tilapia is one of the most traded fish commodities globally (FAO, 2020; Fiorella et al., 2021). In the United States, tilapia is among the four most consumed farmed fish along with salmon, catfish, and trout (Weaver et al., 2008). In Africa tilapia is a favourable farmed fish along with catfish (*Clarias* spp. and *Heterobranchus* spp.) (FAO, 2020).

However, farmed fish (including farmed tilapia) have always received a less positive image from consumers (Claret et al., 2014; Darko et al., 2016; Freitas et al., 2020). Consumers rate wild fish products as tastier, safer, and healthier as compared to farmed fish (Claret et al., 2014). Oftentimes, aquaculture products are chosen due to their relatively lower cost and because of their increasing availability on the global fish market (Carlucci et al., 2015; Polymeros et al., 2015). In

Europe, consumers prefer wild fish over farmed fish (Reinders et al., 2016; Wongprawmas et al., 2022). All this is notwithstanding the increasing importance of aquaculture in supplying fish to meet consumer demand (Freitas et al., 2020).

The low rating of farmed fish among consumers is partly due to a lack of correct and updated information about the quality of such fish and aquaculture in general, as well as insufficient promotion and awareness of farmed fish (Bacher, 2015; Claret et al., 2014). There are several factors that strongly influence perception of consumers towards farmed fish and aquaculture, such as personal experience, preconceived ideas, and the demographic characteristics of the consumers, such as age, sex, education, and income level. In addition to these factors, the regional context of the consumers also influences their rating of different farmed fish in comparison with wild fish (Bacher, 2015; Wongprawmas et al., 2022). Nonetheless, there are emerging changing trends in consumer perceptions on farmed fish particularly among younger generations as observed in some European countries, including, Portugal, Spain, and the United Kingdom (UK) (Polymeros et al., 2015; Reinders et al., 2016). In these countries there are clear segments of high potential aquaculture products consumers with an overall positive image of farmed fish against contrasting segments of low potential aquaculture products consumers (Polymeros et al., 2015; Reinders et al., 2016).

The country of origin of fish is also vital and the importance of correct labelling of fish products regarding country of origin cannot be overemphasized (Claret et al., 2014; Hinkes & Schulze-Ehlers, 2018; Li et al., 2016). Country of origin can be a branding tool for products and a country-of-origin strategy can be influential on the product among consumers in target markets (Claret et al., 2014; Li et al., 2016). The aspect of country of origin of fish products is particularly relevant in the context where Asian countries, especially China, India, Indonesia, and Bangladesh are exporting large volumes of farmed fish worldwide (FAO, 2020). However, little attention has been given to consumer preference research on wild versus farmed fish particularly in developing countries in Africa (Chan et al., 2019; Chikowi et al., 2021). Most of the research in Africa is on production (to increase productivity and fish supply) with limited attention given to consumption trends and consumer preference (Chan et al., 2019). This is despite the recognition of the importance of understanding consumer beliefs, attitudes, and perception as well as consumer preference for farmed fish compared to wild fish (Claret et al., 2014).

The aim of this study was to assess consumer preferences for tilapia from various sources found in Malawian markets. The first objective of the study were as follows: 1) to determine knowledge of fish consumers about different sources of tilapia on the Malawian market; 2) to examine beliefs, attitudes and perceptions that influence consumer preference for wild, farmed and imported tilapia in Malawi; 3) to examine consumer preference for wild versus farmed tilapia in Malawi; 4) to examine consumers prefer for tilapia from Malawi over imported tilapia. Based on literature review, four hypotheses were set to be tested in the study as shown in Table 3.1 (Carlucci et al., 2015; Chikowi et al., 2021; Claret et al., 2014; Darko et al., 2016; FAO, 2020).

Table 3.1 Hypotheses on consumer preference to be tested.

No.	Hypothesis
H_1	Consumers are not aware of the different types of tilapia sold on the Malawian market.
H_2	Beliefs, attitudes, and perceptions among consumers regarding tilapia do not influence their preference for wild, farmed and imported tilapia in Malawi.
H_3	Consumers tend to prefer wild over farmed tilapia.
H_4	Consumers tend to prefer tilapia from Malawi over imported tilapia.

3.2 Materials and methods

In this study consumers were interviewed to examine their preference for wild tilapia from Malawi, farmed tilapia from Malawi, as well as farmed tilapia imported from other countries. The research was conducted in two separate but complementary steps (Claret et al., 2014; Wongprawmas et al., 2022; Zander et al., 2022). The first step was a quantitative research where individual consumers were interviewed. The second step was qualitative research approach where focus group discussions (FGDs) were conducted with the consumers to gain a deeper understanding of their preference for wild, farmed and imported tilapia (Claret et al., 2014).

The study was conducted in Lilongwe City in Malawi. Wild tilapia is supplied mainly from Lake Malawi while farmed tilapia is supplied from cage aquaculture from Lake Malawi as well as from small scale pond aquaculture. Farmed tilapia is also imported from other countries particularly China, Zambia, and Zimbabwe (Chikowi et al., 2021). Participants in the study were tilapia consumers who went to buy fish from any of four fish shops/market. The four tilapia shops/markets were coded A to D. Source A, B and C were specialised fish shops while source D was an open fish market that was selling wild tilapia.

Some studies reviewed from the literature, where qualitative and quantitative research methods were employed, began with the qualitative approach where consumer knowledge, beliefs, attitudes, and perceptions towards fish were explored. From the exploratory qualitative studies, quantitative questionnaires were designed, and individual interviews followed (Claret et al., 2014; Wongprawmas et al., 2022; Zander et al., 2022). However, in the present study, the quantitative approach preceded the qualitative FGDs, and the survey questionnaire was designed based on a literature review with some modifications (Polymeros et al., 2015). This approach made it easier to organise the subsequent FGDs through the invitation of participants which was done during the face-to-face interaction with the consumers from the quantitative survey. The face-to-face approach was particularly important since online or mail surveys were not easy to conduct in Malawi where internet and postal communication were not easy in 2021.

3.2.1 Quantitative individual consumer interviews

Tilapia consumers (n = 200) were interviewed in a cross sectional face-to-face quantitative survey. The sample size for the study was computed with a power goal of 80% (Columb & Stevens, 2008). Fifty consumers were interviewed from each of the four shops/market (A to D).

The interviews were guided by a structured questionnaire adapted from previous studies on consumer preference studies on fish (Carlucci et al., 2015; Polymeros et al., 2015). The questionnaire is shown in Appendix 6. The questionnaire consisted of 15 questions divided into three sections. The first section consisted of five questions covering tilapia purchase and consumption patterns. The second section asked five questions on knowledge, beliefs, attitudes, and perceptions towards tilapia. The third section consisted of five questions on general information regarding the principal socio-economic characteristics of the consumers (Polymeros et al., 2015). The questionnaire was translated into the local language (Chichewa) by an experienced translator and the interviews were conducted in this local language. Interview responses were translated back to English for further statistical analysis.

Participants in the quantitative interviews were fish consumers who went to buy tilapia from the four shops/market. Recruitment of the interview participants was done through the customer intercept method (Rogers, 2017). In this approach, potential fish consumers who went to buy tilapia from the four shops/market were invited to the study. To qualify for participation, consumers voluntarily showed interest and passed a brief screening procedure. The screening included that the consumer should be over 18 years of age, and that they should be tilapia consumers. In addition to the latter, they should be involved in preparation of the fish at home (Carlucci et al., 2015). Face-to-face interviews were done on the same day at a suitable place at the shops/market. The interviews were facilitated by experienced quantitative research assistants who were trained on the study protocol. The research assistants also signed a non-disclosure agreement (NDA). The interviews were done in October of 2021. At the end of the interviews, the participants were invited to participate in qualitative FGDs arranged for a later date. It was mentioned at this stage that their transport costs will be reimbursed (Wongprawmas et al., 2022; Zander et al., 2022).

3.2.2 Focus group discussions with tilapia consumers

Four different FGDs were conducted with participants invited from each of the four shops/market (section 3.2). The discussions were guided by checklist with six questions on consumer knowledge, beliefs, attitudes, and perceptions as well consumer preference for fish from different sources as shown in Appendix 5. The FGD checklist was consistent with the quantitative survey questionnaire and was designed to gain further insights on the topic (Claret et al., 2014; Wongprawmas et al., 2022; Zander et al., 2022). The checklist was translated into the local language (Chichewa) by an experienced translator who was also the moderator for the FGDs. All the four FGDs were conducted by the same experienced moderator while an observer was present to take notes. Each FGD session was audio recorded for a deeper qualitative analysis (Claret et al., 2014). The discussions lasted between 30 and 60 min. For each FGD, eight participants were involved making a total of 32 participants from the four shops/market (Claret et al., 2014). The FGDs were conducted at Sunbird Lilongwe Hotel on four different dates in November of 2021. Participants in the FGDs were provided with refreshments after the discussions and their transport costs were reimbursed as communicated at recruitment stage (Claret et al., 2014; Wongprawmas et al., 2022; Zander et al., 2022).

3.2.3 Data analysis

3.2.4 Statistical analysis for the quantitative survey data

Data from the quantitative consumer interviews were analysed using descriptive univariate statistical techniques as well as a contemporary multivariate data reduction approach. Since the quantitative survey data were mainly categorical, in the univariate step, χ^2 test was used to assess association between the variables. Contingency tables were built and examined using Fisher's exact test. The contingency tables were constructed by the frequency of fish consumption variable against the rest of the study aspects. Tilapia consumption frequency was categorised as *high* for 1-2 times of tilapia consumption per week; *medium* for 1 - 2 times of tilapia consumption per month; and *low* for 5-6 times of tilapia consumption per year. This classification was based on the standard practice as reported in literature (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015).

The second step of the analysis was a multivariate statistical technique where correspondence analysis (CA) was run on the data to portray the association of categories of variables (Jaeger et al., 2022; Stemn & Krampah, 2022). Correspondence analysis is a novel paradigm for statistical analysis of categorical data in psychology and other social science research fields (Phan & Chambers, 2016; Stemn & Krampah, 2022). The technique is an exploratory dimension reduction statistical procedure that transforms tabular numerical data and produces a graphical display known as a perceptual map or a biplot (Cuadras & Greenacre, 2022). The perceptual map is an important output in CA, and it helps to visualise the relationship of the variables and permits a rapid understanding and interpretation of rather hidden patterns in a dataset (Stemn & Krampah, 2022). Input to a simple CA is a two-way contingency table as in χ^2 test. However, CA is not restricted by preliminary requirements for data normality tests and distribution assumptions as is the case with χ^2 test (Cuadras & Greenacre, 2022; Phan & Chambers, 2016; Stemn & Krampah, 2022).

The mathematical model for CA is expressed in the following equation known as the *reconstitution formula* and is particularly useful for the CA biplots (Cuadras & Greenacre, 2022).

$$p_{ij} = r_i c_j \left(1 + \sum_{k=1}^{K} \sqrt{\lambda_{ik}} \varphi_{ik} \gamma_{jk}\right) \quad (1)$$

In this equation, p_{ij} are the relative proportions n_{ij}/n, *n* being the grand total $\sum_i \sum_j n_{ij}$; r_i and c_j are the row and column masses; λ_k is the *k*-th principal inertia, also known as variance, denotes the level of association between variables and illustrates how well the column and row profile points are represented in the graphical display; φ_{ik} and γ_{jk} are the row and column standard coordinates, respectively. The mathematical reasoning behind CA computation as well as a detailed procedure for conducting CA is available in the literature (Cuadras & Greenacre, 2022).

Sample size calculation and all quantitative statistical analyses were done using Statistica™ software version 14 (Botlíková, 2021). Differences were considered significant at $p < 0.05$.

3.2.5 Qualitative data analysis

Audio recordings from the four FGDs were transcribed verbatim and translated to English by the experienced translator who moderated the interviews. The recordings, transcripts and translations were reviewed for accuracy by the researcher. The transcripts were coded followed by grouping of the codes into categories and organizing the categories into themes (Bruce Lauber et al., 2017; Cuevas et al., 2021). Relevant quotes that illustrate findings from the study are cited in the results in section 3.3.2. The analysis was guided by the three dimensions of the Theory of Planned Behaviour. The dimensions are attitudes, subjective norm, and perceived behavioural control (Cuevas et al., 2021). The qualitative data were analysed using ATLAS.ti 22 for Windows (ATLAS.ti Scientific Software Development GmbH, 2022).

3.2.6 Ethics approval statement

The study was conducted according to the guidelines of the Declaration of Helsinki. The research protocol was reviewed and approved by the Research Ethics Committee on Social, Behavioural and Education Research (SBER) at Stellenbosch University in South Africa (protocol number: SU-REC-2021-18970), (Appendix 1). In Malawi, the research was reviewed and approved by the National Committee on Research Ethics in the Social Sciences and Humanities, National Commission for Science and Technology (NCST), (protocol number: P.07-21-584), (Appendix 2). Gatekeeper permission was granted by the Department of Fisheries in the Ministry of Agriculture and Food Security in Malawi (Appendix 3). Furthermore, permission was sought from the owners of the shops/market, and they accepted.

Participation in this research was voluntary and written informed consent was obtained from each participant (Appendix 4). Participants in the FGDs were informed that the discussions would be audio recorded and they provided consent. The research team complied with all COVID-19 guidelines issued by the Malawi Government during all research activities. Individual interviews and FGDs were delayed until such a time when the Covid-19 infection rate went down to less than 5% in the country as guided by SBER.

3.3 Results

Results from the study are presented in two separate parts. Section 3.3.1 presents quantitative results from the individual surveys while section 3.3.2 focuses on the results from the qualitative FGDs.

3.3.1 Results from the quantitative individual interviews

Table 3.2 presents the socio-economic characteristics of the consumers by tilapia consumption frequency (section 3.2.4). Fish consumption frequency in this study was specific for tilapia and it is possible that the consumers ate other fish species in addition to tilapia. Consequently, the results on tilapia consumption frequency reported in this study may not be comparable with total fish consumption frequency among the surveyed population or the general population in the country (Malawi).

Seventy one percent (n = 142) of the consumers were high tilapia consumers, 26% (n = 52) were medium tilapia consumers and 3% (n = 6) were low tilapia consumers. There was no statistical difference in the gender representation of the consumers across the three tilapia consumption frequencies. Fifty three percent (n = 106) of the consumers were female while 47% (n = 94) were male. There were differences in the proportion of age categories among the consumers (χ^2 = 26.44, P < 0.01). More consumers (50%, n = 72) from high tilapia consumption frequency were within the 31 – 40 years age category compared to the medium and low tilapia consumption frequencies. There were also differences in the proportion of education level among the consumers (χ^2 = 9.51, P = 0.03). A greater proportion of consumers (56%, n = 76) from high tilapia consumption frequency attained tertiary education as compared to medium and low tilapia consumption frequencies.

There was no statistical difference in the proportions of type of employment reported by the consumers from the three tilapia consumption frequencies. Forty seven percent (n = 94) of the consumers were businesspeople, 11% (n = 23) were working in the civil service, 28% (n = 56) were working in the private sector, 6% were engaged in casual labour and 7% were unemployed. There was also no statistical difference in the proportions of monthly income among the consumers. Fifteen percent of the consumers earned below MWK 50,000.00, and 8% earned over MWK 1,000,000.00 (MWK stands for Malawi Kwacha which is the currency in Malawi; in October of 2021, the exchange rate was USD 1.00 = MWK 824.48 according to the Reserve Bank of Malawi).

Table 3.2 Socio-economic characteristics consumers by tilapia consumption frequency[a].

Variable	Level	Tilapia consumption frequency[a]			Total	χ^2	P value[b]
		High	Medium	Low			
Gender	Female	52.82 (75)	53.85 (28)	50.00 (3)	53.00 (106)		
	Male	47.18 (67)	46.15 (24)	50.00 (3)	47.00 (94)		
	Total	71.00 (142)	26.00 (52)	3.00 (6)	100 (200)	0.04	0.98
Age category (years)	18 – 20	0.70 (1)	5.77 (3)	16.67 (1)	2.50 (5)		
	21 – 30	21.13 (30)	30.77 (16)	33.33 (2)	24.00 (48)		
	31 – 40	50.70 (72)	32.69 (17)	16.67 (1)	45.00 (90)		
	41 – 50	16.20 (23)	26.92 (14)	16.67 (1)	19.00 (38)		
	51 – 60	10.56 (15)	0 (0)	16.67 (1)	8.00 (16)		
	Over 60	0.70 (1)	3.85 (2)	0 (0)	1.50 (3)	26.44	<0.01
Education level	Primary	16.43 (23)	17.65 (9)	50.00 (3)	17.50 (35)		
	Secondary	27.14 (38)	43.14 (22)	33.33 (2)	31.00 (62)		
	Tertiary	56.43 (79)	39.22 (20)	16.67 (1)	50.00 (100)	9.51	0.03
Employment	Business	47.18 (67)	46.15 (24)	50.00 (3)	47.00 (94)		
	Civil service employee	9.15 (13)	17.31 (9)	16.67 (1)	11.50 (23)		
	Private sector employee	31.69 (45)	21.15 (11)	0 (0)	28.00 (56)		
	Casual labourer	5.63 (8)	9.62 (5)	0 (0)	6.50 (13)		
	Unemployed	6.34 (9)	5.77 (3)	33.22 (2)	7.00 (14)	12.09	0.13
Monthly income level (MWK)[c]	Below 50,000	12.68 (18)	17.31 (9)	50.00 (3)	15.00 (30)		
	50,000 – 100,000	14.08 (20)	25.00 (13)	16.67 (1)	17.00 (34)		
	100,000 – 250,000	18.31 (26)	17.31 (9)	16.67 (1)	18.00 (36)		
	250,000 – 500,000	22.54 (32)	19.23 (10)	16.67 (1)	21.50 (43)		
	500,000 – 1,000,000	21.83 (31)	17.31 (9)	0 (0)	20.00 (40)		
	Over 1,000,000	10.56 (15)	3.85 (2)	0 (0)	8.50 (17)	12.68	0.31

Values are percentages (%) and their frequencies (n).
[a]Tilapia consumption frequency: High = 1-2 times per week; Medium = 1-2 times per month; Low = 5-6 times per year (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015).
[b]The p value was from the Fisher's exact test.
[c]MWK: Malawi Kwacha which is the currency in Malawi. In October 2021, the exchange rate was USD 1.00 = MWK 824.48 according to the Reserve Bank of Malawi.

Table 3.3 presents results on tilapia purchase and consumption patterns by tilapia consumption frequency. There were differences in the distribution of consumers on the place where they usually purchased tilapia (χ^2 = 29.24, P <0.01). Thirty three percent of all the consumers often purchased tilapia from source D (open fish market). However, a higher proportion of consumers from medium and low tilapia consumption frequencies (58% n = 30 and 83% n = 5, respectively) purchased tilapia from source D as compared to consumers with high tilapia consumption frequency.

Over half (59%) of the consumers often purchased fresh (never frozen) whole tilapia. However, more consumers from the medium and low tilapia consumption frequencies (62%, n = 32 and 100%, n = 6, respectively) purchased fresh whole tilapia as compared to consumers from high tilapia consumption frequency (χ^2 = 18, P <0.01). There was no statistical difference in the type of tilapia often purchased regarding wild versus farmed tilapia among the consumers. Forty two percent (n = 84) of all the consumers purchased wild tilapia most of the times followed by 34% (n = 67) who purchased farmed tilapia, while 15% (n = 29) purchased both wild and farmed tilapia. There was no statistical difference in the preferred method of cooking/preparation of tilapia. Fifty six percent (n = 105) of the consumers preferred fried tilapia (deep fried in vegetable cooking oil), followed by 39% (n = 77) that preferred steamed tilapia and 7% (n = 14) preferred grilled tilapia.

Table 3.4 presents results on consumer preference for tilapia by consumption frequency. There was no difference in the proportion of consumers regarding questions/responses related to consumer preference for wild versus farmed tilapia. Almost all (98%, n = 197) of the consumers reported that they were aware of the different types/sources of tilapia found on the Malawian market. Seventy two percent (n = 143) of the consumers indicated that wild tilapia is of better quality (taste, aroma, freshness, and safety) as compared to farmed tilapia. Imported tilapia was not favourably rated and over one third (72%, n = 143) of the consumers reported that imported tilapia is of lower quality. There was also consensus on the consumers' opinion on the price of tilapia. Wild tilapia was rated as more expensive as compared to farmed tilapia according to 84% (n = 168) of the consumers. Sixty five percent (n = 130) of the consumers reported that they prefer wild tilapia from Malawi over farmed tilapia from Malawi and imported tilapia.

Table 3.3 Tilapia purchase and consumption patterns by tilapia consumption frequency[a].

Variable	Level	Tilapia consumption frequency[a]			Total	χ^2	P value[b]
		High	Medium	Low			
Place where tilapia was frequently purchased[c]	Source A	19.72 (28)	9.62 (5)	0 (0)	16.50 (33)		
	Source B	17.61 (25)	11.54 (6)	0 (0)	15.50 (31)		
	Source C	32.39 (46)	17.31 (9)	16.67 (1)	28.00 (56)		
	Source D	22.54 (32)	57.69 (30)	83.33 (5)	33.50 (67)		
	Source E	7.75 (11)	3.85 (2)	0 (0)	6.5 (13)	29.24	<0.01
Form of tilapia often purchased	Fresh whole tilapia (never frozen)	57.86 (81)	61.54 (32)	100 (6)	59.50 (119)		
	Frozen whole tilapia	40.00 (56)	25.00 (13)	0 (0)	34.54 (69)		
	Smoked tilapia	1.43 (2)	3.85 (2)	0 (0)	2.00 (4)		
	Dried tilapia	0.71 (1)	9.62 (5)	0 (0)	3.00 (6)	18.11	<0.00
Type of tilapia often purchased	Wild	38.73 (55)	51.92 (27)	33.33 (2)	42.00 (84)		
	Farmed	36.62 (52)	26.92 (14)	16.67 (1)	33.50 (67)		
	Both	14.08 (20)	13.46 (7)	33.33 (2)	14.50 (29)		
	Do not know	10.56 (15)	7.69 (4)	16.67 (1)	10.00 (20)	5.06	0.41
Tilapia preparation/cooking method preferred	Fried tilapia	55.63 (79)	42.31 (22)	66.67 (4)	52.50 (105)		
	Steamed tilapia	35.21 (50)	48.08 (25)	33.33 (2)	38.50 (77)		
	Grilled tilapia	7.04 (10)	7.69 (4)	0 (0)	7.00 (14)		
	Other preparation methods[d]	2.11 (3)	1.92 (1)	0 (0)	2.00 (4)	4.30	0.63

Values are percentages (%) and their frequencies (n).

[a]Tilapia consumption frequency: High = 1-2 times per week; Medium = 1-2 times per month; Low = 5-6 times per year (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015).

[b]The p value was from the Fisher's exact test.

[c]This was the place where the consumer usually purchases tilapia. Source A to source C were fish shops while source D was open fish market and source E were supermarkets.

[d]Other preparation methods mentioned included roasting and baking.

Table 3.4 Consumer preference for tilapia by consumption frequency[a].

Variable	**Level**	**Tilapia consumption frequency[a]**			**Total**	χ^2	**P value[b]**
		High	**Medium**	**Low**			
Awareness of different sources of tilapia	Aware	98.59 (140)	100 (52)	83.33 (5)	98.15 (197)		
	Not aware	1.41 (2)	0 (0)	16.67 (1)	1.50 (3)	4.72	0.09
Perceived quality (taste, aroma, freshness, and safety) of wild tilapia in comparison with farmed tilapia	Wild tilapia is of better quality	71.13 (101)	69.23 (36)	100 (6)	71.50 (143)		
	Farmed tilapia is of better quality	1.41 (2)	3.85 (2)	0 (0)	2.00 (4)		
	Both are of good quality	10.56 (15)	19.23 (10)	0 (0)	12.50 (25)		
	There are no differences	16.90 (24)	7.69 (4)	0 (0)	14.00 (28)	9.69	0.24
Perceived quality (taste, aroma, freshness, and safety) of imported tilapia	Imported tilapia is of high quality	20.42 (29)	13.46 (7)	16.67 (1)	18.50 (37)		
	Imported tilapia is of low quality	69.01 (98)	76.92 (40)	83.33 (5)	71.50 (143)		
	There are no differences	10.56 (15)	9.62 (5)	0 (0)	10.00 (20)	2.77	0.86
Opinion on the price of wild, farmed and imported tilapia on the Malawian market	Wild tilapia is more expensive	86.62 (123)	75.00 (39)	100 (6)	84.00 (168)		
	Farmed tilapia is more expensive	4.93 (7)	1.92 (1)	0 (0)	4.00 (8)		
	Imported tilapia is more expensive	0.70 (1)	9.62 (5)	0 (0)	3.00 (6)		
	I don't have any opinion	7.75 (11)	13.46 (7)	0 (0)	9.00 (18)	13.35	0.05
Consumers' preference for tilapia from the different sources	Wild tilapia from Malawi	63.38 (90)	67.31 (35)	83.33 (5)	65.00 (130)		
	Farmed tilapia from Malawi	16.90 (24)	11.54 (6)	16.67 (1)	15.50 (31)		
	Imported tilapia	14.79 (21)	13.46 (7)	0 (0)	14.00 (28)		
	No preference	4.93 (7)	7.69 (4)	0 (0)	0.06 (11)	4.05	0.89

Values are percentages (%) and their frequencies (n)

[a]Tilapia consumption frequency: High = 1-2 times per week; Medium = 1-2 times per month; Low = 5-6 times per year (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015)

[b]The p-value was from the Fisher's exact test

Figure 3.1 shows the relationship between tilapia consumption frequencies and the consumers' perceived quality of wild tilapia in comparison with farmed tilapia. The first dimension of the perceptual map explains 71% percent of the total inertia. This dimension separates consumers who indicated that "*Wild is better*" or "*Farmed is better*" from consumers who indicated that "*No difference*" or "*Both are good*". The high tilapia consumption frequency and the opinion that "*Wild is better*" are closer to each other and not far away from the centroid. On the other hand, the opinion that "*Farmed is better*" is far away from the centroid. Most importantly, this opinion is much farther away from the medium and low tilapia consumption frequencies as compared to the high tilapia consumption frequency. This shows that consumers from the medium and low tilapia consumption frequencies were less likely to indicate that farmed tilapia is of better quality as compared to consumers from the high tilapia consumption frequency.

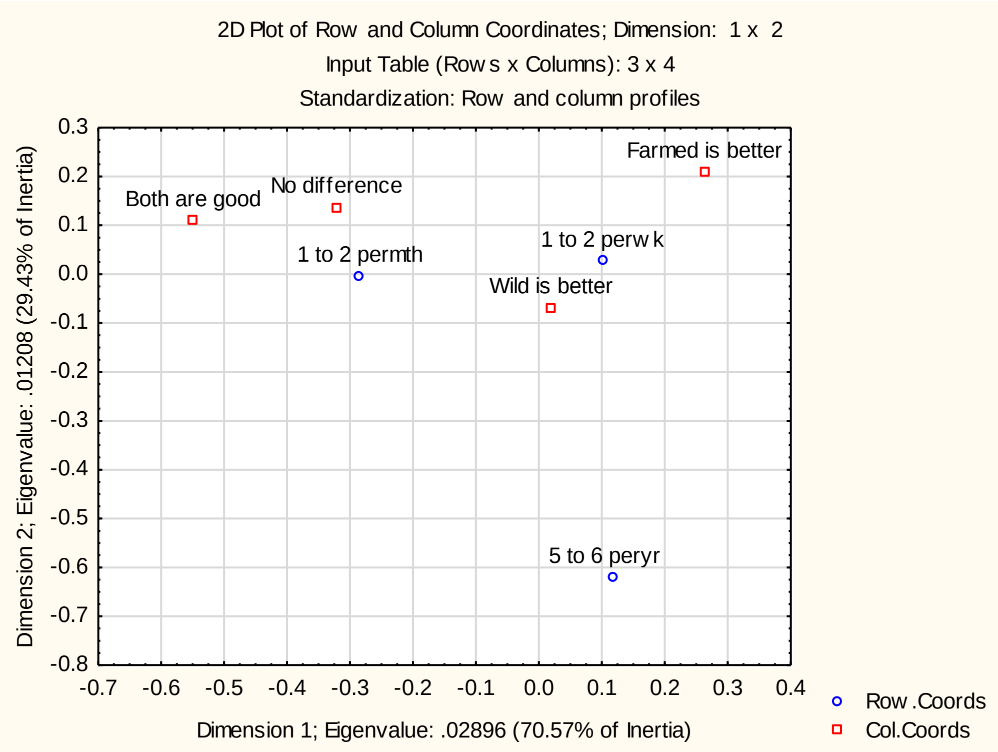

Figure 3.1 Perceptual map of consumers' perceived quality of tilapia versus tilapia consumption frequency.

Tilapia consumption frequency was defined as: 1 to 2 perwk = 1-2 times per week (High); 1 to 2 permth = 1 - 2 times per month (Medium); 5 to 6 peryr = 5 - 6 times per year (Low) (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015). Perceived quality of tilapia was defined as: Wild is better = "Wild tilapia is of better quality than farmed tilapia"; Farmed is better = "Farmed tilapia is of better quality than wild tilapia"; Both are good = "Both wild and farmed tilapia are of good quality"; No difference = "There is no difference between the quality of wild and farmed tilapia"

Figure 3.2 is a perceptual map of the opinion of consumers on the price of wild and farmed tilapia versus the consumers' tilapia consumption frequency. The first dimension of the perceptual map explains 94% of the total inertia. This dimension separates the opinion that wild tilapia is more expensive than other types of tilapia ("*Wild expensive*") and the opinion farmed tilapia is more expensive than other types of tilapia ("*Farmed expensive*") from the opinion that imported tilapia is more expensive than other types of tilapia ("*Imported expensive*") and no opinion. Although the study considered imported tilapia as a category, consumers indicated that they were aware that imported tilapia fall in the farmed tilapia category. The figure shows that the opinion that wild tilapia is expensive is very close to the high tilapia consumption frequency. These items are also close to the centroid of the perceptual map. This shows that consumers from high tilapia consumption frequency were likely to rate wild tilapia as more expensive than other types of tilapia.

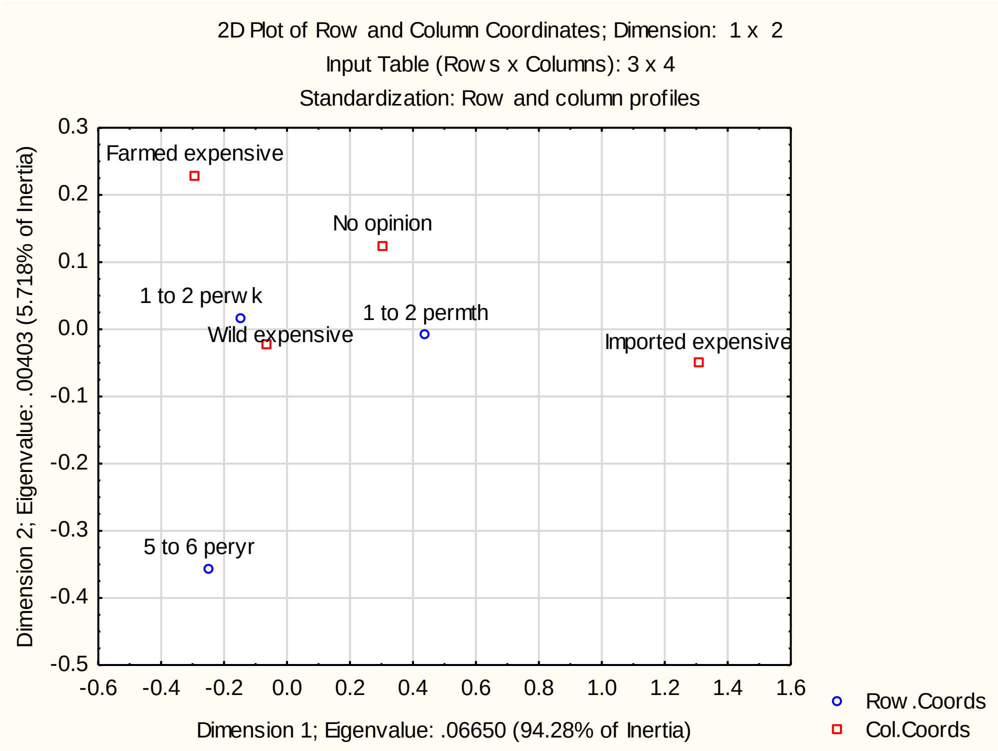

Figure 3.2 Perceptual map of consumers' opinion on the price of tilapia versus tilapia consumption frequency.

Tilapia consumption frequency was defined as: 1 to 2 perwk = 1 - 2 times per week (High); 1 to 2 permth = 1-2 times per month (Medium); 5 to 6 peryr = 5 - 6 times per year (Low) (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015). Consumers' opinion on the price of tilapia was defined as: Wild expensive = "Wild tilapia is more expensive than other types of tilapia"; Farmed expensive = "Farmed tilapia is more expensive than other types of tilapia"; Imported expensive = "Imported tilapia is more expensive than other types of tilapia"; No opinion = "No opinion on the price of different types of tilapia"

Figure 3.3 is a perceptual map of consumer preference for tilapia versus tilapia consumption frequency. The first dimension of the map accounts for 55% of the total inertia. This dimension separates consumers from high tilapia consumption frequency from consumers from medium and low tilapia consumption frequencies. The second dimension accounts for 45% of the total inertia and separates wild tilapia from farmed and imported tilapia. High tilapia consumption frequency is closer to the centroid and closer to farmed and imported tilapia. On the other hand, the medium tilapia consumption frequency is closer to wild tilapia and far from farmed and imported tilapia. This demonstrates that consumers from high tilapia consumption frequency were more likely to prefer famed tilapia as compared to consumers from the medium and low tilapia consumption frequencies.

Figure 3.4 is a perceptual map of type of tilapia often purchased (wild or farmed) versus tilapia consumption frequency. The first dimension of the perceptual map accounts for 55% of the total inertia. This dimension separates wild from farmed tilapia. The second dimension accounts for 45% of the total inertia. It separates high tilapia consumption frequency from medium tilapia consumption frequency. The high tilapia consumption frequency is closer to the centroid of the perceptual map, and it is also closer to farmed tilapia. On the other hand, medium tilapia consumption frequency is closer to wild tilapia. This shows that consumers from high tilapia consumption frequency were more likely to indicate that they often purchase farmed tilapia. On the other hand, consumers from the medium consumption frequency were more likely to indicate that they often purchase wild tilapia. Figure 3.4 differs from Figure 3.3 since it examines purchase behaviour while Figure 3.3 portrays consumer preference for the various tilapia.

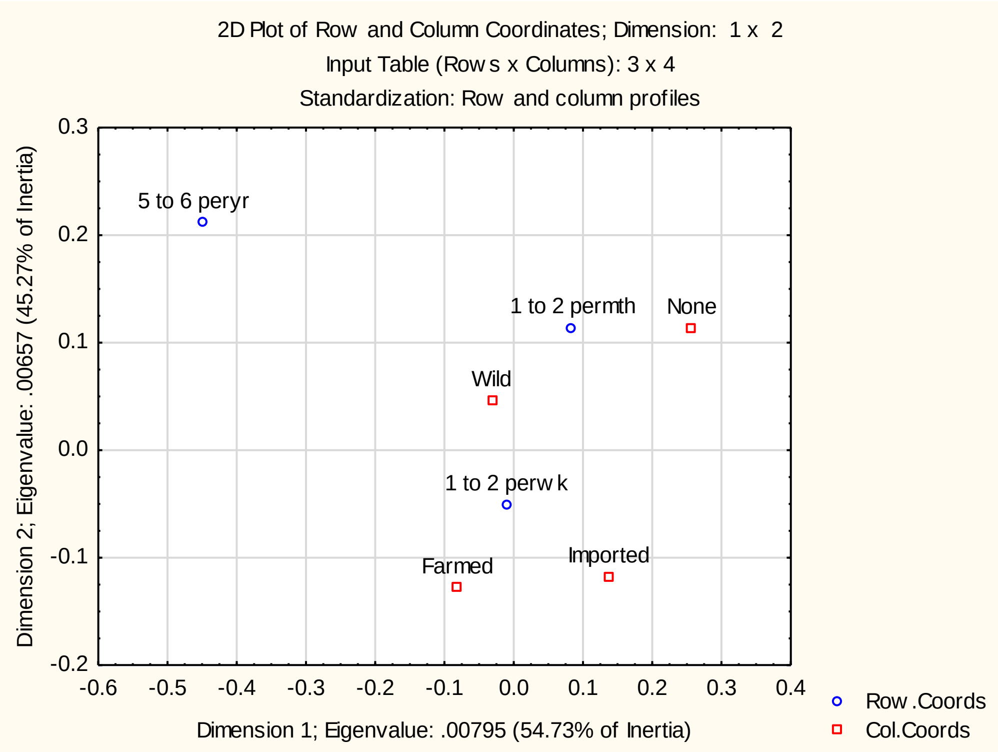

Figure 3.3 Perceptual map of consumer preference for different types of tilapia versus tilapia consumption frequency.

Tilapia consumption frequency was defined as: 1 to 2 perwk = 1 - 2 times per week (High); 1 to 2 permth = 1-2 times per month (Medium); 5 to 6 peryr = 5 - 6 times per year (Low). (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015). Different types of tilapia were defined as: Wild = “Wild tilapia from Malawi”; Farmed = “Farmed tilapia from Malawi”; Imported = “Farmed tilapia imported from other countries such as China, Zambia and Zimbabwe”.

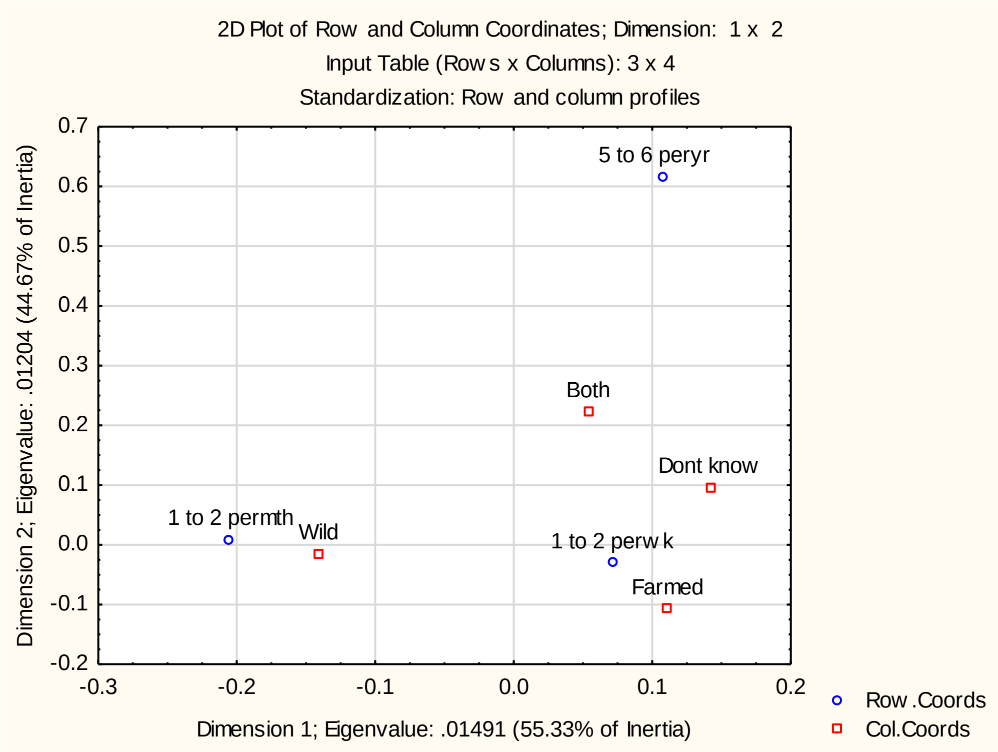

Figure 3.4 Perceptual map of type of tilapia purchased (wild versus farmed) against tilapia consumption frequency.

Tilapia consumption frequency was defined as: 1 to 2 perwk = 1 - 2 times per week (High); 1 to 2 permth = 1-2 times per month (Medium); 5 to 6 peryr = 5 - 6 times per year (Low) (Carlucci et al., 2015; Chikowi et al., 2021; Polymeros et al., 2015). Different types of tilapia: Wild = "Wild tilapia from Malawi"; Farmed = "Farmed tilapia from Malawi and imported from other countries such as China, Zambia and Zimbabwe"; Both = "Both wild and farmed tilapia".

3.3.2 Results from the qualitative focus group discussions

In the qualitative FGDs the consumers were asked to explain types of tilapia and the sources of tilapia sold on the Malawian market. This was done to assess their knowledge on different types and sources of tilapia on the Malawian market. It was observed that the participants were able to describe the different types of tilapia on the Malawi market. The explanation was mainly based on the colour and size of the fish. Consumers reported that the colour of tilapia is an important attribute that distinguishes the wild tilapia from the farmed tilapia from Malawi as well as the imported tilapia from other countries. They indicated that there are mainly two types of tilapia in terms of colour. These were the white/silver/shiny tilapia and the black tilapia. In terms of size, it was indicated that there is big and small tilapia.

The consumers were also able to explain the different sources of the tilapia. Source was mainly the country of origin and production method. The countries of origin mentioned were Malawi, Zambia, Zimbabwe, Tanzania, Mozambique, and China. The production methods mentioned were wild and famed. It was reported that some retailers label the fish in terms of country of origin and production method. It was also indicated that frozen tilapia from China, Zambia and Zimbabwe are packaged in cartons and were clearly labelled in terms of product name, country of origin and production method. They further said that fish traders from the open fish market also indicated to their clients that they sell wild tilapia.

"Chambo [local name for tilapia] comes from lakes, rivers, and dams, like Lake Malawi, Shire River and Bunda dam. Some [tilapia] come from Mozambique. There is also tilapia from Tanzania, but this one is salty, so do not add more salt when cooking…, but Malawian tilapia from the lake [wild tilapia] is white, has more muscle and is delicious."

The consumers were asked to explain their beliefs, attitudes, and perceptions towards the quality of wild tilapia from Malawi, farmed tilapia from Malawi and farmed tilapia imported from other countries. Consumers indicated that wild tilapia from Malawi is of better quality than farmed tilapia from Malawi and other countries. They indicated that wild tilapia from Malawi has a good tilapia aroma when cooked, it has a firm texture meat and is delicious. Consumers indicated that wild tilapia from Malawi goes through a short value chain and is sold mostly fresh. Furthermore, consumers indicated that wild tilapia from Malawi is easy to cook while farmed tilapia requires more spices and special cooking skills to prepare to taste good. On the other hand, farmed tilapia from other countries is frozen and goes through a longer value chain. The consumers indicated that they believe that imported frozen tilapia is treated with chemicals to preserve it and prolong its shelf life in addition to the freezing process. They reported that farmed tilapia from dams/ponds from Malawi has an earthy odour, is not clean and is less delicious. Consumers pointed out that farmed tilapia from other countries has less 'muddy' (also known as 'earthy') odour as compared to the farmed tilapia from Malawi.

"*The lake one [tilapia] is good quality fish, even if you cut it [the cooked one] to eat, it is fresh, firm and does not lose its integrity while the one from the dam is soft. It [farmed tilapia] requires special skills to cook, but when it is cooked in a normal way, it will not be appetizing like the one from the lake [wild tilapia].*"

In terms of overall quality, the consumers ranked wild tilapia from Malawi as number one seconded by imported farmed tilapia while farmed tilapia from Malawi was rated last.

"*When we compare wild fish [tilapia] with the imported one, the Malawi fish is declining of course [dwindling supply], the imported fish when we compare it with the tilapia from Malawi, the tilapia from Lake Malawi is number one, better than imported tilapia. But if you compare the imported one with our Malawian fish but from the dam, then the imported one is better than the ones from the local dams.*"

The participants were asked to express their perceptions on the price of wild, farmed and imported tilapia. They indicated that wild tilapia from Malawi is more expensive as compared to farmed tilapia from Malawi and from other countries. They said that they believe that wild tilapia is more expensive because it is fresh and is of excellent quality.

"*Well, my opinion I think the [price of] tilapia from Lake Malawi is on the higher side [most expensive] since it is of good quality and is on high demand despite the low supply. We say that [it]* *is the best. The one which comes second regarding prices is the imported one which is a bit expensive, while the one from the dam/pond comes third, may be because it is locally harvested, has a lower price [least expensive] than the other two.*"

Farmed tilapia from shops (shops A, B and C) was weighed and was sold per kilogram while wild tilapia from the open fish market (source D) was sold per fish. During the time of the study, the price of farmed tilapia was MWK 3,026.00 per kilogram. On the other hand, the price of a single wild tilapia (about 600 g) from the open fish market was MWK 3,000.00. Therefore, the estimated price of wild tilapia was MWK 5,000.00 per kilogram, (USD 1.00 = MW K824.48).

3.4 Discussion

Consumers are the final users of the fish at the very end of the fish value chain. Therefore, the significance of the opinions of these consumers regarding the fish cannot be overemphasised. There are several fish attributes that may influence consumer preference and their purchase/consumption behaviour ultimately affecting the fish value chain (Claret et al., 2014). Such attributes include sensory properties, nutritional value, health related aspects (content of essential fatty acids), price, easiness to prepare, availability, country of origin, fresh versus frozen, as well as wild versus farmed fish. The latter is very important since wild fish is facing extinction while farmed fish production is gaining significant growth in aquaculture operations worldwide (Carlucci et al., 2015; Claret et al., 2014). The current study contributes to the understanding of consumer preference for wild, farmed and imported tilapia by interviewing target consumers to analyse their views with a focus on tilapia.

Results from the current study provide a deeper understanding of consumer knowledge, beliefs, attitudes, and preference for tilapia from different sources. Consumers were aware of the different sources/types of tilapia sold on the Malawian market. They rated the quality (safety, sensory and nutritional) of wild tilapia highly in comparison with farmed/imported tilapia. They indicated that wild tilapia is more expensive as compared to farmed/imported tilapia. However, the consumers showed a greater preference for wild tilapia from Malawi due to its perceived superior quality despite the high cost.

Although participants (consumers) in this study reported that they rely on colour of the fish to distinguish wild from farmed fish, they were also assisted by wild fish traders who declare the type of tilapia they sell. The labels on cartons for imported frozen farmed tilapia also help consumers to identify the tilapia regarding country of origin and production method. However, cases where frozen tilapia is presented in display freezers in shops may pose a challenge for consumers to correctly identify the fish species or whether it is wild or farmed (Cawthorn et al., 2018). The recommended international standard for labelling of fish products is the use of scientific names for the fish, declaration of the country of origin and specification of the production method with regards to wild versus farmed fish (Cawthorn et al., 2018). This is done particularly for imported farmed tilapia from China, Zambia and Zimbabwe but may be a challenge for wild and farmed tilapia from

Malawi which is not packaged or labelled when sold in the open market or in retail shops (Cawthorn et al., 2018).

The Malawi Bureau of Standards (MBS) is responsible for formulating standards and monitoring to ensure that products are properly labelled and marked in Malawi (Kasapila & Shaarani, 2013). Fish and fish products are regulated by the fresh and frozen whole fin fish – Specification (DMS 115: 2018) which is based on Codex standard for quick frozen finfish, (Codex Alimentarius, 1995). The Malawi standard, requires the following information required on the label:

Name of the product shall be "Fresh or frozen fin fish;" Storage and transportation conditions declaring the temperature to be -18 ºC or lower; Name and physical address of processor; Net weight in metric units; Date of production; Batch or code number; Expiry date; and Country of origin and/or water body.

Despite this regulation being comprehensive it is important to revise it and include the scientific name of the fish to avoid mislabelling of fish products on the Malawian market (Cawthorn et al., 2018).

The high rating for wild tilapia from Malawi was due to the production environment and feeding habits of wild tilapia. It was evident from the qualitative FGDs that consumers were referring to tilapia from Lake Malawi when they mentioned wild tilapia. Lake Malawi is one of the biggest freshwater bodies in the world and hosts major fishing grounds for tilapia in the country (Banda et al., 2005). The lake has not been subjected to extensive pollution (Bell et al., 2012). Therefore, tilapia from Lake Malawi returns the natural fish aroma and is relatively clean (Mussa et al., 2017). On the other hand, the low rating for farmed tilapia from Malawi is due to production method and fish feed provided. Tilapia farmers from Malawi are small scale pond famers and do not afford commercial floating feed but depend on locally produced sinking feed (Mussa et al., 2020). Therefore, fish from these systems are associated with a 'muddy' (also known as 'earthy') odour (Abd El-Hack et al., 2022). Imported farmed tilapia is from cage aquaculture (Zambia and Zimbabwe) or pond (China) systems but they are fed commercial pelleted floating feed (Abd El-Hack et al., 2022).

From the χ^2 test results the study has shown that medium and low tilapia consumers like purchasing wild tilapia from the open fish market as compared with consumers from the high consumption frequency (Table 3.3). The medium and low tilapia consumers also like purchasing fresh whole tilapia as compared to consumers in the high tilapia consumption frequency. The perceptual map from the CA (Figure 3.4) supports the fact that consumers from the high tilapia consumption frequency were flexible and were likely to indicate that they purchase farmed tilapia. Comparable results in Malawi were also reported where consumers from high tilapia consumption frequency were likely to consume farmed tilapia (Chikowi et al., 2021). In Tanzania consumers eat more farmed tilapia as compared to wild tilapia particularly due to the availability of farmed tilapia on the market (Darko et al., 2016).

Results from this research provide important insights from a consumers' point of view regarding wild, farmed and imported tilapia in Malawi. The study demonstrates the increasing demand for wild tilapia and calls for renewed efforts for tilapia fisheries conservation and sustainability. The fact that consumers from high tilapia consumption frequency were likely to indicate that they purchase farmed tilapia from Malawi and farmed tilapia imported from other counties presents a business opportunity for aquaculture entrepreneurs and tilapia traders (Chan et al., 2019).

There is need to improve the quality of farmed tilapia and reduce the 'muddy' odour. The belief that imported frozen tilapia is treated with chemicals to preserve it and prolong its shelf life should be addressed. To the best of the authors knowledge there is no published evidence that shows that frozen tilapia is treated with chemicals. Therefore, there is need for frozen tilapia traders to produce promotion materials to help their customers understand that frozen tilapia is free from chemical preservatives. The information from the research clarifies consumer preference for tilapia in Malawi and other countries with similar characteristics in Southern Africa. These countries include Zambia, Zimbabwe Mozambique, Namibia, Angola, Botswana, Eswatini, Lesotho and South Africa (Chan et al., 2019; Chikowi et al., 2021; Kaminski et al., 2018).

3.5 Conclusions

Consumers were aware of the different types and sources of tilapia sold on the Malawian market. They showed a greater preference for wild tilapia from Malawi due to its superior perceived quality even though they perceived the price of wild tilapia to be higher than the price of farmed tilapia. Consumers from high tilapia consumption frequency were more likely to purchase farmed tilapia and in a frozen state compared to consumers from medium and low tilapia consumption frequency. The study provides valuable information on consumer preference with relevance for consideration to improve the quality of tilapia from aquaculture. It demonstrates the potential demand for farmed tilapia from Malawi and farmed tilapia imported from other countries. It helps in providing a basis for the need to improve the quality of farmed tilapia in Malawi to reduce the associated 'muddy' odour. The study demonstrates the potential market for imported and farmed tilapia in Malawi and other countries in Southern Africa with similar characteristics. However, the belief that imported frozen tilapia is treated with chemicals to preserve it and prolong its shelf life should be addressed.

3.6 Strengths and limitations

The current study used both qualitative and quantitative methods of data collection and analysis to gain a deeper understanding of consumer preference for wild versus farmed fish in Malawi. The study focused on one specific type of fish (tilapia) which is a very important fish to Malawian consumers, contributes significantly to fish trade and it is a strategic fish for aquaculture development in the country. Study participants were appropriate since they were involved in purchase, preparation as well as consumption of tilapia. However, results of this study should be interpreted considering some limitations. The intercept interview method used in the quantitative survey may not always produce a representative sample of the population of interest. Only three shops dedicated to selling fish and one open market for wild tilapia were visited for the interviews. Future studies should include supermarkets which also sell fish to get a wider variety of consumers. The study lumped together farmed tilapia from Malawi and farmed tilapia imported from other countries in one category of “farmed tilapia”, even though the participants indicted that they were aware of the various sources of tilapia. Future studies should treat these categories as separate and further specify the country of origin of the fish.

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CHAPTER 4: DNA analysis and descriptive sensory analysis of wild versus farmed tilapia

Abstract

Fish is a healthy food and contributes significantly to global food security and nutrition. The globalised food supply chain means food (including fish) produced from one region is accessible in other parts of the world. Tilapia is an important fish species and one of the most traded fish species on the global food market. High demand and low supply of tilapia from wild sources results in increase in tilapia aquaculture and imports from other countries. However, there is lack of published information of the genetic identity and descriptive sensory profile of wild versus famed tilapia on the market in Southern Africa. This study was aimed at identifying the species of wild and farmed tilapia in retail distribution in Malawi by deoxyribonucleic acid (DNA) analysis and assessing the descriptive sensory profile of the fish using descriptive sensory analysis. The tilapia was from five sources namely: 1) wild tilapia from Malawi; 2) farmed tilapia from Malawi; 3) farmed tilapia imported from Zambia, 4) farmed tilapia imported from Zimbabwe; and 5) farmed tilapia imported from China. DNA analysis was done based on the sequencing of the 12S and 16S genes. Descriptive sensory analysis on the full sensory profile (aroma, flavour, taste, and texture) of the tilapia samples was done by a trained panel of eight members following standard guidelines and recommendations. DNA analysis revealed that all the tilapia from the five sources were *Oreochromis niloticus*. Tilapia traded in Malawi but imported from Zambia, Zimbabwe and China were validated as *O. niloticus* which is what is indicated on their respective packaging material at retail level. The latter gives confidence to both retailers and customers and clears mislabelling concerns related to such products. However, the discovery of *O. niloticus* from the market samples of wild tilapia calls for further research. This is because *O. niloticus* is regarded as an alien species and is prohibited by law in the water bodies in Malawi. Therefore, confirmatory focused DNA analysis studies should be done. Such studies should use the 12S, 16S, as well as the cytochrome c oxidase I (COI) gene to distinguish the closely related tilapia fish species. The sensory analysis experiment showed that there were statistical differences in only three sensory attributes of the fish evaluated in this study (musty mouldy aroma, earthy flavour, and musty mouldy flavour). This demonstrates that the wild and farmed tilapia were of comparable sensory quality. Consumer awareness campaigns should be done to promote farmed tilapia as a potential fish supply in Malawi that can sustainably complement wild tilapia.

Keywords: Aquaculture; Fish species; Lake Malawi; Nile tilapia; Sensory profiling; Wild fish

4.1 Introduction

Fish contributes significantly to global food security, nutrition, and trade (FAO, 2020). In 2018, world per capita fish consumption was 20.5 kg, and the aggregate global fish consumption was 140 million tonnes (FAO, 2020). Aquaculture contributes about 46% of total global fish supply (FAO, 2020). Tilapia is one of the fish species that is widely and successfully farmed in different aquaculture systems (Day et al., 2016). It is the second most popular farmed fish globally, after the carp (*Cyprinus carpio*) (FAO, 2020; Freitas et al., 2020). Moreover, Tilapia is one of the most traded fish commodities globally, while in Africa, tilapia is a favourable farmed fish along with catfish (*Clarias gariepinus* and *Heterobranchus* spp.) (Tran et al., 2019).Different species of tilapia exist, such as *Oreochromis niloticus* (Nile Tilapia), *Oreochromis mossambicus* and *Oreochromis andersonii* (FAO, 2020). However, *Oreochromis niloticus* is the most widely farmed tilapia species worldwide because of its higher growth rate and easiness to raise in aquaculture systems (Day et al., 2016; FAO, 2020). In 2018 the total global Nile Tilapia production from aquaculture was about five million tonnes (FAO, 2020). China is the leading producer of farmed tilapia and continues to export large volumes of tilapia globally including to African countries such as Malawi (FAO, 2020; Wang & Lu, 2015). In Southern Africa, Zambia produces over half of the total farmed tilapia (Kaminski et al., 2018) and this country is the sixth largest producer of farmed tilapia in Africa after Kenya, Ghana, Uganda, Nigeria, and Egypt (FAO, 2020; Kaminski et al., 2018).

In Malawi tilapia supply is mainly from wild sources and is supplemented by imports and aquaculture (Chikowi et al., 2021). Wild tilapia in Malawi is made up of *Oreochromis* spp., mainly *O. karongae*, *O. lidole*, and *O. squamipinnis* (Banda et al., 2005). Wild tilapia is caught by fishermen from the four lakes (Lake Malawi, Lake Malombe, Lake Chilwa and Lake Chiuta) as well as the Shire River (Banda et al., 2005). Farmed tilapia is defined as the tilapia that is raised in cages in Lake Malawi as well as in ponds by both small scale and large-scale farmers while imported tilapia species are the ones imported from other countries (Chikowi et al., 2021). Tilapia (locally known as Chambo in the local language in Malawi and some parts of Zambia, Mozambique, and Zimbabwe) is traded commercially and is highly prized in local markets (Banda et al., 2005). Tilapia tops fish menus in the hotel industry in Malawi due to its exceptional sensory qualities such as flavour, taste and visual appearance/colour of the tilapia fish when cooked (Chikowi et al., 2021).

There is a steady growth of tilapia imports from Zambia, Zimbabwe, and China to complement the capture fisheries for tilapia in Malawi (Mussa et al., 2017). This raises concerns of possible mislabelling of tilapia on the Malawi market (Cawthorn et al., 2012). Fraud in the fish sector includes mislabelling of products with regards to geographical region of origin, wild versus farmed fish, misrepresentation of fish species, as well as misclassification of fresh versus frozen and thawed fish (Cawthorn et al., 2012). The problem is worsened because of the use of generic names of fish such as “tilapia” or “snapper” which includes hundreds of different species within such groups (Cawthorn et al., 2012, 2018). In addition to this, fish processing techniques such as filleting makes it difficult for consumers to verify fish species at the point of sell or consumption (Wong & Hanner, 2008).

Fish identification methods include morphometric techniques, deoxyribonucleic acid (DNA) analysis, stable isotope analysis, elemental profiling, chemical analysis particularly use of fatty acid profiling, descriptive sensory analysis, as well as application of near infrared reflectance spectroscopy (NIRS) (Cawthorn et al., 2012, 2018). Among the different fish authentication methods, DNA analysis is a specialised and well-standardised procedure (Ivanova et al., 2007). The method involves the sequencing of a standardised region of the mitochondrial gene (Ivanova et al., 2007). The target gene can be either the cytochrome c oxidase subunit 1 (COI) mitochondrial gene, 12S or 16S gene (Ivanova et al., 2007). DNA analysis has been validated to be efficient in diagnosing species across the animal kingdom including fish species (Cawthorn et al., 2018; Wong & Hanner, 2008)

Despite the significant contribution of aquaculture to fish supply, consumers tend to prefer wild tilapia over farmed tilapia and rate wild tilapia as the reference (Claret et al., 2014). There are also unsubstantiated claims among consumers in Malawi that the wild tilapia endemic to Malawi tastes better than the farmed and the imported ones (Chikowi et al., 2021). However, results from objective descriptive sensory evaluation of wild versus farmed fish show inconsistent results and, in many cases, farmed fish is just as acceptable as their wild types (of the same species) in terms of appearance, odour, flavour, texture, aftertaste and overall acceptability (Farmer et al., 2000; Olsson et al., 2003; Wu et al., 1996). Therefore, this study was aimed at identifying the species of wild,farmed, and imported tilapia in retail distribution in Malawi by DNA analysis and assessing the descriptive sensory profile of the fish using descriptive sensory analysis.

4.2 Materials and methods

4.2.1 Sample description and experimental design

Tilapia used in this study were from five sources as shown in Table 4.1 and Figure 4.1. The sources were: 1) farmed tilapia imported from Zimbabwe; 2) farmed tilapia from Malawi; 3) wild tilapia from Malawi; 4) farmed tilapia imported from Zambia; and 5) farmed tilapia imported from China. Fresh wild tilapia (C) from Lake Malawi were purchased from an open market in Lilongwe Malawi. Fresh farmed tilapia (B) from cage aquaculture on Lake Malawi, and frozen farmed tilapia (*Oreochromis niloticus*) imported from Zimbabwe (A), Zambia (D), and China (E) were purchased from fish shops in Lilongwe. The samples were purchased in September of 2022. They were collected and packed in a cooler box with ice and transported to a laboratory at Lilongwe University of Agriculture and Natural Resources (LUANAR) Bunda Campus in Lilongwe. The samples were stored in a laboratory freezer (- 20 °C) until preparation (Bosch et al., 2016; Silva et al., 2020).

4.2.2 Sample preparation and DNA analysis

Whole tilapia samples were thawed overnight at 4°C, weighed (Adam, Pw 124, AE43642), filleted, freeze dried (BK-FD18S, F1812-0849) and vacuum sealed (Bennett Read, BRVS120W) in clear nylon vacuum plastic bags (Al-Souti et al., 2012). DNA analysis was done based on the sequencing of a standardised region of the 12S and 16S genes (Cawthorn et al., 2012; Ivanova et al., 2007).

Table 4.1 Treatment structure and description of tilapia samples used for the study.

N	Description	Country of origin	Weight of whole tilapia (g)*	Code
1	Farmed tilapia, gutted, frozen whole Labelled (*Oreochromis niloticus*)	Zimbabwe	319.05 ± 13.85	A
2	Farmed tilapia, fresh on ice, whole No species specified	Malawi	351.01 ± 9.40	B
3	Wild tilapia, fresh on ice, whole. No species specified	Malawi	437.66 ± 8.90	C
4	Farmed tilapia, gutted, frozen whole Labelled (*Oreochromis niloticus*)	Zambia	303.60 ± 12.17	D
5	Farmed tilapia, gutted, frozen whole Labelled (*Oreochromis niloticus*)	China	320.49 ± 14.68	E

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi.
*Values for weight of whole tilapia (g) are means and their standard deviation (SD).
N is the number of tilapia sources

Figure 4.1 Photograph of tilapia samples used for the study.

The tray was 42 cm long and 27 cm wide. This photograph shows one fish from each of the five types of tilapia used in the study (Table 1). A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi.

Total genomic DNA was extracted from ca. 200 mg of homogenous muscle tissue using Qiagen DNeasy extraction kit following manufacturer's instructions. The homogenous sample was placed in a 2 ml microcentrifuge tube and 1 ml Food Lysis Buffer and 2.5 µl Proteinase K solution were added. The mixture was vortexed briefly to ensure complete distribution and moistening of the sample material. Incubation was done in a thermomixer for 30 ± 2 min at 60 ± 2 °C with constant shaking 1000 rpm (~300 - 1500 rpm). This was followed by centrifuging for 5 ± 1 min at 2550 g (~1990 – 3600 g). About 500 µl of chloroform were transferred into a 2 ml microcentrifuge tube. A clear supernatant was drawn from each lysis tube replicate without disturbing the inhibitor precipitate at the bottom of the tube.

The supernatant aliquots were combined in one microcentrifuge tube and mixed by pipetting up and down several times to ensure a homogeneous solution. About 700 µl of the clear supernatant pool were transferred to the microcentrifuge tube containing the chloroform. One millilitres of buffer PB were pipetted into a fresh 2 ml microcentrifuge tube, and 250 µl of the upper aqueous phase were added and mixed thoroughly by vortexing. About 600 µl of the mixture were pipetted into the QIAquick spin column placed in a 2 ml collection tube. Centrifugation was done at 17900 x g for 1 min and the flow-through was discarded. About 500 µl Buffer AW2 were added to the QIAquick spin column, centrifuged at 17,900 x g for 1 min and the flow through was discarded. The QIAquick spin column was transferred to a 1.5 ml or 2 ml microcentrifuge tube, and 100 µl Buffer EB were pipetted directly onto the QIAquick membrane. The mixture was incubated for 1 min at room temperature (15–25°C), and then centrifuged at 17,900 x g for 1 min to elute.

The 25 µl polymerase chain reaction (PCR) reaction mixtures contained 2.5 µl (1×) reaction buffer, 2.5 µl (2.5 mm), 0.3 µl (0.12 µM) of each primer, 0.20 µl (1.0 U), 0.25 µl (0.1 mm) and 1 µl (ca. 1 µg) of DNA template. The PCR cycling conditions used were as follows: initial denaturation at 94 °C for 2 min, 30 cycles of denaturation at 93 °C for 30 sec, primer annealing at 55 °C for 40 s and chain elongation at 72 °C for 60 sec, followed by final extension at 72 °C for 5 min. All PCR amplifications were performed in a Mastercycler Personal (Eppendorf, Germany). PCR products were separated by electrophoresis (90 V for 45 min) in 1.5% (m/v) agarose gels and were visualised under an ultraviolet light (Vilber Lourmat, Marne La Vallee, France). Sequencing of PCR products was performed using BigDye chemistry and analysis was done on an ABI 3100 Genetic Analyser (Applied Biosystems, Foster City, USA). Generated sequences were compared with those available in the GenBank to determine top species matches (Galal-Khallaf et al., 2014; Warner et al., 2013).

4.2.3 Sample preparation and cooking for sensory analysis

On a day prior to sensory training/testing, the tilapia samples were defrosted overnight at 4°C (Al-Souti et al., 2012). On the day of the sensory training/testing the samples were weighed, followed by filleting. The fillets were cut into tasting size pieces (18.67 ± 2.51 g) and packed in coded aluminium foil (AMSA, 2015; Tayengwa et al., 2021). Cooking was done by steaming the samples for 10 min using a pressure cooker (Russell Hobbs 6L electric pressure cooker, model No. RHEP7) (AMSA, 2015). To keep the samples warm until serving, they were placed in a preheated tempered glass dish with a lid and the dish was placed in a thermostatically controlled water bath (Biobase, model No. BK-601) programmed at 70 °C (Koch et al., 2012).

4.2.4 Descriptive sensory analysis

Descriptive sensory analysis of the samples was done by a trained panel of eight members comprised of five females and three males, aged between 26 and 38 years (Lawless & Heymann, 2013; Rogers, 2017; Wu et al., 1996). The panel was recruited through invitations to LUANAR staff members and graduate students. Twelve individuals responded to the call and eight candidates were selected based on their satisfactory performance in triangle screening tests (Lawless & Heymann, 2013). The panellists were trained for descriptive sensory analysis according to standard guidelines and recommendations (AMSA, 2015; Lawless & Heymann, 2013; Rogers, 2017). Training was done so that the panellists would learn to differentiate and identify sensory descriptors associated with the product under investigation, as well as to calibrate the panellist on the use of a 100-point unstructured line scale in the intensities of aroma, flavour, taste, and texture attributes. Physical and chemical reference standards as well as tilapia samples (steamed tilapia) were used during the training sessions as shown in Table 4.2 (AMSA, 2015; Lawless & Heymann). Ten aroma, ten palate (flavour and taste) and five texture attributes were identified and elucidated during the training phase (Table 4.2). The training was conducted in the morning over four days, with two sessions (lasting for 1 h) per day with a 15 min break in-between the sessions. Appendix 7 shows the ballot for DSA.

The intensity rating (i.e., DSA testing phase) of the samples was done over eight sessions over four days in a similar design to the training (Lawless & Heymann, 2013). During each session, each panel member evaluated one coded piece of the fish samples with a serving temperature of 70°C. Samples from each of the five types (i.e., treatments) of tilapia (Table 4.1) were presented one at a time in a randomised and counterbalanced serving order in each session. Panellists were allocated individual tasting areas with no interaction with each other. Sensory evaluation was conducted in a well-lit and ventilated sensory laboratory.

Table 4.2 Reference standards, definitions, and scale of attributes used for sensory analysis.

Sensory attributes	Definitions	Reference standards
Aroma*		
Fresh fish aroma	Smell associated with plant, cucumber- and mushroom- like characteristics.	Liquid from canned tuna (Liberty Select, light meat tuna chunks in salt water) = 65
Cooked fish aroma	Smell associated with steamed fish (i.e., prepared with a wet heat cooking method).	Liquid from canned tuna (Liberty Select, light meat tuna chunks in salt water) = 65
Sea breeze aroma	Smell associated with saltiness, similar to the smell of the sea.	Liquid from canned tuna (Liberty Select, light meat tuna chunks in salt water) = 75
Earthy aroma	Smell associated with woody or fertile soil; similar to the smell of wet, brown soil after rain (positive attribute).	Borneol (1% PG dilution) = 100
Buttery aroma	Smell associated with melted butter (a dairy product made from the fat and protein components of churned cream of milk derived from cow's milk).	Melted butter (First Choice, salted butter, 500 g) = 85
Sweet-associated aroma	Smell associated with the outside browned edges of roasted red meat.	
Metallic aroma	A smell associated with slightly oxidised metals, such as iron, copper, and silver spoon or associated with raw meat (blood-like).	
Musty/Mouldy aroma	Smell associated with a mould and the overall impression of dampness.	Terpinen-4-ol (1% ALC dilution) = 100
Green aroma	Smell associated with leaf trimmings, a mowed lawn, or crushed green leaves.	*Cis*-3-hexanoate (1% PG dilution) = 100
Oxidised/Rancid flavour	Smell associated with rancid or reused oil; sometimes described as sharp or paint- like.	
Palate*		
Fresh fish flavour	Flavour associated with plant, cucumber- and mushroom- like characteristics.	Liquid from canned tuna (Liberty Select, light meat tuna chunks in salt water) = 65
Cooked fish flavour	Flavour associated with steamed fish (i.e., prepared with a wet heat cooking method).	Liquid from canned tuna (Liberty Select, light meat tuna chunks in salt water) = 65
Earthy flavour	Flavour associated with woody or fertile soil; like the smell of wet, brown soil after rain (positive attribute).	Borneol (1% PG dilution) = 100
Buttery flavour	Flavour associated with melted butter (a dairy product made from the fat and protein components of churned cream of milk derived from cow's milk).	Melted butter (First Choice, salted butter, 500 g) = 85
Sweet-associated flavour	Flavour associated with the outside browned edges of roasted red meat.	
Metallic flavour	Flavour associated with slightly oxidised metals, such as iron, copper, and silver spoon or associated with raw meat (blood-like).	
Salty taste	A fundamental taste sensation associated with salt or sodium.	Table salt (NaCl) solution (0.2%) =

		40; Baumann's cream crackers (200 g) = 50; Table salt (NaCl) (2%) = 100
Musty/Mouldy flavour	Flavour associated with mould and the overall impression of dampness (negative attribute).	
Green flavour	Flavour associated with leaf trimmings, a mowed lawn, or crushed green leaves.	
Oxidised/Rancid flavour	Flavour associated with rancid or reused oil; sometimes described as sharp or paint- like.	
Texture		
Juiciness 0=dry; 100=very juicy	Amount of water released during chewing (evaluated in the first 5 chews).	
Firmness 0=very soft; 100=very firm	The perception of moderate resistance when force is applied in the mouth or by touch. Based on memory, catfish would be 25; chicken breast meat would be 70).	
Pasty texture 0=none; 100=very pasty	The perception of the product which sticks together like paste in the mouth when mixed with saliva; sticks to the teeth during chewing (like the texture of the yellow from a hard-boiled egg).	
Mushy*	Texture, which is soft, thick, with a pulpy consistency.	
Mouth coating*	The perception of a film in the mouth.	

**Attribute intensity was rated on an unstructured line scale from 0 to 100, where 0 and 100 was anchored as none and prominent intensities, respectively.*

Data were captured on hard copy questionnaires then transferred to Compusense® (Compusense Inc, Guelph, Canada) to capture the data electronically (due to extreme loadshedding conditions at the time in Malawi, the panellists could not log into Compusense® cloud software (Compusense Inc, Guelph, Canada).

4.2.5 Statistical analyses

This was a completely randomised design (CRD) experiment. Following this design, during sensory evaluation each of the five sources of tilapia (treatments) was tested by each panellist over one session on the same day, thus randomising the five treatments over one session and all panellists evaluated all treatments and all (random) replications in a total of eight sessions (Tayengwa et al., 2021).

Data were analysed using the general linear model (PROC GLM) procedure of SAS version 9.4 (SAS® Institute Inc., Cary, North Carolina, USA). Source of tilapia (A to E, Table 1) was set as the fixed factor, while session and panellist were random factors. Shapiro-Wilk test was performed using the univariate procedure (PROC UNIVARIATE) to test for normality of the residuals for each variable and residuals larger than three were identified as outliers and removed. Post-hoc mean separation was carried out using Fisher's protected least significant difference (LSD). Differences were considered significant at $P \leq 0.05$. Principal component analysis (PCA) was performed using XLSTAT software (Version 2022.3.1.1324, Addinsoft, Paris, France) based on a Pearson's correlation matrix.

4.2.6 Ethics approval statement

The study was conducted according to the guidelines of the Declaration of Helsinki. Ethical approval for the involvement of human subjects in this study was granted by the Research Ethics Committee on Social, Behavioural and Education Research (SBER) at Stellenbosch University in South Africa on June 11th, 2021 (protocol number: SU-REC-2021-18970). In Malawi, the research was reviewed and approved by the National Committee on Research Ethics in the Social Sciences and Humanities, National Commission for Science and Technology (NCST), on August 20th, 2021 (protocol number: P.07-21-584). Gatekeeper permission was granted by the Department of Fisheries in the Ministry of Agriculture and Food Security in Malawi. Furthermore, permission was sought from the owners of the shops/market, and they accepted. Participation in this research was voluntary and written informed consent was obtained from each participant. The research team complied with all COVID-19 guidelines issued by the Malawi Government during all research activities.

4.3 Results

4.3.1 Identification of tilapia species by DNA analysis

Table 4.3 presents results for the identification of the of wild versus farmed tilapia from the Malawi market using DNA analysis. DNA analysis enabled the successful identification of the tilapia samples to the species level (Ivanova et al., 2007). Maximum species identities based on generated sequences were in the range of 98.89-99.82% according to queries made in GenBank database (Cawthorn et al., 2012). From this procedure, all the five types of tilapia (Table 4.1) were identified as *Oreochromis niloticus*.

4.3.2 Sensory profiles of wild versus farmed tilapia

All the aroma attributes were similar (P<0.050) across the five types of tilapia (Table 4.4), except for ‘musty mouldy’ aroma which was higher in Tilapia E (farmed) (P = 0.043). Most of the flavour attributes were not different across the five types of tilapia (Table 4.5), except for ‘earthy’ flavour (P = 0.012) and ‘musty mouldy’ flavour (P = 0.004) which were both higher in Tilapia D (farmed) and Tilapia E (farmed). There were no differences in the texture attributes across all the five types of wild and farmed tilapia samples (Table 4.6). The multivariate PCA procedure produced low overall explained variance of 38.76% and was not able to separate the five types of tilapia based on the sensory attributes examined in this study (Figure 4.2).

Table 4.3 Identification results of wild and farmed tilapia species by DNA analysis.

Parameters	Tilapia sources				
	A	B	C	D	E
Gene target	12S	16S	16S	12S	16S
Top species match	*Oreochromis niloticus*	*Oreochromis niloticus*	*Oreochromis niloticus*	*Oreochromis niloticus*	*Oreochromis niloticus*
Specimen similarity (%)	98.89%	99.82%	99.48%	99.44%	99.65%
Database	GenBank	GenBank	GenBank	GenBank	GenBank
Accession number	MN255618.1	MT078697.1	MT078697.1	MN255618.1	MT078697.1

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi. A species match was made between the queried sample and *Oreochromis niloticus* in the Barcode of Life Database (BOLD) and/or GenBank. For accurate species identifications with DNA sequencing methods, it is generally considered adequate that there should be at least 97% similarity between investigated sequences and reference sequences, although this depends on, inter alia, the DNA marker, the size of the sequenced amplicon and the degree to which a species is represented in a database (Ivanova et al., 2007).

Table 4.4 Aroma attributes of wild versus farmed tilapia from different sources in Malawi.

Aroma attribute	Tilapia sources					P value
	A	B	C	D	E	
Fresh fish	68.27 ± 3.62	65.51 ± 1.28	68.07 ± 1.39	66.09 ± 3.18	66.37 ± 3.84	0.231
Cooked fish	67.56 ± 2.80	65.93 ± 1.58	67.06 ± 2.04	66.38 ± 3.73	66.27 ± 2.27	0.722
Sea breeze	50.52 ± 4.18	47.49 ± 2.32	51.14 ± 2.89	47.36 ± 3.77	50.97 ± 3.76	0.066
Earthy	32.59 ± 2.36	30.74 ± 3.48	32.21 ± 3.36	31.78 ± 3.02	34.02 ± 5.59	0.517
Buttery	32.59 ± 4.55	33.29 ± 5.31	36.86 ± 3.88	34.54 ± 4.35	31.04 ± 5.23	0.163
Sweet associated	22.54 ± 5.90	22.73 ± 4.51	23.72 ± 2.35	24.93 ± 4.42	21.17 ± 3.08	0.486
Metallic	8.27 ± 1.43	7.65 ± 1.85	8.94 ± 1.55	9.70 ± 0.83	9.18 ± 2.37	0.148
Musty mouldy	1.95 ± 1.18^{a}	1.69 ± 0.71^{a}	2.72 ± 1.59^{ab}	2.60 ± 1.43^{a}	4.78 ± 3.87^{b}	**0.043***
Green	1.40 ± 1.46	0.89 ± 1.62	0.85 ± 0.55	1.13 ± 0.77	2.39 ± 2.97	0.371
Oxidised rancid	0.54 ± 0.44	0.36 ± 0.40	0.37 ± 0.22	0.42 ± 0.55	0.29 ± 0.30	0.759

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi. Values are means and their standard deviation (SD).

$^{a-b}$Means with different superscripts in the same row are significantly different ($P \leq 0.05$).

Table 4.5 Flavour and taste attributes of wild versus farmed tilapia from different sources in Malawi.

Flavour attributes	**Tilapia sources**					**P value**
	A	**B**	**C**	**D**	**E**	
Fresh fish flavour	64.65 ± 2.47	62.88 ± 2.41	63.66 ± 1.50	62.80 ± 3.05	64.65 ± 2.71	0.387
Cooked fish flavour	67.31 ± 2.82	65.37 ± 2.23	66.32 ± 1.77	63.69 ± 3.35	66.89 ± 2.67	0.068
Earthy flavour	30.17 ± 3.47^{b}	28.15 ± 4.70^{b}	27.50 ± 5.18^{b}	31.15 ± 6.27^{ab}	35.60 ± 2.94^{a}	**0.012***
Buttery flavour	29.25 ± 3.68	26.58 ± 4.93	27.57 ± 4.81	29.80 ± 4.98	27.85 ± 4.53	0.639
Sweet associated flavour	16.79 ± 2.30	17.06 ± 1.78	16.32 ± 1.30	17.13 ± 1.51	16.26 ± 1.70	0.790
Metallic flavour	7.08 ± 1.35	7.02 ± 1.22	7.55 ± 1.67	8.29 ± 0.94	8.67 ± 1.12	0.053
Salty taste	15.41 ± 1.96	15.64 ± 2.80	15.49 ± 2.33	14.46 ± 1.60	15.32 ± 2.38	0.849
Musty mouldy flavour	1.65 ± 0.83^{b}	2.10 ± 1.14^{b}	2.39 ± 1.22^{b}	4.25 ± 1.87^{a}	4.69 ± 2.96^{a}	**0.004***
Green flavour	0.96 ± 1.14	0.64 ± 0.69	0.44 ± 0.26	1.27 ± 0.72	1.11 ± 2.10	0.611
Oxidised rancid flavour	0.23 ± 0.16	0.23 ± 0.15	0.12 ± 0.17	0.23 ± 0.24	0.21 ± 0.18	0.704

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi.

Values are means and their standard deviation (SD).

$^{a-b}$Means with different superscripts in the same row are significantly different ($P \leq 0.05$).

Table 4.6 Texture attributes of wild versus farmed tilapia from different sources in Malawi.

Texture attributes	**Tilapia sources**					**P value**
	A	**B**	**C**	**D**	**E**	
Juiciness	55.27 ± 4.39	53.70 ± 1.46	53.57 ± 2.19	54.08 ± 3.72	54.36 ± 4.22	0.864
Firmness	46.27 ± 3.09	47.84 ± 2.71	47.54 ± 4.12	47.83 ± 3.89	45.77 ± 2.89	0.632
Pasty	19.83 ± 2.00	20.00 ± 1.74	19.59 ± 2.54	20.02 ± 2.77	19.69 ± 2.98	0.996
Mushy	12.62 ± 2.52	12.51 ± 1.43	10.27 ± 1.90	11.63 ± 1.44	12.89 ± 1.82	0.051
Mouth coating	10.11 ± 1.40	9.67 ± 1.12	10.29 ± 1.90	10.43 ± 1.47	9.33 ± 2.43	0.692

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi.
Values are means and their standard deviation (SD).

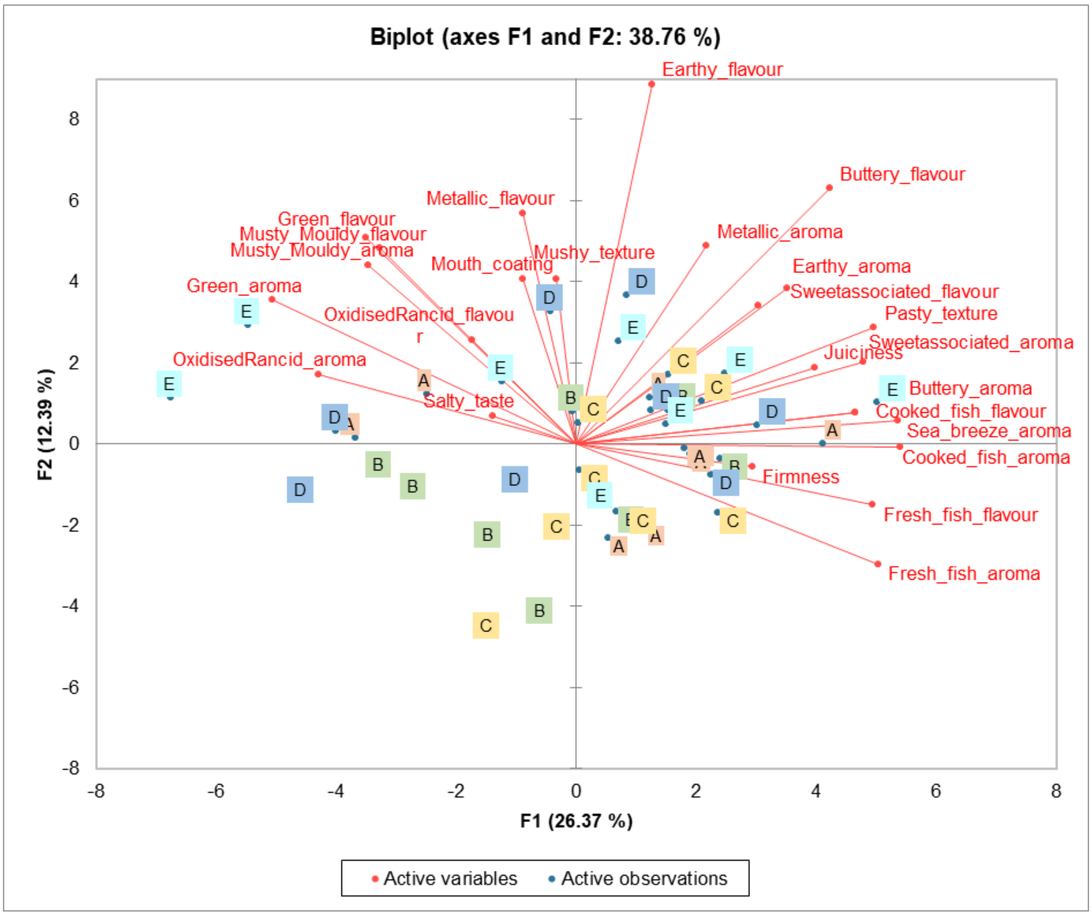

Figure 4.2 Principal component analysis (PCA) of sensory attributes of wild versus farmed tilapia from different sources in Malawi.

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi.

4.4 Discussion

4.4.1 Identification of tilapia species by DNA analysis

To the best of the authors knowledge and literature reviewed, this is the first study on the identification of wild tilapia from open fish markets in Malawi using DNA analysis techniques. DNA analysis is a well validated technique for the accurate identification of animal species (Ivanova et al., 2007). This method unambiguously identified the fish species in all the five types of tilapia investigated in the current study (Table 4.3). Consequently, species labelling (*Oreochromis niloticus*) of the tilapia samples in Malawi imported from Zambia, Zimbabwe and China were validated (Barendse et al., 2019). This demonstrates, the traders were following good practices since there was no case of mislabelling among the imported farmed tilapia analysed in the current study (Mariani et al., 2015).

However, the discovery of *Oreochromis niloticus* from the market samples of wild tilapia in Malawi is important and requires an explanation. This is because *Oreochromis niloticus* is regarded as an alien species in the water bodies in Malawi (Stauffer et al., 2022). Common native tilapia in Malawi are *Oreochromis shiranus and Oreochromis (Nyasalapia)* spp. *(O. karongae, O. lidole* and *O. squamipinnis)* (Chikowi et al., 2021). The Malawi government prohibits introduction of exotic fish for aquaculture. It further forbids the introduction of any non-indigenous fish species to any water body in the country (Banda et al., 2005). The rationale for rejecting introduction of foreign species in Malawi is to protect the native fish fauna. Evidence shows that introduction of non-native invasive species such as *Oreochromis niloticus* is associated with negative impacts on the ecosystems (Genner et al., 2013; Stauffer et al., 2022). The damaging impacts include: a decline or extinction of native fish; competition for food; predation; hybridization; vegetation removal; undesirable changes in water quality; introduction of parasites and diseases; trophic alterations; spatial alterations and competition for space (Stauffer et al., 2022).

There are two possible explanations for the identification of *Oreochromis niloticus* among wild tilapia from Lake Malawi. Firstly, it is possible that the samples were genuinely from lake Malawi and indicates the presence of the species despite the long history of prohibiting the introduction of the species in Malawi (Shechonge et al., 2019; Stauffer et al., 2022). Lake Malawi is bordered by three countries: Malawi, Tanzania, and Mozambique but it is only Malawi that has explicit laws banning the introduction of alien species in the lake (Stauffer et al., 2022). One study demonstrated the occurrence of two invasive tilapiines, *Oreochromis niloticus* and *Oreochromis leucostictus*, inside Lake Malawi on the Tanzanian section of the lake in the year 2011 (Genner et al., 2013). Despite lack of concrete evidence on the spread of these introductions, theoretical discussions and prediction models indicate the potential for these introduced species to successfully expand across water bodies in the Eastern and Southern Africa region (Shechonge et al., 2019; Stauffer et al., 2022). Therefore, the presence of *Oreochromis niloticus* among wild tilapia catch in Malawi may be a true reflection of the successful invasion of the fish in Lake Malawi.

The second explanation is the possible misrepresentation of farmed tilapia particularly imported from other countries as wild tilapia from Malawi by fish traders in the country (Cawthorn et al., 2012, 2018). This might have been the case because at the time of the study (September of 2022), wild tilapia was scarce and there were days when there was no wild tilapia on the open wild fish market in Lilongwe. Further to that, wild tilapia was more expensive than farmed tilapia from Malawi or farmed tilapia imported from other countries. During the time of the study, the price of farmed tilapia was MWK 5,200.00 per kg while the price of wild tilapia was MWK 6,900.00 per kg, for medium size tilapia of about 450 g (USD 1.00 = MWK 1,270.00). The price differences could be due to the high demand and low supply of wild tilapia as well as perceived high quality (aroma, flavour, and texture of tilapia) of wild tilapia among consumers in Malawi (Chikowi et al., 2021).

Therefore, traders would be motivated to trade farmed tilapia as wild tilapia for economic gains (Cawthorn et al., 2012).

The DNA analysis also used 12S and 16S genes for the different tilapias. Future studies should use the cytochrome c oxidase I (COI) gene in distinguishing the closely related tilapia fish species. This is important because the selected gene targets have varying capabilities in distinguishing very closely related animal species (Cawthorn et al., 2012, 2018; Ivanova et al., 2007).

4.4.2 Profiles of sensory attributes of wild versus farmed tilapia

The study demonstrated that tilapia from the five different sources had comparable sensory profiles. The intensities of the sensory attributes can be classified as low (≤ 20), intermediate (21-40) and high (41-100). Tilapia in this study was described as high in 'fresh fish', 'cooked fish' and 'sea breeze' aroma (de Souza et al., 2022; Liu et al., 2022), intermediate intensities of 'earthy', 'buttery' and 'sweet-associated' aroma and low in 'metallic', musty mouldy', 'green' and 'oxidised rancid' aroma (Table 4.4). No statistical differences among the five types of tilapia were identified, except for 'musty mouldy' aroma that was present at higher intensities ($P \geq 0.050$) in Tilapia C (wild) and Tilapia E (farmed).

Tilapia E (farmed) was consistently higher in 'musty mouldy' aroma and flavour, as well as 'earthy' and flavour. Earthy aroma in fish is associated with presence of the compounds geosmin (GSM) and/or 2-methyl-isoborneol (2-MIB) (Percival et al., 2008; Yarnpakdee et al., 2014). The latter two compounds are metabolites produced from algae and cyanobacteria found in freshwater systems. Earthy aroma and flavour taints are common problems reported in other fish species produced from freshwater systems (Yarnpakdee et al., 2014).

The lack of many statistical differences based on the examined sensory attributes may be attributed to the fact that all the five types of tilapia analysed were of the same species (*Oreochromis niloticus*) despite being from different sources (de Souza et al., 2022). The wild tilapia from Malawi (C) and the farmed tilapia from Malawi (B), Zambia (D) and Zimbabwe (A) are reared in freshwater lakes (Kaminski et al., 2018). Farmed tilapia from China (E) is produced mainly through pond aquaculture. The current study has demonstrated that all the fish were of comparable sensory quality (Wang & Lu, 2015). Although consumers tend to prefer wild tilapia over farmed tilapia in Malawi, the current study suggests that this preference may be based on other factors than objective sensory qualities of the fish (Claret et al., 2014; Freitas et al., 2020).

4.5 Conclusions

This study has, for the first time, revealed the identity of the species of wild and farmed tilapia in retail distribution in Malawi by DNA analysis. The study has demonstrated the sensory profile of the fish using descriptive sensory analysis. The results can be a reference on which future research can be based. The presence of 'musty mouldy' and 'earthy' aroma and flavour attributes due to the presence of the specific two compounds and/or bacteria species should be investigated further and confirmed. Tilapia traded in Malawi but imported from Zambia, Zimbabwe and China have been validated as *Oreochromis niloticus* which is what is indicated on their respective packaging material at retail level. This gives confidence to both retailers and customers/consumers and clears mislabelling concerns. However, the discovery of *Oreochromis niloticus* from the market samples of wild tilapia calls for further investigation. There is need for further research and monitoring of the tilapia species from Lake Malawi and in the respective wild fish markets. The lack of statistical differences based on the examined sensory attributes demonstrates that the wild and farmed tilapia examined in this study were of comparable sensory quality. Therefore, there is need to raise awareness and promote farmed tilapia as a potential fish supply in Malawi that can sustainably complement wild tilapia.

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CHAPTER 5: Proximate composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia from retail distribution in Malawi

Abstract

Fish contribute significantly to food security and nutrition to fish consumers in many countries. Tilapia is an important fish species in fisheries, aquaculture development and it is a popular fish among consumers. However, there is limited published scientific information on the chemical profile and heavy metal concentrations in wild versus farmed tilapia particularly in Southern Africa. The aim of this study was to determine and compare the proximate composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia from Malawi, Zambia, Zimbabwe, and China. Wild tilapia from Malawi had the highest total ash while farmed tilapia from Malawi had the highest crude fat content. Farmed tilapia from Malawi had the highest total fatty acid concentration (115.62 mg/g) and content of individual fatty acids while wild tilapia from Malawi had the lowest total fatty acid composition (23.06 mg/g). All the tilapia from the five sources contained relatively high amounts of essential minerals particularly potassium (K), phosphorus (P), sodium (Na), magnesium (Mg), calcium (Ca), and iron (Fe). Potassium was higher than Na in all the samples. All non-essential heavy metals in all the tilapia samples were below the maximum recommended limits according to the FAO/WHO standards.

Keywords: Aquaculture; Fatty acids; Heavy metals; *Oreochromis* spp.; Southern Africa; Wild fish

5.1 Introduction

Fish accounts for 17% of the world's animal protein intake and it is crucial in the provision of vitamins, minerals and lipids, particularly fatty acids such as eicosapentaenoic (EPA) acid and docosahexaenoic acid (DHA) (Sroy et al., 2021). Consumption of fish is therefore important for a healthy and balanced diet for optimal human nutrition and health (Nölle et al., 2020). However, the health benefits of consuming fish can be compromised by the presence of toxic heavy metals such as lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) (Bosch et al., 2016). These heavy metals can harm the human body when consumed in toxic amounts beyond the FAO/WHO standards (FAO/WHO, 2011). The balance between some essential minerals particularly sodium (Na) and potassium (K) is also critical in mediating cardiovascular diseases (Donfrancesco et al., 2021). Therefore, monitoring heavy metal levels in fish is important to ensure compliance with food safety regulations to protect consumers (Bosch et al., 2016). Farmed fish from aquaculture complement wild fisheries to meet consumer demand for fish (Freitas et al., 2020). Aquaculture is the fastest growing animal food industry in the world, with an average annual growth estimated at 7% since 1970 (FAO, 2020). In 2018, aquaculture contributed to over 82 million tonnes of fish. This represented 46% of the world's total fish supply (FAO, 2020). Tilapia is one of the most widely farmed fish species in various aquaculture systems (FAO, 2020). It is the second most popular farmed fish in the world after carp (*Cyprinus carpio*) (FAO, 2020). Tilapia is one of the most traded fish (FAO, 2020; Freitas et al., 2020). In Southern Africa wild tilapia is declining while tilapia aquaculture is growing particularly in Zambia and Zimbabwe along Lake Kariba. There are also imports of frozen tilapia from China into several countries in the region (Hasimuna et al., 2019).

However, there is limited published data on nutrient profile and heavy metal concentrations in wild versus farmed tilapia from retail distribution particularly in developing countries in Southern Africa. Therefore, the aim of this study was to examine the proximate composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia from Malawi, Zambia, Zimbabwe, and China but found in retail distribution in Malawi.

5.2 Materials and methods

5.2.1 Tilapia sampling and sample preparation

Tilapia used in this study were from five sources namely: 1) farmed tilapia imported from Zimbabwe; 2) farmed tilapia from Malawi; 3) wild tilapia from Malawi; 4) farmed tilapia imported from Zambia; and 5) farmed tilapia imported from China. Ten tilapia were sampled per source making a total of 50 tilapia for the experiment. Table 5.1 shows the treatment structure and description and weight of tilapia samples used for the study. All the five types of tilapia were found on the Malawian markets (Chikowi et al., 2021). Fresh wild tilapia from Malawi purchased from an open market in Lilongwe Malawi. Fresh farmed tilapia (from cage aquaculture on Lake Malawi) and frozen farmed tilapia imported from Zambia, Zimbabwe and China were purchased from fish shops in Lilongwe Malawi. The samples were purchased in May of 2022. Whole tilapia samples were weighed (Adam, Pw124, AE43642) and filleted. The fillets were freeze dried (BK-FD18S, F1812-0849) and vacuum sealed (Bennett Read, BRVS120W) in clear nylon vacuum plastic bags (Al-Souti et al., 2012). All analyses (proximate composition, fatty acid, and mineral analysis) were determined for the fillets (muscle meat) when raw (not cooked). Table 5.1 shows the treatment structure of the experiment, description and weight of tilapia used for the study.

Table 5.1 Treatment structure and description and weight of tilapia samples used for the study.

N	Description	Country of origin	Weight of whole tilapia (g)*
1	Farmed tilapia, gutted, frozen whole Labelled (*Oreochromis niloticus*)	Zimbabwe	357.89 ± 26.15
2	Farmed tilapia, fresh on ice, whole Not labelled	Malawi	369.73 ± 25.48
3	Wild tilapia, fresh on ice, whole. Not labelled	Malawi	362.63 ± 23.25
4	Farmed tilapia, gutted, frozen whole Labelled (*Oreochromis niloticus*)	Zambia	379.70 ± 16.9
5	Farmed tilapia, gutted, frozen whole Labelled (*Oreochromis niloticus*)	China	375.18 ± 23.16

*Values for weight of whole tilapia (g) are means and their standard deviation (SD).
Ten fish were sampled per source making a total of 50 tilapia for the experiment.
There were no statistically significant differences in the weight of the tilapia among the five sources (P= 0.227).
N is the number of tilapia sources

5.2.2 Proximate analysis of tilapia

Proximate composition (moisture, crude protein, total crude fat and ash) of the tilapia from the five sources was determined following standard official methods. Moisture content was determined according to method 934.01, ash according to method 942.05, protein according to method 992.15 and crude fat determined using the chloroform/methanol (1:2 vol/vol) extraction method (AOAC, 2005; O'Neill et al., 2015).

5.2.3 Analysis of fatty acids in tilapia

Fatty acids were analysed by gas chromatography and flame-ionization detector (GC-FID) method. Fatty acid methyl esters (FAMEs) were prepared following recommended methods (Folch et al., 1957; Mahachi et al., 2023; Tayengwa et al., 2021). Two millilitres (2:1 chloroform: methanol) were added to ca. 25 mg of the sample and were vortexed and sonicated at room temperature for 30 min. The sample was centrifuged at 3000 rpm for 1 min. One hundred and thirty microliters of the bottom layer (chloroform) were dried completely with a gentle stream of nitrogen and reconstituted and vortexed with 100 µl of methyl tert-butyl ether (MTBE) and 30 µl of trimethylsulfonium hydroxide (TMSH). Analysis of the methyl esters was performed on a gas chromatograph (6890N, Agilent Technologies) coupled to flame ionization detector (FID) (Mahachi et al., 2023; Tayengwa et al., 2021). Separation of the FAMEs was performed on a polar RT-2560 (100 m, 0.25 mm ID, 0.20 µm film thickness) (Restek, USA) capillary column. Hydrogen was used as the carrier gas at a flow rate of 1.2 ml/min. The injector temperature was maintained at 240°C. One microliters of the sample were injected in a 5:1 split ratio. The oven temperature was programmed as follows: 100°C for 4 min, ramped to 240°C at a rate of 3°C/min for 10 min.

5.2.4 Analysis of heavy metals in tilapia

Inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the concentrations of heavy metals in the tilapia samples (O'Neill et al., 2015). The metals analysed were: potassium (K); phosphorus (P); magnesium (Mg); calcium (Ca);iron (Fe); silicon (Si); zinc (Zn); copper (Cu); boron (B); manganese (Mn); selenium (Se); chromium (Cr); nickel (Ni); molybdenum (Mo); cobalt (Co); sodium (Na); aluminium (Al); strontium (Sr); arsenic (As); barium (Ba); antimony (Sb); lead (Pb); vanadium (V); tin (Sn); cadmium (Cd); and mercury (Hg). Approximately 0.3 g of homogenised tilapia samples were digested in 2 ml HCl and 8 ml HNO_3 in a Mars 240/50 microwave digester (produced by CEM) at 160 ºC and for 20 min. After cooling, the solutions were diluted to 50 ml with deionised water in sample bottles cleaned with 5% HNO_3. The digested samples were then analysed on an Agilent 7700 ICP-MS, with metals measured in no-gas mode using the unique HMI function of the instrument, which provides robust conditions and online dilution with argon gas. The instrument was tuned to optimise sensitivity and minimise oxides to <1% and calibrated with NIST-traceable standards, with quality control checks performed to verify accuracy of results. Results were given as mg/kg tilapia sample.

5.2.5 Statistical analysis

The data were examined by the Grubbs' outlier detection statistical procedure to detect and remove any outliers (Jain, 2010). One-way analysis of variance (ANOVA) was used to compare the proximate composition, fatty acid profile and heavy metal concentrations in the five types of tilapia. Homogeneity of variances was examined using Levene's test. Multiple comparisons of means among the tilapia from the five sources were performed using Tukey HSD post hoc test. Where conditions for homogeneity of variances were not satisfied, non-parametric Kruskal Wallis test was performed, followed by the Games-Howell post hoc test (Martins et al., 2011). Differences were considered significant at $P \leq 0.05$. Data were analysed using Statistica™ software version 14.

5.3 Results

5.3.1 Proximate composition of wild versus farmed tilapia

There were significant differences in the total ash content of the wild and farmed tilapia (Table 5.2). Wild tilapia from Malawi had the highest total ash composition while farmed tilapia from China had the lowest ash composition ($P = 0.008$). Farmed tilapia from Malawi had the highest crude fat composition while wild tilapia from Malawi had the lowest crude fat composition ($P < 0.00$). There were no significant differences in the moisture and crude protein composition between the wild and farmed tilapia ($P > 0.05$).

5.3.2 Fatty acid profile of wild versus farmed tilapia

Twenty fatty acids were identified in all the wild and farmed tilapia analysed in this study (Table 5.3). There were significant differences in the total fatty acid content as well individual fatty acids. Farmed tilapia from Malawi had the highest total fatty acids concentration as well as content of individual fatty acids while wild tilapia from Malawi had the lowest total fatty acid composition ($P < 0.00$). Palmitic acid (C16:0) was the highest among saturated fatty acids (SFA) analysed in the tilapia from the five sources. Among monounsaturated fatty acids (MUFA) identified, oleic acid

(C18:1cis) was the most common MUFA. Linoleic acid (C18:2cis) was the most common polyunsaturated fatty acids (PUFA) identified and varied significantly across the five tilapia sources (P<0.001). Both n-6 and 3-n PUFA were present in all the tilapia sources, however n-6 PUFA content were higher than n-3 PUFA in all the five tilapia sources.

Table 5.2 Proximate composition of wild versus farmed tilapia in Malawi (g/100 g).

Composition	**Tilapia sources**					**SEM[1]**	**P value**
	A	**B**	**C**	**D**	**E**		
Moisture	75.52	74.06	75.51	76.08	75.66	0.59	0.168
Ash	1.23^{abc}	1.25^{ab}	1.34^{a}	1.12b^{c}	1.08^{c}	0.05	**0.008**
Protein	14.98	14.96	16.68	13.50	14.85	0.84	0.142
Fat	1.91^{c}	4.75^{a}	1.54^{c}	3.17^{b}	3.34^{b}	0.19	**<0.001**

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from country Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi.
SEM – Pooled standard error of means (n = 50)
$^{a-c}$Least square means with different letter superscripts in the same row are significantly different (P ≤ 0.05)

5.3.3 Concentration of heavy metals in wild versus farmed tilapia

Table 5.4 shows results for essential and non-essential metals analysed in the wild and farmed tilapia. Sixteen essential heavy metals had concentrations in the following order: K>P>Na>Mg>Ca>Fe>Si>Zn>Cu>B>Mn>Se>Cr>Ni>Mo>Co. There were significant differences in all the minerals across the five sources except for iron. Wild tilapia from Malawi had the highest concentration of most of the essential minerals analysed (P ≤ 0.05). Ten non-essential heavy metals were analysed but mercury was below the limit of quantification (LOQ). Concentrations of the analysed non-essential metals were in the following order: Al>Sr>As>Ba>Sb>Pb>V>Sn>Cd. There were significant differences in all the non-essential heavy metals across the five tilapia sources except for Sr and Cd (P ≤ 0.05). Farmed tilapia from Zimbabwe had generally higher concentrations of the non-essential heavy metals (P ≤ 0.05). However, all the non-essential heavy metals were below the maximum recommended limits according to the FAO/WHO standards.

Table 5.3 Fatty acid profiles of wild versus farmed tilapia in retail distribution in Malawi (mg/g).

Fatty acids	**Tilapia sources**					**SEM[1]**	**P value**
	A	**B**	**C**	**D**	**E**		
∑ Fatty acids	32.83^{c}	115.62^{a}	23.06^{c}	64.67^{b}	66.32^{b}	7.70	**<0.001**
Saturated fatty acids (SFA)							
∑ SFA	13.68^{c}	47.43^{a}	11.66^{c}	25.51^{b}	26.99^{b}	2.86	**<0.001**
C14:0	0.92^{c}	2.57^{a}	0.49^{c}	1.80^{b}	2.04^{ab}	0.24	**<0.001**
C15:0	0.08^{c}	0.17^{b}	0.32^{a}	0.12^{bc}	0.13^{bc}	0.02	**<0.001**
C16:0	9.12^{cd}	34.41^{a}	8.01^{d}	17.50^{bc}	18.63^{b}	2.12	**<0.001**
C17:0	0.19^{b}	0.31^{a}	0.28^{a}	0.26ab	0.30a	0.03	**0.056**
C18:0	3.12^{c}	9.42^{a}	2.31^{c}	5.30^{b}	5.40^{b}	0.57	**<0.001**
C20:0	0.10^{c}	0.27^{a}	0.06^{d}	0.17^{abc}	0.16^{b}	0.02	**<0.001**
C22:0	0.14^{a}	0.28^{ab}	0.20^{bc}	0.37^{a}	0.33^{a}	0.04	**0.001**
Monounsaturated fatty acids (MUFA)							
∑ MUFA	10.22^{cd}	41.50^{a}	4.47^{d}	21.87^{abc}	21.84^{b}	3.15	**<0.001**
C16:1	1.26^{c}	6.41^{a}	1.78^{bc}	2.53^{bc}	2.90^{b}	0.56	**<0.001**
C18:1cis	8.43^{c}	33.60^{a}	2.54^{d}	18.09^{abc}	17.75^{b}	2.51	**<0.001**
C20:1	0.45^{b}	1.28^{a}	0.12^{c}	1.08^{a}	1.01^{a}	0.10	**<0.001**
C22:1	0.07^{b}	0.20^{a}	0.02^{b}	0.17^{a}	0.18^{a}	0.03	**<0.001**
Polyunsaturated fatty acids (PUFA)							
∑ PUFA	8.94^{c}	26.69^{a}	6.92^{c}	17.29^{b}	17.49^{b}	1.90	**<0.001**
C18:2cis	4.77^{b}	18.43^{a}	1.00^{c}	11.41^{a}	10.32^{a}	1.51	**<0.001**
C18:3n6 (GLA)	0.22^{c}	1.15^{a}	0.12^{c}	0.66^{b}	0.46^{b}	0.07	**<0.001**
C18:3n3 (ALA)	0.36^{c}	1.40^{a}	0.09^{c}	0.82^{b}	0.76^{b}	0.95	**<0.001**
C20:2	0.26^{b}	0.74^{a}	0.10^{c}	0.60^{a}	0.49^{a}	0.05	**<0.001**
C20:3n6 (dimo GALA)	0.32^{b}	0.90^{a}	0.17^{c}	0.60^{a}	0.61^{a}	0.06	**<0.001**
C20:4n6	0.77^{c}	1.59^{a}	1.93^{a}	1.15^{b}	1.22^{b}	0.13	**<0.001**
C22:2	0.01^{c}	0.07^{a}	0.04^{b}	0.05^{b}	0.03^{b}	0.01	**<0.001**
C20:5n3 (EPA)	0.19^{bc}	0.16^{bc}	0.80^{a}	0.12^{c}	0.24^{b}	0.03	**<0.001**
C22:6n3 (DHA)	2.04^{cd}	2.24^{c}	2.67^{b}	1.88^{d}	3.36^{a}	0.11	**<0.001**
∑PUFA/∑SFA	0.65^{a}	0.56^{b}	0.62^{ab}	0.70^{a}	0.65^{a}	0.03	**0.036**
∑PUFA n-6	1.31^{c}	3.64^{a}	2.22^{b}	2.41^{b}	2.29^{b}	0.23	**<0.001**
∑PUFA n-3	1.14^{c}	3.06^{a}	2.06^{b}	2.02^{b}	2.02^{b}	0.21	**<0.001**
∑PUFA n-6/∑PUFA n-3	1.17^{ab}	1.22^{a}	1.08^{c}	1.20^{ab}	1.14^{bc}	0.03	**0.003**

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from country Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi

SEM – Pooled standard error of means (n = 50)

$^{a-d}$Least square means with different letter superscripts in the same row are significantly different ($P \leq 0.05$)

SFAs - Saturated fatty acids and was a summation of all fatty acids identified in the sample

MUFAs - Monounsaturated fatty acids

PUFAs - Polyunsaturated fatty acids

∑ - total

Table 5.4 Element concentrations in wild versus farmed tilapia in Malawi (mg/kg dry weight).

Elements	**ML**	**Tilapia sources**					**SEM**[1]	**P-value**
		A	**B**	**C**	**D**	**E**		
Essential elements								
Potassium (K)		15353.39^{d}	17536.47^{c}	22093.17^{a}	17234.62^{c}	20689.46^{b}	357.14	**<0.001**
Phosphorus (P)		6724.64^{c}	7014.80^{c}	8521.16^{a}	6021.49^{d}	7837.74^{b}	102.73	**<0.001**
Sodium (Na)		2502.74^{b}	2100.08^{c}	1844.24^{d}	2941.30^{a}	1972.11^{cd}	87.24	**<0.001**
Magnesium (Mg)		1224.91^{b}	1225.24^{b}	1409.03^{a}	1070.95^{c}	1424.25^{a}	21.88	**<0.001**
Calcium (Ca)		850.79^{b}	626.25^{b}	558.81^{b}	1261.37^{a}	791.89^{b}	134.40	**0.006**
Iron (Fe)	450	29.14	17.82	13.16	18.08	18.80	3.95	0.082
Silicon (Si)		28.58^{bc}	38.37^{a}	24.20^{c}	32.57^{b}	30.64^{b}	1.90	**<0.001**
Zinc (Zn)	40	17.03^{a}	15.20^{bc}	12.52^{d}	16.37^{ab}	14.31^{c}	0.54	**<0.001**
Copper (Cu)	40	7.42^{a}	2.63^{b}	2.01^{b}	1.11^{c}	1.06^{c}	1.24	**0.004**
Boron (B)		2.76^{a}	2.36^{a}	2.62^{a}	2.28^{a}	1.52^{b}	0.22	**0.002**
Manganese (Mn)	500	0.74^{ab}	0.62^{b}	0.59^{c}	0.64^{b}	0.81^{a}	0.05	**0.023**
Selenium (Se)		0.49c	0.51^{bc}	0.56^{b}	0.63^{a}	0.46^{c}	0.02	**<0.001**
Chromium (Cr)	5	0.35^{b}	0.35^{b}	0.26^{b}	0.31^{b}	0.49^{a}	0.04	**0.004**
Nickel (Ni)	6.7	0.15^{b}	0.38^{a}	0.14^{b}	0.15^{b}	0.23^{ab}	0.07	0.062
Molybdenum (Mo)		0.08^{b}	0.15^{a}	0.15^{a}	0.16^{a}	0.04^{c}	0.01	**<0.001**
Cobalt (Co)		0.02b^{c}	0.04^{b}	0.11^{a}	0.02^{c}	0.02^{c}	0.01	**<0.001**
Non-essential elements								
Aluminium (Al)	30	16.15^{a}	10.81^{ab}	6.04^{b}	9.93^{ab}	10.92^{ab}	2.19	**0.041**
Strontium (Sr)		1.09	1.29	1.33	1.40	0.91	0.22	0.506
Arsenic (As)		0.54^{a}	0.21^{c}	0.09^{d}	0.22^{c}	0.34^{b}	0.03	**<0.001**
Barium (Ba)		0.21^{b}	0.17^{b}	0.25^{ab}	0.17^{b}	0.40^{a}	0.05	**0.023**
Antimony (Sb)		0.04^{ab}	0.04^{abc}	0.04^{a}	0.02^{bc}	0.01^{c}	0.01	**0.042**
Lead (Pb)	0.2	0.03^{ab}	0.04^{a}	0.03^{ab}	0.02^{b}	0.02^{b}	0.01	**0.040**
Vanadium (V)		0.03^{b}	0.04^{b}	0.07^{a}	0.04^{b}	0.04^{b}	0.01	**<0.001**
Tin (Sn)	250	0.02^{a}	0.01^{ab}	0.01^{ab}	0.01^{b}	0.01^{b}	0.01	**0.200**
Cadmium (Cd)[2]	0.05	0.00	0.00	0.00	0.00	0.00		**0.013**
Mercury (Hg)[3]	0.5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ		na

A was farmed tilapia imported from Zimbabwe but purchased in shops in Malawi; B was farmed tilapia from Malawi purchased in shops in Malawi; C was wild tilapia from Malawi but purchased from open wild fish market in Malawi; D was farmed tilapia imported from country Zambia but purchased in shops in Malawi; E was farmed tilapia imported from China but purchased in shops in Malawi
[a-d]Least square means with different letter superscripts in the same row are significantly different ($P \leq 0.05$)
[1]SEM – Pooled standard error of means (n = 50)
LOQ – Limit of quantification
ML – Maximum limit according to FAO/WHO standards
[2]Values for Cadmium were low and could only be seen at three decimal places
[3]Mecury concentrations were below LOQ

5.4 Discussion

This study is considered to be the first research done to analyse proximate composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia from retail distribution in Malawi. The study has demonstrated that wild tilapia from Malawi had higher ash content and lower fat content compared to farmed tilapia from Malawi and farmed tilapia imported from other countries. The high ash content and low fat content in sample C support the hypothesis that the samples were from wild sources (Acharya et al., 2022). Crude ash content of fish is a proxy indicator for the total mineral content of the fish (Acharya et al., 2022; Al-Souti et al., 2012). Ash content in fish is determined by various conditions such as diet, species, environmental variables mainly temperature, seasons, salinity, geographical location (Acharya et al., 2022; Ayisi et al., 2017). Moisture and protein content were comparable ($P > 0.050$) in the wild and farmed tilapia. Wild tilapia from Malawi was from Lake Malawi, the fifth largest freshwater lake in the world and the second deepest lake in Africa (Hecky et al., 2003). Farmed tilapia from Malawi (B), Zambia (D) and Zimbabwe (A) are raised in cages in lakes while farmed tilapia from China (E) was from ponds in polyculture systems (Hasimuna et al., 2019; Wang & Lu, 2016). Farmed fish tend to have higher fat content and lower moisture content compared to wild individuals of the same species (Freitas et al., 2020). This is mainly because of fish feed composition and feeding regimes in the farmed tilapia (Islam et al., 2021). This was the case in the current study where farmed tilapia had high fat content while wild tilapia had lower fat content.

Tilapia feeding trials show that chemical composition of farmed tilapia is determined by the composition of feed provided (Al-Souti et al., 2012). However, in the present study the exact feed used for the five sources of market samples of wild and farmed tilapia for chemical analysis could not be accessed. Therefore, the precise composition of the feed was not known. Moreover, the ingredients used in the formulation of commercial tilapia feed varies (El-Sayed, 2019). Generally, feed may be formulated from a varied combination of ingredients, which include animal sources ingredients such as fishmeal, meat, and bone meal; seed meals such as cottonseed cake, peanut meal, soybean meal and sunflower seed cake; cereals such as maize, rice, millet sorghum; cereal bran such as rice bran, maize bran, and wheat bran; vitamin and mineral premixes (El-Sayed, 2019). Some of the common commercial feed for cage tilapia aquaculture in Southern Africa has the following composition: crude protein 34%; crude fat 5%; nitrogen free extract (NFE) 37%; ash 8%; fibre 4%; and phosphorus 1% (El-Sayed, 2019).

Wild tilapia from Lake Malawi follow a natural feeding habit and they are generally herbivorous/omnivorous meaning they are low on the aquatic food chain. During larval stages, tilapia feed on zooplankton (Turner et al., 1991). At juvenile stage wild tilapia feed on a variety of aquatic vegetation, filamentous green algae (*Mougeotia*), detritus, phytoplankton, zooplankton, periphyton and detritus. Specifically, adult tilapia in Lake Malawi feed on filamentous diatom

Aulacoseira (Melosira), *Mougeotia* and zooplankton. They have a narrow dietary range, dominated by the filamentous diatom Melosiru (El-Sayed, 2019; Turner et al., 1991).

The fatty acid profiles and variability followed the crude fat composition of the tilapia from the five sources in the present study. Fatty acid profiles observed in the farmed tilapia sources were comparable with results from similar studies (Al-Souti et al., 2012; Sroy et al., 2021; Weaver et al., 2008). The high fatty acid concentration in farmed tilapia and low fatty acids observed in the wild tilapia may also be attributed to the diets of the fish (Al-Souti et al., 2012). Fish feed that is high in lipids affect the fatty acid composition of tilapia and other fish. Studies have shown that tilapia fed diets high in fatty acids have significantly high levels of fatty acids in the muscle tissue (Sroy et al., 2021). Specifically, addition of 6% palm oil in tilapia feed was shown to significantly increase total saturated fatty acids, as well as total n-3 and n-6 PUFA in muscle tissue of farmed *Oreochromis niloticus* (Ayisi et al., 2017). Therefore, the high fatty acid profile observed in the farmed tilapia sources in the present study may be a proxy indication that the fish were fed diets high in total fatty acids as well as specific fatty acids such as PUFAs (Al-Souti et al., 2012; Ayisi et al., 2017).

All the tilapia from the five sources contained relatively high amounts of essential minerals particularly K, P, Na, Mg, Ca, and Fe. Although Na is not necessarily an essential mineral, it was included in the analysis so that K results could be viewed together with Na. This is important because K/Na ratio is crucial in diet, nutrition, and health (Donfrancesco et al., 2021). An imbalance of Na and K with higher levels of Na and low levels K in the body is associated with hypertension and cardiovascular disease (Vaudin et al., 2022).

There were variations in individual minerals across the sources where some minerals were higher in farmed tilapia while others were higher in wild tilapia. Wild tilapia from Malawi contained significantly higher amounts of K, P, Mg, B, Mo, and Co while farmed tilapia from Malawi and imported from other countries contained higher amounts of Na, Ca, Fe, Zn and Cu. These findings agreed with findings from a similar study on heavy metal concentrations in muscles of wild and farmed tilapia from Lake Kariba in Zambia (Nölle et al., 2020; Simukoko et al., 2022). In the Zambia study, some essential metals were higher in farmed tilapia, whereas non-essential metals were higher in wild tilapia (Simukoko et al., 2022). Highest Cu level was found in farmed tilapia (3.5 mg/kg) and the lowest in wild tilapia (0.25 mg/kg). In the present study Cu level was highest in farmed tilapia from Zimbabwe (7.42 mg/kg) but was relatively lower in wild tilapia (2.01 mg/kg).

All non-essential heavy metals in all the tilapia were below the maximum recommended limits according to the FAO/WHO standards (FAO/WHO, 2011). Al was the only non-essential heavy metal with values higher than 10 mg/kg (still below the FAO/WHO maximum limit of 30 mg/kg) in farmed tilapia from Zimbabwe, Malawi, and China. Farmed tilapia from Zimbabwe had generally higher concentrations of the non-essential heavy metals despite the very low levels observed ($P \leq 0.05$). High levels of heavy metals in feed and water where fish are raised are associated with corresponding high levels of the respective metals in fish (Sroy et al., 2021; Varol & Sünbül, 2020).

Fish can absorb and then bioaccumulate these metals through gills and skin or ingesting contaminated water and feed (Firth et al., 2019). Studies show that heavy metal accumulation in fish is related with the age of the fish where older fish tend to accumulate higher levels of metals that younger ones (Bosch et al., 2016). The current study did not calculate the specific age of the fish since these were retail/market samples and some of the samples were purchased in a frozen state. However, there were no statistically significant differences in the weight of the fish from the five tilapia sources analysed in the present study as shown in Table 5.1 (Ponzoni et al., 2011).

Some studies on heavy metal contaminants in fish also include analysis of the metals in sediment samples as well as water samples where the fish were raised (Kidd et al., 2003; Martins et al., 2011; Weber et al., 2013). This helps to demonstrate correlations of heavy metal accumulation in the fish, water, and sediment samples (Weber et al., 2013). In the present study, the sediment and water samples could not be assessed since the tilapia were only retail/market samples. Lake Malawi and Lake Kariba have not been subjected to extensive pollution that would result in high accumulation of heavy metals in the water and fish (Gondwe et al., 2011; Simukoko et al., 2022). The present results show very low levels of non-essential heavy metals in the tilapia from these water bodies and add to the evidence of low metal contamination. However, some studies showed concerns of high levels of Pb and Hg in some water bodies used for aquaculture in China (Kong et al., 2005; Leung et al., 2014). The low heavy metal levels in tilapia from China demonstrated in the present study may show efforts to contain the problem. However, these findings should be interpreted with caution since heavy metal concentrations vary by site and seasons in different water bodies (Simukoko et al., 2022).

5.5 Conclusions

The present study contributes to the literature on proximate composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia. Farmed tilapia from Malawi had the highest total fatty acid concentration and the content of individual fatty acids while wild tilapia from Malawi had the lowest total fatty acid composition. Both n-6 and 3-n PUFA were present in all the tilapia, however n-6 PUFA were higher than n-3 PUFA in all the tilapia from the five sources. All the tilapia contained relatively high amounts of essential minerals particularly K, P, Na, Mg, Ca, and Fe compared to the other minerals analysed. Potassium was higher than Na in all the samples. All non-essential heavy metals in all the tilapia were below the maximum recommended limits according to Food and Agriculture Organisation (FAO) and World Health Organisation (WHO) standards.

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CHAPTER 6: General discussion and conclusions

6.1 Introduction

The aim of this study was to review tilapia consumption trends, assess consumer preference, analyse descriptive sensory profile, identify tilapia species, and determine the proximate composition of wild versus farmed tilapia on the Malawian market. This was achieved by conducting a review and experiments guided by four related objectives to address specific research questions as presented in chapter two to chapter five. The current chapter summarises the work by providing a general discussion, suggesting recommendations based on the research findings and conclusions drawn as well as highlighting areas for further research. There were some limitations of the study, which are presented so that the study results, discussions, conclusions, and recommendations should be interpreted in the context of such shortcomings.

6.2 General discussion

Tilapia plays an important role in food security and livelihoods of people in Southern Africa (Chan et al., 2019; Tran et al., 2019). The review of the FAO data on fish supply over a 20-year period (2000 to 2019) highlighted trends in tilapia consumption in Southern Africa focusing on supply, quality, and consumer preference for wild and farmed tilapia (Chapter 2) (FAO, 2020). The latter analysis demonstrated the diminishing supply of tilapia from wild sources using data from three countries only (Botswana, Malawi, and Zimbabwe) (FAO, 2020). The low volumes of wild tilapia reported by the three countries and the lack of data on wild tilapia catch from the remaining seven countries alluded to the declining stocks of wild tilapia, as well as the challenges in reporting (to the FAO) the wild tilapia production data by these countries (Blasco et al., 2020; FAO, 2020). The main factors reported as causes of the decline in wild tilapia were overfishing, pollution, climate change, illegal fishing, habitat destruction, violation of closed seasons (for breading) also exacerbate the problem (Banda et al., 2005; Bell et al., 2012; FAO, 2020). The decline in wild tilapia is a cause for concern since wild tilapia contributes significantly to the livelihoods, food security, nutrition, and health of vulnerable fishing communities along the fishing grounds (Belton et al., 2018; Belton & Thilsted, 2014; FAO, 2020).

Zambia demonstrated to be a model for successful cage aquaculture in Southern Africa (FAO, 2020; Hasimuna et al., 2019). Zambia has an enabling biophysical, economic, and social factor that makes tilapia culture feasible in the country (Moyo & Rapatsa, 2021). These factors include availability of freshwater for cage aquaculture on Lake Kariba, interest in aquaculture from commercial companies, availability of fingerlings (juvenile fish), and availability of fish feed (Hasimuna et al., 2019; Moyo & Rapatsa, 2021). Other countries should encourage private sector involvement in aquaculture, researching and legalising the use of high performing tilapia strains (*Oreochromis niloticus*), supporting feed processing and fingerlings production, and synchronising the process for issuing permits and licences (Moyo & Rapatsa, 2021). Tilapia imports particularly from China play a critical role of sustaining fish supply to meet increasing demand in countries like

Angola, Namibia and South Africa who are major tilapia importers (FAO, 2020; Tran et al., 2019). Preference for wild tilapia over farmed tilapia was noted in some countries in the region. However, increases in farmed tilapia imports demonstrated the potential acceptability of farmed tilapia in some countries (Chikowi et al., 2021).

The survey on consumer preference for wild versus farmed tilapia from Malawi and farmed tilapia imported from other countries provided an updated perspective of consumer preference among tilapia consumers in Malawi (Chapter 3). Consumers (98%) were aware of the different types and sources of tilapia sold on the Malawian market (wild versus farmed and locally produced versus imported tilapia). A common trend from literature where consumers rate wild tilapia favourably over farmed tilapia was validated among tilapia consumers interviewed in the current study (Claret et al., 2014; Darko et al., 2016; Uddin et al., 2019). Sixty five percent (n=130) of the consumers preferred wild tilapia from Malawi due to its perceived better sensory properties than farmed tilapia. This was also consistent with purchase patterns where 42% (n=84) of the consumers purchased wild tilapia most of the times while 34% (n = 67) purchased farmed tilapia. However, it was interesting to note that CA revealed that consumers from high tilapia consumption frequency (1 - 2 times tilapia consumption per week) were more likely to purchase frozen farmed tilapia than consumers from medium (1 - 2 times tilapia consumption per month) and low tilapia consumption frequencies (5 - 6 times tilapia consumption per year). This alludes to changing consumption patterns where consumers are embracing farmed tilapia in the country (Chikowi et al., 2021; Darko et al., 2016; Uddin et al., 2019).

Despite the results that more consumers preferred wild tilapia from Malawi the descriptive sensory analysis showed statistical differences in only a three sensory attributes (musty mouldy aroma, earthy flavour, and musty mouldy flavour) of the wild versus farmed tilapia evaluated in the study (Chapter 4). The sensory analysis results demonstrate that the wild and farmed tilapia were of comparable sensory quality (Freitas et al., 2020). Therefore, the preference for wild over farmed tilapia among the consumers observed in the consumer study (Chapter 3) may only be based on past experiences (i.e., their frame of reference) and a long history of consuming fresh wild tilapia from Malawi rather than on objective sensory attributes of the fish (Claret et al., 2012; Darko et al., 2016; FAO, 2020).

Furthermore, the DNA analysis (Chapter 4) showed that all the tilapia analysed in the study were of the same species (*Oreochromis niloticus*). However, the proximate analysis (Chapter 5) showed significant differences ($P < 0.001$) in the fat content of the different tilapia. Wild tilapia from Malawi (C) had the lowest fat content (1.54 g/100g) while farmed tilapia from Malawi (B) had the highest fat content (4.75 g/100 g). The low fat content in tilapia sample C supports the hypothesis that the samples were from wild sources (Garduño-Lugo et al., 2003). However, fat content alone cannot tell the type of species of the tilapia as DNA analysis does (Ivanova et al., 2007).

Nonetheless, these fat content differences did not translate to detectable sensory differences particularly in the buttery aroma and flavour attributes in the sensory study.

The investigation of the proximate composition, fatty acid profile and heavy metal concentrations in wild versus farmed tilapia provided more evidence that the wild and farmed tilapia in retail distribution in Malawi is nutritious and safe for human consumption (Chapter 5).

6.3 Recommendations

Based on the study findings, discussions and conclusions drawn, the following recommendations can be made to improve the tilapia value chain in Southern Africa:

i. Although the best way to capture per capita fish consumption is through direct consumption surveys, such survey data are not available for the region. The FAO data provides a synopsis of the fish supply in Southern Africa. Therefore, there is need for coordinated direct consumption surveys to provide accurate and comparable data on per capita fish consumption in the region.

ii. Governments in the region should strengthen efforts to restore and protect fish ecosystems and regulate fisheries so that people can continue to benefit from wild fish supply.

iii. Countries should increase farmed tilapia supply by encouraging private sector involvement in cage aquaculture, researching, and legalising the use of high performing tilapia strains (*Oreochromis niloticus*), supporting feed processing and fingerlings production, and synchronising the process for issuing permits and licences for aquaculture operations.

iv. International and regional fish trade in Southern Africa should be supported. Fish trade can benefit from initiatives such as the African Continental Free Trade Area (AfCFTA) and efforts aimed at reducing tariff and non-tariff technical barriers to trade. This would also reduce the prevalence of informal fish trade between countries and enhance the process of compiling fish trade statistics.

v. Consumer awareness campaigns should be done on the quality of farmed tilapia so that consumers can make informed purchase decisions on farmed tilapia instead of relying on past negative beliefs regarding farmed fish.

vi. The discovery of *Oreochromis niloticus* from the market samples of wild tilapia calls for further investigation. Further research and monitoring of the tilapia species from Lake Malawi and in the respective wild and farmed fish markets should be done.

6.4 Areas for further studies

The study provided some insights on areas for further research. The following are some of the key areas which future research may focus:

i. Harmonised direct fish consumption surveys should be conducted in Southern Africa and Africa as well. These surveys should establish accurate per capita fish consumption in the respective countries. If possible, the data should be disaggregated by species consumed. This information is crucial and will form a basis for decision making for healthy diets among consumers.

ii. A systematic review should be done on tilapia consumption in Southern Africa.

iii. Further research should be conducted on the FAO fish data reporting systems and finding ways and innovative means of making the process efficient and reliable.

iv. There is lack of literature on the extent and value of cross boarder fish trade in Southern Africa and Africa as continent. More research should be done on the extent of cross boarder fish trade as well as barriers and enablers of fish trade across countries.

v. Research should focus on monitoring of the tilapia species from Lake Malawi and in the respective wild and farmed fish markets. A routine monitoring system should also be designed and put in place.

vi. Policy research should be done in Malawi to examine the feasibility of prohibiting the culture of *Oreochromis niloticus* in the context where other countries which boarder along Lake Malawi have no stringent policies that bar the culture of *Oreochromis niloticus.*

vii. Further research on tilapia amino acid and vitamin profile. This is important because tilapia is an important source of animal protein for most tilapia consumers in Southern Africa.

viii. The microbiology safety of frozen tilapia should be examined along the tilapia value chain. Although the present study did not find any concerns for tilapia spoilage in the descriptive sensory analysis study, an investigation into the microbial safety is still important because the frozen fish is given a long shelf life (two years) on the label of the package under normal circumstances (frozen at -18 °C or less).

6.5 Limitations of the study

The review on trends in tilapia consumption in Southern Africa relied on the FAO data (Chapter 2). This was the case because the FAO database on fish is the most comprehensive dataset on fish statistics despite the shortcomings that exist. However, FAO relies on voluntary submission of annual landings of wild and farmed fish from national correspondents from the participating countries. The latter process is not easy since capture fisheries and small-scale farmed fish data are difficult to compile in the selected countries (Blasco et al., 2020). Therefore, the review should be interpreted with caution due to this limitation.

In the consumer preference study (Chapter 3) the interviews were done with participants from Lilongwe in Malawi only. Therefore, the results should be interpreted with caution since there could be differences in consumer preference across countries and cultures. Furthermore, the intercept interview method used in the quantitative survey may not always produce a representative sample of the population of interest. Only three shops dedicated to selling fish and one open market for wild tilapia were visited for the interviews. Future studies should include supermarkets which also sell fish to get a wider variety of consumers. The study lumped together farmed tilapia from Malawi and farmed tilapia imported from other countries in one category of “farmed tilapia”, even though the participants indicted that they were aware of the various sources of tilapia. Future studies should treat these categories as separate and specify the country of origin of the fish.

Despite providing valuable insights with regards to identity and chemical profile of tilapia in retail distribution in Malawi the DNA analysis (Chapter 4) and chemical composition experiments (Chapter 5) lacked proper history of the fish. This would include important paraments regarding the environment (water bodies) where the fish was raised, diet fed to the fish, sex of the fish as the age of the fish. Future studies should take these factors into consideration. The DNA analysis also used 12S and 16S genes for the different tilapias. Future studies should use the cytochrome c oxidase I (COI) gene in distinguishing the closely related tilapia fish species.

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Appendices

Appendix 1 Ethics approval letter, Stellenbosch University

UNIVERSITEIT STELLENBOSCH UNIVERSITY

CONDITIONAL APPROVAL GRANTED
REC: Social, Behavioural and Education Research (SBER) - Initial Application Form

11 June 2021

Project number: REC-2021-18970

Project title: Sensory analysis, consumer preference and meat quality of wild and farmed tilapia (Oreochromis species) on the Malawian market

Dear Mr V Mlotha

Your REC: Social, Behavioural and Education Research (SBER) - Initial Application Form submitted on 19/05/2021 14:47 was reviewed by the REC: Social, Behavioural and Education Research (REC: SBE) and approved with certain conditions.

This conditional approval means that the researcher may proceed with the envisaged research provided that they respond or adhere to the stipulations/conditions.

Ethics approval period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
11 June 2021	10 June 2022

REC STIPULATIONS/CONDITIONS:

Ethics clearance from the National Commission for Science and Technology (NCST) in Malawi must be obtained before data collection may start. Please attach proof of this clearance to your application once it has been obtained. [ACTION REQUIRED]

HOW TO RESPOND:

Some of these stipulations/conditions may require your response. Where a response is required, you must respond to the REC within **three (3)** months of the date of this letter.

Your conditional approval will lapse automatically should your response not be received by the REC within 3 months of the date of this letter.

For instructions on how to respond to these stipulations, please download the FAQ on how to edit your application and follow the steps carefully: HOW TO RESPOND TO REC FEEDBACK.

Where revision to supporting documents is required, please ensure that you replace all outdated documents on your application form with the revised versions.

INVESTIGATOR RESPONSIBILITIES

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: SBE, the researcher must notify the REC of these changes.

Please use your SU project number (18970) on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

Appendix 2 Ethics approval letter, National Commission for Science and Technology, Malawi

NATIONAL COMMISSION FOR SCIENCE & TECHNOLOGY

Lingadzi House
Robert Mugabe Crescent
P/Bag B303
City Centre
Lilongwe

Tel: +265 1 771 550
+265 1 774 169
+265 1 774 869
Fax: +265 1 772 431
Email: directorgeneral@ncst.mw
Website: http://www.ncst.mw

NATIONAL COMMITTEE ON RESEARCH ETHICS IN THE SOCIAL SCIENCES AND HUMANITIES

Ref No: NCST/RTT/2/6 **20th August, 2021**

Mr Vincent Mlotha
LUANAR, Bunda Campus
P.O. Box 219
Lilongwe
Email: vinmlotha@gmail.com
Mobile: +25995193629

E-mail address: vinmlotha@gmail.com

Dear Mr Mlotha,

Research Ethics Approval and Permit of Research Protocol No. P.07/21/584: Sensory analysis, consumer preference and meat quality of wild and farmed tilapia (Oreochromis species) on the Malawian market

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

NCRSH Address:
Secretariat, National Committee on Research Ethics in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw

Appendix 3 Gatekeeper permission letter, Department of Fisheries, Malawi

Telephone +265 (0) 788 511
Facsimile +265 (0) 788 712
Email: fisheriesdept@sdnp.org.mw

UNITY AND FREEDOM

DEPARTMENT OF FISHERIES
Ministry of Forestry and Natural Resources
P.O. Box 593,
LILONGWE.
MALAWI.

Ref. No. DOFI/20/6/14 **6th April, 2021**

Vincent Mlotha
LUANAR
Bunda Campus
P.O. Box 219
Lilongwe

Dear Sir,

RE: REQUEST FOR GATEKEEPER PERMISSION TO CONDUCT RESEARCH

Reference is made to your letter dated 29th March, 2021 on the above mentioned subject.

I am pleased to inform you that your request has been granted to conduct the research. Please update us on the probable dates for the study.

Yours faithfully,

Friday Njaya, PhD
DIRECTOR OF FISHERIES

Appendix 4 Consent to participate in research

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

You are invited to take part in a study conducted by Mr Vincent Mlotha Dr Khalid Salie Dr J Marais and Dr A Molotsi, from the Department of Animal Science at Stellenbosch University. The research is about the quality of tilapia fish found on the Malawian market. You were approached as a possible participant because you are a potential consumer of tilapia and would provide some useful information in this regard.

1. **PURPOSE OF THE STUDY**

Tilapia fish (*Chambo*) on the Malawian market comes from different sources including natural sources in the country for instance Lake Malawi, from ponds while some tilapia fish are imported from countries like China. The aim of the research is assessing the quality and diversity of the tilapia fish found on the Malawian market. Therefore, we would like to engage consumers and document their views regarding the quality of the fish in aspects like availability, taste as well as price.

2. **WHAT WILL BE ASKED OF ME?**

If you agree to take part in this study, you will be requested to participate in any one of the following activities, (**please tick one** √).

SN	Activity	Tick (√)
1	Key informant interview where you will be asked to discuss issues related with availability, quality and consumption of tilapia fish in Malawi. This interview will take an hour to complete. NOTE: This interview will be audio recorded to assist the researcher to organise and process the data effectively.	
2	Focus group discussion where issues related with availability, quality and consumption of tilapia fish in Malawi. You will be in a group of about 8 to 12 people and the discussions will be done at a well organised place. This interview will take an hour to complete NOTE: The focus group discussions will be audio recorded to assist the researcher to organise and process the data effectively.	
3	Individual interview where you will be asked some questions on your opinions and experience regrading tilapia fish consumption in Malawi. This interview will take 20 minutes to complete	
4	Sensory evaluation of tilapia fish where you will be asked to eat and evaluate different cooked tilapia fish. This exercise will take 30 minutes to complete	

3. **POSSIBLE RISKS AND DISCOMFORTS**

All the activities in this research involve no risk and discomforts. They only require your time to take part in the study and answer some questions or provide your views in an organised discussion.

4. POSSIBLE BENEFITS TO PARTICIPANTS AND/OR TO THE SOCIETY

There is no direct benefit you may accrue from participating in this study. However, your contribution of opinions and thoughts in the research will provide valuable information for further analysis. Once finalised the research will provide consumers with current knowledge on the different sources of tilapia found on the Malawi market. Sensory qualities of the fish as well as consumer preferences will also be established. This information will help consumers to make informed decisions when purchasing tilapia fish from the Malawi market. Tilapia fish traders will also benefit from the results of the consumer beliefs and attitudes towards tilapia from different sources and make necessary adjustments in their tilapia fish trade. Similarly, tilapia fish farmers will benefit from the sensory and consumer preference information to make necessary improvements in the fish farming systems.

5. PAYMENT FOR PARTICIPATION

Participation in this study is voluntary and out of good will to contribute to the topic under discussion. There will be no cash payment to individuals for participation in the study. However, for Focus Group Discussions and Sensory evaluation, participants will be reimbursed their transport costs since the sessions will be done at an organised date and place and participants will be requested to meet at such a place.

6. PROTECTION OF YOUR INFORMATION, CONFIDENTIALITY AND IDENTITY

Any information you share with me during this study and that could possibly identify you as a participant will be protected. This will be done by ensuring that all personnel working on the project (research assistants) adhere to confidentiality protocols for the study. All research assistants who will be involved in this study will sign a non-disclosure agreement and will confirm that all data remains confidential. Secondly, all electronic data will be password protected and the computer that will be used to handle the data will also be password protected. Only the researcher, the supervisory team and staff from the Centre for Statistical Consultation at Stellenbosch University will have access to the data.

Information from the study will be used to prepare a PhD thesis for the researcher and publications will be made from the work in the form of original research articles. However, in all the published work, no direct link will be made to any participants and their views will be pooled and will be treated beyond an individual participant.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you agree to take part in this study, you may withdraw at any time without any consequence. You may also refuse to answer any questions you don’t want to answer and still remain in the study.

8. RESEARCHERS' CONTACT INFORMATION

If you have any questions or concerns about this study, please feel free to contact Vincent Mlotha at 21559376@sun.ac.za and/or the supervisor Dr Khalid Salie at ks1@sun.ac.za.

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development or Secretariat, National Committee on Research Ethics in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw

DECLARATION OF CONSENT BY THE PARTICIPANT

As the participant I confirm that:

- I have read the above information and it is written in a language that I am comfortable with.
- I have had a chance to ask questions and all my questions have been answered.
- All issues related to privacy, and the confidentiality and use of the information I provide, have been explained.

By signing below, I ______________________________ agree to take part in this research study, as conducted by Vincent Mlotha.

____ ______________________

Signature of Participant **Date**

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator,** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator (who has signed a non-disclosure agreement), and this "Consent Form" is available to the participant in a language in which the participant is fluent.

____ ______________________

Signature of Principal Investigator **Date**

Appendix 5 Checklist for focus group discussions (FGDs)

TKAB	**Knowledge, beliefs, attitudes and perceptions towards tilapia**	**TKAB00**
***NOTE**: This checklist should be used to guide focus group discussions on tilapia knowledge, beliefs, attitudes and perceptions among fish consumers towards tilapia fish from different sources in Malawi. The interviews should be conducted with selected fish consumers buying tilapia fish from various sources.*		
TKAB01	**Consumer knowledge on different sources of tilapia on the Malawian market.** *Can you please explain the different types of tilapia and the different sources of tilapia on the Malawian market?*	
TKAB02	**Beliefs, attitudes and perceptions of consumers towards wild and farmed tilapia.** *What are your beliefs, attitudes and perceptions towards wild and farmed tilapia in Malawi?*	
TKAB03	**Beliefs, attitudes and perceptions of tilapia consumers towards imported tilapia.** *What are your beliefs, attitudes and perceptions towards imported tilapia versus indigenous tilapia species in Malawi?*	
TKAB04	**Attitudes and perceptions of consumers towards the quality of wild and farmed tilapia.** *How would you describe the quality (taste, aroma, freshness and safety) of wild tilapia in comparison with farmed tilapia?*	
TKAB05	**Attitudes and perceptions of consumers towards the quality of imported tilapia.** *How would you describe the quality (taste, aroma, freshness and safety) of imported tilapia?*	
TKAB06	**Attitudes and perceptions of consumers towards the price of wild, farmed and imported tilapia.** *What is your opinion on the price of wild, farmed and imported tilapia on the Malawian market?*	

Appendix 6 Questionnaire for consumer survey

TQN	Knowledge, beliefs, attitudes and perceptions towards tilapia	TQN00
***NOTE**: This questionnaire should be used to guide individual interviews on tilapia knowledge, beliefs, attitudes and perceptions among fish consumers towards tilapia fish from different sources in Malawi. The interviews should be conducted with selected fish consumers buying tilapia fish from various sources.*		
TQNA	**Tilapia fish purchase and consumption patterns**	**QNA00**
TQNA01	How frequently do you eat tilapia fish? *1=1-2/week, 2=1-2/month, 3=5-6/year, Never*	[____]
TQNA02	Where do you purchase tilapia fish most of the times? *1=Supermarkets such as Shoprite; 2=MALDECO fisheries shops; 3=Yalelo/Boss fisheries fish outlets; 4=Open market for tilapia fish; 5=Others (specify)____________________*	[____]
TQNA03	What form of tilapia fish do you purchase most of the times? *1=Fresh whole tilapia (never frozen); 2=Frozen whole tilapia; 3=Frozen tilapia fillets; 4=Smoked tilapia; 5=Dried tilapia; 6=Others (Specify)______________________________*	[____]
TQNA04	What type of tilapia do you often purchase in terms of origin (wild or farmed)? *1=Wild tilapia; 2=Farmed tilapia; 3=Both wild and farmed tilapia; 4=Do not know*	[____]
TQNA05	Which tilapia preparation/cooking method do you prefer most? *1=Fried tilapia, 2=Steamed tilapia; 3=Grilled tilapia; 4= Others (Specify)________________*	[____]
TQNB	**Knowledge, beliefs, attitudes, and perceptions towards tilapia**	**TQNB00**
TQNB01	Are you aware of the different sources of tilapia on the market such as from Lake Malawi, from ponds (farmed) and imported tilapia? *1=Yes, 2=No*	[____]
TQNB02	How would you describe the quality (taste, aroma, freshness and safety) of wild tilapia in comparison with farmed tilapia? *1=Wild tilapia is of better quality than farmed tilapia; 2=Farmed tilapia is of better quality than wild tilapia; 3= Botha wild and farmed tilapia are of good quality; 4=There are no differences in the quality of wild and farmed tilapia.*	[____]
TQNB03	How would you describe the quality (taste, aroma, freshness and safety) of imported tilapia? *1=Imported tilapia is of high quality; 2=Imported tilapia is of low quality; 3= Botha imported and local tilapia are of good quality 4=There are no differences in the quality of imported tilapia and local tilapia in Malawi*	[____]
TQNB04	What is your opinion on the price of wild, farmed and imported tilapia on the Malawian market? *1=Wild tilapia is more expensive than the other tilapia; 2=farmed tilapia is more expensive than the other tilapia; 3=Imported tilapia is more expensive than the other tilapia; I don't have any opinion.*	[____]
TQNB05	What is your preference among the tilapia from different sources? *1=Wild tilapia from Malawi; 2=Farmed tilapia from Malawi; 3=Imported tilapia*	[____]
TQN	**Knowledge, beliefs, attitudes and perceptions towards tilapia**	**TQNC00**
TQNC	**Principal socio-economic characteristics of consumers**	**TQNC00**
TQNC01	What is your estimated monthly disposable income (MWK[1])? *1=Less than MWK50,000.00;* *2=MWK50,000.00 - MWK1,000.00;* *3=MWK100,000.00 – MWK250,000.00;* *4=MWK250,000.00 – MWK500,000.00;* *5=MWK500,000.00 - MWK1,000,000.00;* *6=Over MWK1,000,000.00*	[____]
TQNC02	What is your educational level?	[____]

[1] *MWK stands for Malawi Kwacha which is the currency in Malawi. In 2020 the exchange rate between Malawi Kwacha and the United States Dollar was as follows USD 1.00= MWK740.00 (Reserve Bank of Malawi, August 2020).*

TQN	**Knowledge, beliefs, attitudes and perceptions towards tilapia**	**TQN00**
	1=No education; 2=Primary school; 3=Secondary school education; 4=Tertiary education;	
TQNC03	What is your profession? *1=Civil servant; 2=Private sector employee; 3=Business person; 4=Casual labour;* *5=Others (specify)*__________________	[____]
TQNC04	What is the gender of the respondent? *1=Male; 2=Female 3=Not applicable; 4=Prefer not to say*	[____]
TQNC05	What is the age category of the respondent? *1= 18 – 20 years;* *2=21 – 30 years;* *3=31 – 40 years;* *4=41 – 50 years;* *5=51 – 60 years;* *6=61 years and above*	[____]

Appendix 7 Questionnaire for descriptive sensory analysis (DSA)

P1 Project: Sensory characterisation of Tilapia fish

Testing day: 2 of 4 (Session 3; Rep 3)

Judge name:

Date: Wednesday (14 Sep 2022)

AROMA ATTRIBUTES

Carefully open the foil and evaluate the aroma of the sample in the first few sniffs. Score the attributes from top to bottom and do not move back to score previous attributes.

Code: 442

A

ATTRIBUTE	DESCRIPTION OF ATTRIBUTE	SCALE & REFERENCE STANDARDS	Score
Fresh fish aroma	A smell associated with planty, cucumber- and mushroom-like characteristics.	Min=50; Salt water (canned tuna)=65; Max=80; 0 = None; 100 = Prominent	
Cooked fisharoma	A smell associated with steamed fish (i.e., prepared with awet heat cooking method).	Min=50; Max=80; 0 = None; 100 = Prominent	
Sea breeze aroma	A smell associated with saltiness, similar to the smell of thesea.	Min=40; Max=70; Salt water (canned tuna)=75; 0 = None; 100 = Prominent	
Earthy aroma	A smell associated with woody or fertile soil; similar to thesmell of wet, brown soil after rain (positive attribute).	Min=20; Max=60; Borneol; 0 = None; 100 = Prominent	
Buttery aroma	A smell associated with melted butter (a dairy product madefrom the fat and protein components of churned cream of milk derived from cow's milk).	Min=20; Max=60; Melted butter=85; 0 = None; 100 = Prominent	
Sweet-associated aroma	A smell associated with the outside browned edges ofroasted red meat.	Min=10; Max=50; 0 = None; 100 = Prominent	

Metallic aroma	A smell associated with slightly oxidised metals, such as iron, copper, and silver spoon or associated with raw meat (blood-like).		
Musty/ Mouldy aroma	A smell associated with a mould and the overall impression of dampness.		
Green aroma	A smell associated with leaf trimmings, a mowed lawn, or crushed green leaves.		
Oxidised/ Rancid flavour	A smell associated with rancid or reused oil; sometimes described as sharp or painty.		

P2

Project:	Sensory characterisation of Tilapia fish	
		Testing day: 2 of 4 (Session 3; Rep 3)
Judge name:		Date: Wednesday (14 Sep 2022)

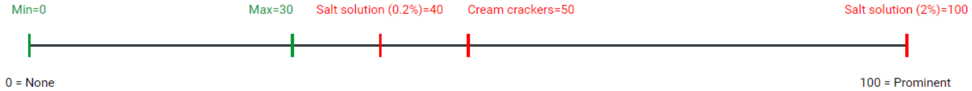
PALATE ATTRIBUTES

Carefully open the foil and remove a thumb-sized piece of the sample. Place the sample in the mouth and evaluate the palate attributes within the first few chews (no retasting). Score the attributes from top to bottom and do not move back to score previous attributes.

Code: 442

P

ATTRIBUTE	DESCRIPTION OF ATTRIBUTE	SCALE & REFERENCE STANDARDS	SCORE
Fresh fish flavour	A flavour associated with planty, cucumber- and mushroom-like characteristics.	Min=50 Max=70 0 = None 100 = Prominent	
Cooked fish flavour	A flavour associated with steamed fish (i.e., prepared with a wet heat cooking method).	Min=50 Max=80 0 = None 100 = Prominent	
Earthy flavour	A flavour associated with woody or fertile soil; similar to the smell of wet, brown soil after rain (positive attribute).	Min=10 Max=60 0 = None 100 = Prominent	
Buttery flavour	A flavour associated with melted butter (a dairy product made from the fat and protein components of churned cream of milk derived from cow's milk).	Min=10 Max=50 0 = None 100 = Prominent	
Sweet-associated flavour	A flavour associated with the outside browned edges of roasted red meat.	Min=10 Max=30 0 = None 100 = Prominent	
Metallic flavour	A flavour associated with slightly oxidised metals, such as iron, copper, and silver spoon or associated with raw meat (blood-like).	Min=0 Max=25 0 = None 100 = Prominent	
Salty taste	A fundamental taste sensation associated with salt or sodium.		

			
Musty/ Mouldy flavour	A flavour associated with mould and the overall impression of dampness (negative attribute).		
Green flavour	A flavour associated with leaf trimmings, a mowed lawn, or crushed green leaves.		
Oxidised/ Rancid flavour	A flavour associated with rancid or reused oil; sometimes described as sharp or painty.		

P3 Project: Sensory characterisation of Tilapia fish

Testing day: 2 of 4 (Session 3; Rep 3)

Judge name:

Date: Wednesday (14 Sep 2022)

TEXTURE ATTRIBUTES
Carefully open the foil and remove a thumb-sized piece of the sample. Place the sample in the mouth and evaluate the texture attributes within the first few chews (no retasting). Score the attributes from top to bottom and do not move back to score previous attributes.

Code: 442

	ATTRIBUTE	DESCRIPTION OF ATTRIBUTE	SCALE & REFERENCE STANDARDS	SCORE
TEXTURE	Juiciness 0=dry 100=very juicy	Amount of water released during chewing (evaluated in the first 5 chews)	Min=40 Max=70 0 = Dry — 100 = Very juicy	
	Firmness 0=very soft 100=very firm	The perception of moderate resistance when force is applied in the mouth or by touch.	Catfish=25 Min=30 Max=60 Chicken breast meat=70 0 = Very soft — 100 = Very firm	
	Pasty texture 0=none 100=very pasty	The perception of the product which sticks together like paste in the mouth when mixed with saliva; sticks to the teeth during chewing (similar to the texture of the yellow from a hard-boiled egg).	Min=10 Max=40 0 = None — 100 = Very pasty	
	Mushy texture 0=none 100=very mushy	A texture which is soft, thick, with a pulpy consistency.	Min=0 Max=30 0 = None — 100 = Very mushy	
	Gelatinous texture 0=none 100=prominent	A thick, viscous, semi-solid, slimy, of slippery texture.	0 = None — 100 = Prominent	
	Mouth coating 0=none 100=prominent	The perception of a film in the mouth.	Min=0 Max=25 0 = None — 100 = Prominent	