Original Research Article

Assessment of Food Safety Practices, Associated Factors and Microbial Contamination of Fried Nile Perch in Mwanza City Markets: A Cross-Sectional Study

ABSTRACT

Fish and fishery products might be contaminated with food-borne pathogens due to unsatisfactory hygienic practices, poor handling, and improper storage after the fish are harvested. This study assessed the food safety practices, their associated factors, and microbial contamination levels of fried Nile Perch in Mwanza City across three markets: Kirumba, Butimba, and Nyakato. A cross-sectional study using a structured questionnaire examined the food safety practices of traders and processors, and their associated factors including experience, income, and training. Standard methods for Microbial analysis were conducted to determinethe levels of Coliforms, *Escherichia coli*, and *Staphylococcus aureus*. SPSS version 27 was used to compute the frequency and percentages. The factors and behaviors of fried Nile perch processors and traders were assessed using a 95% chi-square test. R-software was employed to perform the Aligned Rank Transformation on market microbiological mean contamination. Tukey's Honest Significant Difference was employed for post hoc group comparisons. The results show that temperature control during transportation showed a significant association ($X^2 = 6.153$, $p = 0.046$), with most processors transporting raw materials at ambient temperatures. Moreover, tap water was the primary water source across the Butimba (88.9%), Kirumba (90%), and Nyakato (100%) markets. Moreover, hand-washing facilities were inadequate in Butimba (55.6%) and Nyakato (64.3%). Income was significantly associated ($X^2 = 16.201$, $p = 0.013$) with a clear separation between storage and processing areas, while training was linked ($X^2 = 6.032$, $p = 0.014$) to temperature control. Microbial analysis showed that fried fish from all markets exceeded safe limits of assessed microorganisms, with Nyakato having the highest levels of total plate count (9.53 log CFU/g), coliforms (8.74 log CFU/g), and *S. aureus* (5.51 log CFU/g). Contamination levels differed significantly between markets ($p<0.05$), despite similar activities across locations.To reduce microbial contamination, consumers must reheat fried Nile perch before consumption. The government should support operators by providing formal training on food safety and environmental hygiene, enabling them to adhere to safety standards.

Keywords: *Fried Nile perch, Food safetypractices,factors influencing practices, Microbial contamination*

1.0. INTRODUCTION

The fishery sector in Tanzania contributes to the economy in terms of income, food security, employment, and livelihood security [1]. Its contribution to the Gross Domestic Product is approximately 1.7% per annum and has been growing at an average of 1.5% [2]. However, despite the sector's importance, Tanzania's per capita fish consumption remains significantly lower than the global average. According to the Food and Agriculture Organization [3], the global per capita fish consumption is 20.5 kg per person per year. In contrast, in Tanzania, it is only 8.5 kg per person annually. Nevertheless, fish accounts for approximately 19.7% of the country's animal protein intake. Moreover, although fish has high nutritional value, pH close to neutral, and high water activity, it is very susceptible to spoilage [4]. It contains proteins and nutrients that are favorable for microbial attack even after processing [5]. Various fish preservation techniques have been used to improve microbial safety and extend its shelf life, such as freezing, chemical preservation, salting, smoking, frying, and filleting [6].

Fish and fishery products might be contaminated with food-borne pathogens due to unsatisfactory hygienic practices, poor handling, and improper storage practices after the fish are harvested [7]. Roughly 10 to 20% of foodborne illnesses are caused by food handlers, either by mishandling food or their poor personal hygiene[8]. Approximately 600 million people worldwide suffer from foodborne diseases each year, leading to 480,000 deaths, with the majority of cases occurring in low- and middle-income countries [9]. Additionally, around 91 million people fall ill annually in Africa due to unsafe food consumption [10]. Several microorganisms, such as coliforms, *Escherichia coli*, and *Staphylococcus aureus*, contribute to the burden of foodborne diseases. *S. aureus* is a significant global concern, as it can be found in respiratory passages, skin, and superficial human wounds[11]. It is one of the pathogenic microorganisms that pose a significant public health risk [12]. Another pathogenic microorganism that can cause fish-borne diseases is *E. coli*. The occurrence of this bacterium in food is directly related to fecal contamination and suggests poor hygienic conditions [12]. Non-compliance with the requirements of Good Hygienic Practices (GHPs) is the main reason behind foodborne diseases worldwide[8].

Tanzania is home to multiple fish species, but the Nile Perch (*Lates niloticus*) dominates the landing volume in Lake Victoria [13].Deep frying is one of the most common methods for Nile Perch processing post-harvest in the Mwanza region. It is a preferred method since it improves fish's palatability and overall sensory quality; hence, most people purchase fried fish products, including Nile Perch. Moreover, consumers opt to buy fried fish because of their convenience and taste while not considering their quality, safety, and hygiene.[11] explained that contamination of ready-to-eat fish products, such as fried fish, comes in many ways, such as contamination from handlers with infected skin lesions and poor hand and nail hygiene on the ready-to-eat fish products that are usually eaten without further processing. Additionally, most fried fish processors and traders have limited knowledge of food hygiene and often operate in non-hygienically designed facilities. Despite the efforts taken by the

Tanzanian government to control and assure food safety, foodborne diseases are repeated. Several food-borne outbreaks have been recorded in Mwanza City in 2023-2024, where consumers prefer eating deep-fried fish products.

Various research activities have been conducted in the Mwanza region to analyze the microbial quality of Nile Perchin salted and sun-dried nature [14], [15].Another study analyzed the handling practices of sun-dried Nile Perch fish processors in Lake Victoria and the possible microbial contaminants[16]. Moreover, in other African countries like Egypt, the microbial quality of dried fish products has been well-studied with the associated handling practices[17]–[19].

Nevertheless, there is limited information on studies assessing Nile perch processors and traders' hygienic handling practices and associated factors. To the best of our knowledge, the pathogenic load of fried Nile Perch is also undocumented. The small fried fish processors are the primary providers of Nile Perch to the low and medium-income consumers in the Mwanza region. Furthermore, most people consume fried Nile Perch at the point of sale or in their homes without further processing. Therefore, this study aims to fill these information gaps.The findings of this study will benefit consumers, small-scale operators, researchers, food control authorities, and policymakersin setting strategies for improving the handling practices to reduce food safety risks along the fish value chain.

2.0. MATERIALS AND METHODS

2.1 Study area

This study was conducted in the Mwanza region of Tanzania. The area is known for its large-scale production of Nile Perch and hosts numerous fish-frying processing and trading operations. Several prominent retail fish markets, including Kirumba, Butimba, and Nyakato, were selected for this study. The Kirumba market is located near the lake and comprises processors with better infrastructures, although traders in this market sell their fishery products alongside the road during the evening. Similarly, the Butimba market is located alongside the lake but runs on a seasonal basis; it works primarily when fishing activities around the lake are in progress. Fried fish traders in this market sell fish mainly in open areas, especially in the evening. Nyakato market is the farthest from the lake and is not well designed in terms of infrastructure; within this market, processors and traders are scattered and sell fried fish mainly in the evening hours.

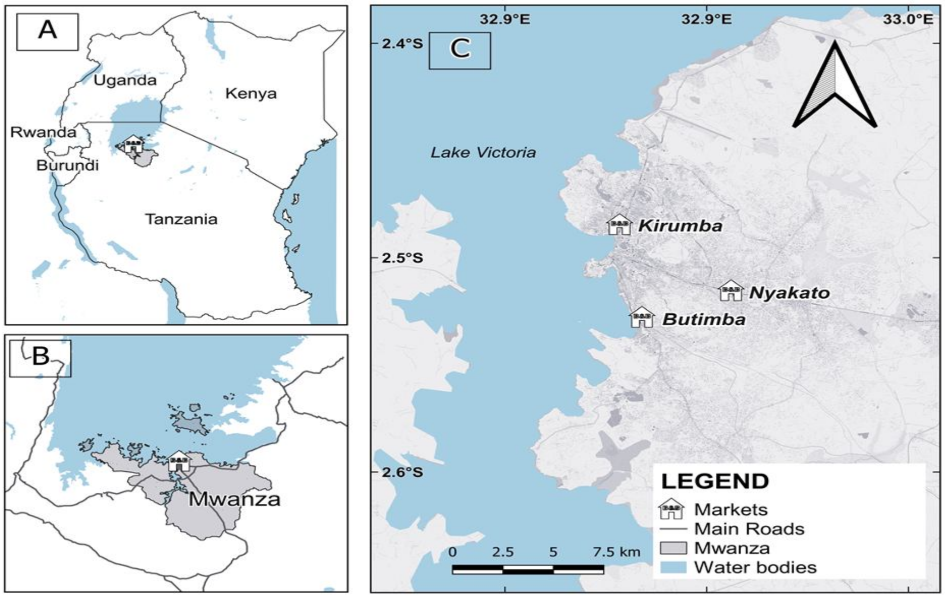

Fig. 1: A map showing the location of study sites

2.2. Research design

A cross-sectionalstudywas used to assess the socio-demographic factors, food safety knowledge, working environment characteristics, and food hygiene practices of fried Nile perch processors and traders. Moreover, fried Nile Perch fish samples were transported to the National Fish Quality Control Laboratory (NFQCL) at Nyegezi, Mwanza,for microbial analysis.

2.3. Study population

A purposive sampling method was adopted to ensure that only fish-frying operators and traders operating in these markets were included in the study. The total number of respondents who participated was 100, including 37 from Kirumba, 30 from Butimba, and 33 from Nyakato.

2.3.1. Inclusion and exclusion criteria

All fried Nile Perch fish processors and traders who gave their consent were included in this study and those working during the study period. However, those who were absent on the day of data collection, who fried sardines and fish at the same time, and those who did not give their consent were excluded from the study.

2.4. Data collection tool

A pre-tested structured questionnaire of socio-demographic factors, food safety knowledge, working environment characteristics, and food hygiene practices were employed to collect data via face-to-face interviews and observation among fried Nile perch traders and processors in the respective markets. The questionnaire was designed from good manufacturing practices and good hygienic practices requirements by reviewing the literature. Food safety professionals were recruited as data collectors.

2.5. Fish sampling

A simple random sampling method was employed to collect 5 fried Nile perch fish from processors and 5 fried fish from traders for microbial analysis from each market. The samples were carefully handled, packed in pre-sterilized polyethylene plastic bags, well-labeled, and transported to the National Fish Quality Control Laboratory (NFQCL) for further examination. The samples were stored at a refrigeration temperature of 4 before analysis. The microbial analysis included total Plate Count (TPC), total Coliforms (TC), *E. coli*, and *S. aureus*.

2.6. Microbial analysis

2.6.1. Sample preparation

A 25-gram portion of each fried Nile perch sample was randomly cut from various parts and placed into a jar containing 225 ml of Buffered Peptone Water (BPW). The mixture was shaken in the stomacher for one minute to obtain the initial suspension of 10^{-1} of the test portions. One ml of the sample solution was aseptically transferred from the initial suspension (10^{-1}) to a 9 nine ml BPW test tube to make the second dilution (10^{-2}). A similar procedure was repeated until the tenth dilution (10^{-10}).

2.6.2. Total Plate Count

Ten to fifteen ml (10-15ml) of molten PCA maintained at 45 were poured on a petri dish and left to solidify. One ml(1 ml) of each dilution was inoculated in duplicate onto Petri dishes containing Plate Count Agar (PCA) and incubated invertedly at 37°C for 24 hours. If results were not visible after the initial incubation period, the plates underwent an additional 24 hours at incubation temperature until microbial growth was observed. Following incubation, the plates were collected for colony counting, whereby Petri dishes with only 30-300 colonies were counted. A digital colony counter was utilized to enumerate the colonies formed post-incubation, facilitating accurate calculations. This was conducted according to[20]. The countable colonies were converted into the weighted mean colony forming units per gram (CFU/g) using a formula;

$$\text{No. of bacteria in CFU/g} = \frac{\text{number of colonies x reciprocal of dilution factor}}{\text{inoculum size(ml)}}$$

2.6.3. Total Coliforms

For the enumeration of total coliforms, the ISO 4832:2006, (2018)[21]standard method was followed. A 1 ml aliquot of the serially diluted sample was inoculated into labeled test tubes containing MacConkey broth of the first to the tenth dilution in triplicateand incubated at 37°C for 48 hours. For confirmation, a portion of the positive tubes, those exhibiting gas or acid productionwere transferred to EC broth, which was then incubated at 44°C for an additional 48 hours to differentiate coliforms from other bacteria. After incubation, the number of positive tubes was recorded, and the Most Probable Number (MPN) table was used to estimate the total number of coliforms per gram of the original sample.

2.6.4. S. aureus

The [22]method for the enumeration of coagulase-positive staphylococci (*S. aureus* and other species) was followed for the enumeration of *S. aureus*. From the serially diluted samples, 0.1 ml of each dilution was inoculated onto the surface of Baird-Parker Agar plates using the spread plate method in duplicate. The inoculum was spread over the surface using a sterile spreader and then allowed to settle for 15 minutes. The inverted petri dishes were then incubated at 37°C for 48±2 hours. Following incubation, the petri dishes were examined for typical *S. aureus* colonies, which appear as black or gray colonies, and these were counted.For confirmation, a representative number of typical colonies were subcultured into the Brain Heart Infusion (BHI) broth and incubated at 37±1□ for 24±2 hours to verify the presence of coagulase-positive staphylococci. Subsequently, 0.1ml of each culture was transferred to 0.3ml of dehydrated rabbit plasma in hemolysis tubes and incubated at 37±1□ for 24±2 hours. Coagulase testing was performed on the isolated colonies to confirm the presence of *S. aureus*. Finally, the number of coagulase-positive staphylococci per gram of the original sample was calculated based on the colony counts. After positive confirmation, two consecutive plates with 15-150 colonies were considered for record.The countable colonies were converted into the weighted mean colony forming units per gram (CFU/g) using a formula;

$$\text{No. of bacteria in CFU/g} = \frac{\text{number of colonies x reciprocal of dilution factor}}{\text{inocilum size(ml)}}$$

2.6.5. E. coli

The enumeration of *E. coli* was performed according to[23]. EC broth was prepared and distributed into 10 test tubes in duplicate. A one ml sample was inoculated into the first test tube, followed by a serial dilution up to the 10th dilution. The test tubes were incubated at 44°C for 24 hours. Post-incubation, turbidity, and gas formation were observed, with gas presence indicating a positive result for coliforms. For confirmation, a loopful of the turbid EC broth was streaked onto Try-Covax agar and incubated at 44°C for 24 hours. After incubation, the Try-Covax agar plates were inspected for specific colony morphology. The most probable number (MPN) tables were then utilized to estimate the total number of *Escherichia coli* microorganisms in the samples.

2.7. Data analysis

Data were collected using a Qualtrics online survey tool and then entered in Microsoft Excel for data coding and cleaning. Frequencies, percentages, and chi-square tests were computed by SPSS VERSION 27 at a 95% significance level.The microbial counts were transformed to $\log_{10}$CFU/g to establish the statistical significance of microbial loads in different samples. Microbial data was tested for normality using the Shapiro-Wilk normality test and revealed that our data groups were not normal. Therefore, using the R software version 4.3.3 (R Core Team, 2024), Aligned Rank TransformationAnalysis of Variance (ANOVA) was employed to check the significant differences in total Plate count, and total coliform contamination, *E. coli*, and *S. aureus*from the three markets for processors and traders. Furthermore, a post hoc comparison based on Tukey's Honest Significant Difference was performed to test the significance difference of each data group across the three markets.

3. RESULTS

3.1.Socio-demographic characteristics

The results for demographic characteristics of fried fish processors and traders in the Mwanza region are presented in Table 1.Findings show that most of the fried Nile perch processors were female, comprising 92% of the respondents. Women are more engaged in street food vending as they depend on it as family income amid a harsh economy. This gender distribution aligns with traditional roles where women are typically responsible for cooking food for the family, making them more likely to engage in food vending activities than men[24].

Table 1.Demographic characteristics of fried fish processors and traders in the Mwanza region

Variable	Categories	Freq N=100	Percent (%)
Activity in the fish value chain	Fried fish processing	52	52.00
	Fried fish trading	48	48.00
Age-group	18-35	51	52.60
	36-45	29	29.90
	46-59	13	13.40
	60 and above	4	4.10
Daily income	1000-20000	65	65.00
	21000-50000	25	25.00
	51000-100000	8	8.00
	Above 100000	2	2.00
Education level	Primary education (classes 1 to 7)	54	55.10
	Secondary education	33	33.70
	College degree	1	1.00
	I have never been to school	10	10.20
Gender	Male	8	8.00
	Female	92	92.00
Markets	Kirumba	37	37.00
	Butimba	30	30.00
	Nyakato	33	33.00
Years of experience	1-5	59	60.20
	6-15	30	30.60
	16-25	7	7.10
	26-30	2	2.00

Moreover, about 52.6% of the respondents were youth (18-35 years), demonstrating how frying and selling Nile perch provides significant employment opportunities for youth.This is also attributed to limited employment opportunities in the country. Additionally, most respondents (55.1%) completed their primary education, while about 10% never attended school.This situationrenders them unqualified for many available jobs. Consequently, many rely on their small food businesses to survive the harsh economic conditions, as reported by [25]in Kenya.Furthermore, most respondents (60.2%) had less than five years of experience in the business. This may be because most of them are youth.Regarding daily income, approximately 65% of the respondents earned less than 20,000 TZS, whereas about 2% earned more than 100,000 TZS.The generated income from fish sales depends on several factors, including the number of hours spent selling, the quantity of fish sold, and the frequency of workdays[25]. Generally, this demographic data underscores the significant involvement of young adults and women in the fish value chain activities within the surveyed markets.Research has highlighted a link between socioeconomic factors and food safety whereby low-income and minority populations demonstrate a higher susceptibility to food-borne illnesses. For example, a study in Ethiopia indicated a correlation between higher income, access to clean water and sanitation facilities, and improved food safety practices [26].

3.2.Food Safety Practices of Nile Perch processors and traders

Food safety practices encompass a comprehensive set of guidelines and procedures designed to prevent foodborne illnesses and ensure safe food for consumption. These practices include personal hygiene, cleaning and sanitation, proper storage of food products, temperature control, waste management, and hygiene of food handlers.Table 2 presents the findings of the different food safety practices employed by fried Nile perch processors in the Butimba, Kirumba, and Nyakato markets.

Table 2.Food safety practices of fried Nile perch processors of Butimba, Kirumba, and Nyakato markets, in Mwanza City.

Variables	Categories	Butimba N (%)	Kirumba N (%)	Nyakato N (%)	Chi-square	P-value
Cleaning of food premises	Any time of convenience	12(66.7)	8(40)	8(57.1)	4.776	0.311
	Daily	6(33.3)	10(50)	4(28.6)		
	Weekly	0(0)	2(10)	2(14.3)		
Cleaning procedures	Sweeping only	17(94.4)	9(45)	13(92.9)	15.611	0
	Sweeping and moping	1(5.6)	11(55)	1(7.1)		
Temperature of water used when washing utensils	Ambient	6(33.3)	12(60.0)	10(71.4)	8.437	0.081
	Warm	10(55.6)	4(20)	2(14.3)		
	Any	2(11.1)	4(20)	2(14.3)		
Is the water used treated?	Yes	3(16.7)	1(5)	4(28.6)	5.104	0.277
	No	13(72.2)	16(80)	10(71.4)		

	Don't know	2(11.1)	3(15)	0(0.0)		
Temperature of raw material transport	Ambient temperature	14(77.8)	20(100)	10(71.4)	6.153	0.046
	Cold temperature	4(22.2)	0(0)	4(28.6)		
Temperature of storing fried fish	Ambient temperature	15(83.3)	17(85)	14 (100)	2.525	0.283
	Cold temperature	3(16.7)	3(15)	0(0)		
Clear separation between storage and processing areas	Yes	0(0.0)	2(10)	0(0)	10.821	0.029
	No	9(50)	11(55)	2(14.3)		
	Not applicable	9(50)	7(35)	12(85.7)		
Storage of raw fish and fried fish	In separate rooms	2(11.1)	4(20.0)	1(7.1)	4.972	0.29
	In the same room space	0(0.0)	2(10)	0(0.0)		
	Not applicable	16(88.9)	14(70)	13(92.9)		

The data in Table 2 indicate that the majority of fried Nile perch processors from Butimba (66.7%) and Nyakato (57.1%) marketplaces clean their food premises at their convenience, although a notable proportion of Kirumba processors clean every day (50%). This illustrates a dedication to preserving a hygienic environment during frying procedures. The predominant cleaning method employed by processors in the Butimba (94.4%) and Nyakato (92.9%) markets is sweeping. On the other hand, processors from the Kirumba market (55%) reported cleaning their food premises by sweeping and mopping (Table 2). This is attributed to the more organized and established infrastructure of part of the Kirumba market, which facilitates mopping activities. These findings underscore the variations in cleaning practices across different markets and highlight the need for improved sanitation measures. Additionally, there was a significant association ($X2 = 6.153, p = 0.046$) between the temperature of transporting raw materials between markets.Some processors in Butimba (22.8%) and Nyakato (28.6%) transport raw fish at cold temperatures while the other majority transports at ambient temperature conditions like in the Kirumba market (100%). Similarly, ambient temperature conditions are applied in storing fried fish across all markets. There was also a significant association ($X^2 = 10.821, p = 0.029$) of clear separation between storage and processing areas between markets (Table 2).Most processors from the Kirumba market (55%) did not have a clear separation between markets, while those from the Nyakato market (85.7%) didn't fry fish at establishments hence the clear separation between storage and processing areas was not applicable. Additionally, houseflies were identified as the most common pests encountered by most (93.4%) of fried Nile Perch traders and processors across all markets.

Respondents engaged in the processing and sale of fried Nile perch at the Butimba, Kirumba, and Nyakato marketplaces employed diverse food safety practices, as illustrated in Table 3.

Table 3. Food safety practices of fried Nile Perch processors and traders of Butimba, Kirumba, and Nyakato markets, in Mwanza City.

Variables	Activity	Categories	Butimba N (%)	Kirumba N (%)	Nyakato N(%)	Chi-square	P-value
Any measures taken to control pest infestation?	Processors	Yes	7(38.9)	12(60)	6(42.9)	1.9	0.387
		No	11(61.1)	8(40)	8(57.1)		
	Traders	Yes	3 (25)	11(64.7)	10 (52.6)	4.523	0.104
		No	9(75)	6(35.3)	9(47.4)		
Do you cover hair during processing or trading?	Processors	Yes	9(50)	15(75)	8(57.1)	2.658	0.265
		No	9(50)	5(25)	6(42.9)		
	Traders	Yes	5(41.7)	8(47.1)	8(42.1)	0.118	0.943
		No	7(58.3)	9(52.9)	11(57.9)		
Clothes worn during processing or trading	Processors	A clean apron	7(38.9)	11(55)	1(7.1)	13.61	0.009
		An unclean apron	1(5.6)	3(15)	0(0.0)		
		Home clothes	10(55.6)	6(30)	13(92.9)		
	Traders	A clean apron	1(8.3)	1(5.9)	2(10.5)	0.253	0.881
		An unclean apron	0(0)	0(0)	0(0)		
		Home clothes	11(91.7)	16(94.1)	17(89.5)		
What happens when one is sick?	Processors	Continue with work if the condition is not worse	5(27.8)	5(25)	4(28.6)	4.533	0.339
		Go to the hospital for a checkup and medication	0(0.0)	4(20)	3(21.4)		
		Take a day off until I feel better	13(72.2)	11(55)	7(50)		
	Trader	Continue with work if the condition is not worse	6(50)	7(42.1)	2(10.5)	7.126	0.129
		Go to the hospital for a checkup and medication	2(16.7)	5(29.4)	9(47.4)		
		Take a day off until I feel better	4(33.3)	5(29.4)	8(42.1)		
Type of waste generated by the facility	Processors	Hard waste	6(33.3)	3(15)	2(14.3)	2.451	0.294
		Soft waste	12(66.7)	17(85)	12(85.7)		
		Not applicable	0(0)	0(0)	0(0)		
	Trader	Hard waste	7(58.3)	13(76.5)	13(68.4)	13.99	0.007
		Soft waste	5(41.7)	0(0.0)	6(31.6)		
		Not applicable	0(0.0)	4(23.5)	0(0.)		
Different waste disposal containers for soft and hard waste	Processor	No	17(94.4)	19(95)	14(100)	0.774	0.679
	Trader	Yes	1(5.6)	1(5)	0(0.0)		
		No	12(100)	17(100)	18(94.7)	1.559	0.459
		Yes	0(0.0)	0(0.0)	1(5.3)		
Frequency of cleaning the waste	Processor	At any time of convenience	12(66.7)	8(40)	8(57.1)	4.776	0.311

disposal containers		Daily	6(33.3)	10(50)	4(28.6)		
		Weekly	0(0)	2(10)	2(14.3)		
	Trader	At any time of convenience	10(83.3)	14(82.4)	7(36.8)	10.774)	0.029
		Daily	1(8.3)	1(5.9)	6(31.6)		
		Weekly	1(8.3)	2(11.8)	6(31.6)		
Frequency of hand washing	Processor	Anytime	11(61.1)	10(50)	2(14.3)	19.839	0.003
		Before and after working	2(11.1)	6(30)	12(85.7)		
		Before working	4(22.2)	3(15)	0(0.0)		
		I don't	1(5.6)	1(5)	0(0)		
	Traders	Anytime	2(16.7)	5(29.4)	3(15.8)	11.641	0.007
		Before and after working	7(58.3)	2(11.8)	7(36.8)		
		Before working	1(8.3)	5(29.4)	8(42.1)		
		I don't	2(16.7)	5(29.4)	1(5.3)		
Water used	Processor	Tap water	16(88.9)	18(90)	14(100)	1.613	0.806
		Tap/Lake water	1(5.6)	1(5)	0(0)		
		Tap/rain	1(5.6)	1(5)	0(0)		
	Traders	Tap	12(100)	17(100)	19(100)		
Is the surrounding environment suitable?	Processors	No	10(55.6)	8(40)	14(100)	17.333	0.002
		Yes	8(44.4)	12(60)	0(0)		
	Trader	No	12(100)	17(100)	19(100)		
Adequate means for washing hands (Soap and water)	Processor	No	10(55.6)	9(45)	9(64.3)	1.256	0.531
		Yes	9(44.4)	11(55)	5(35.7)		
	Traders	No	12(100)	17(100)	19(100)		

The results in Table 3 show that overall, the processors from Kirumba have been portraying satisfactory food-safety practices. Pest control is a pre-requisite program and is one of the essential requirements for good hygienic practices (GHPs) in food establishments [27]. About 60% and 64.7% of processors and traders from the Kirumba market respectively take necessary measures to control pest infestation. These include cleaning tables with soap and water, chasing away pests with newspaper items, and using impenetrable surfaces. Tap water was the main means of water used by processors across all markets; Butimba (88.9%), Kirumba (90%), and Nyakato (100%). Interestingly, most respondents (83%) are unaware of biological treatments to preserve the water's microbial quality, while some (17%) reported that water is treated with chlorine-based products. Additionally, some processors from the Butimba and Kirumba markets reported using lake water in processing, depending on their convenience. This may be attributed to the fact that these markets are located closer to Lake Victoria, therefore in the absence of tap water, processors can easily use lake water for processing and washing utensils. This is alarming due to the high levels of waste deposited in the lake that could contaminate fish products. Equally important, Table 3 indicates a significant association between the type of clothing worn by processors and market variations (X^2 = 13.61, p = 0.009). Approximately 92.2% of Nyakato processors and 55.6% of Butimba processors wear home attire, whereas 55% of Kirumba processors wear a clean apron during processing. Correspondingly, there are inadequate means for washing hands at Butimba (55.6%) and Nyakato market (64.3%), but 55% of the establishments in Kirumba have means for hand washing. Comparatively, about 50% of traders from Butimba and 42.1% from the Nyakato market continue with work even when sick, and when suffering from disorders like diarrhea and flu. Moreover, there was a significant association (X^2 = 19.839, p = 0.003) between the hand-washing practices of processors in the three markets. Although most fish fryers from Nyakato market claimed to wash their hands before and after working (85.7%), those from Butimba (61.1%) and Kirumba (50%) washed their hands at any time of convenience. This may be due to the absence of adequate hand-washing facilities at their premises and the surrounding environment as well. The main kind of waste from processors is soft waste while traders generate solid waste as shown in Table 3. Solid wastes mainly consisted of paper, magazines, and plastic debris, whereas soft wastes include food scraps, dirty water from cleaning operations, and fish preparation for frying. Interestingly, both processors and traders do not have different containers for the disposal of soft and hard wastes and the cleaning of waste disposal containers is mainly done at any time of convenience. There was also a significant association (X^2 = 17.333, p = 0.002) between the working environment across markets as highlighted in Table 3. Most processors from Butimba (55.6%) and Nyakato (100%) had poor working environment conditions, while a significant number of processors from the Kirumba market (60%) had good working environmental conditions.

Additionally, there was a significant difference between different common behaviors across markets (p=0.001), where talking, chewing, and scratching of body parts were the main practices (figure 2). Vividly, processors from Kirumba market reported talking as the most common behavior, while chewing, eating, and talking were more practiced by Nyakato traders. These are unacceptable as they may contaminate fried fish products with harmful pathogenic microorganisms, including S. aureus.

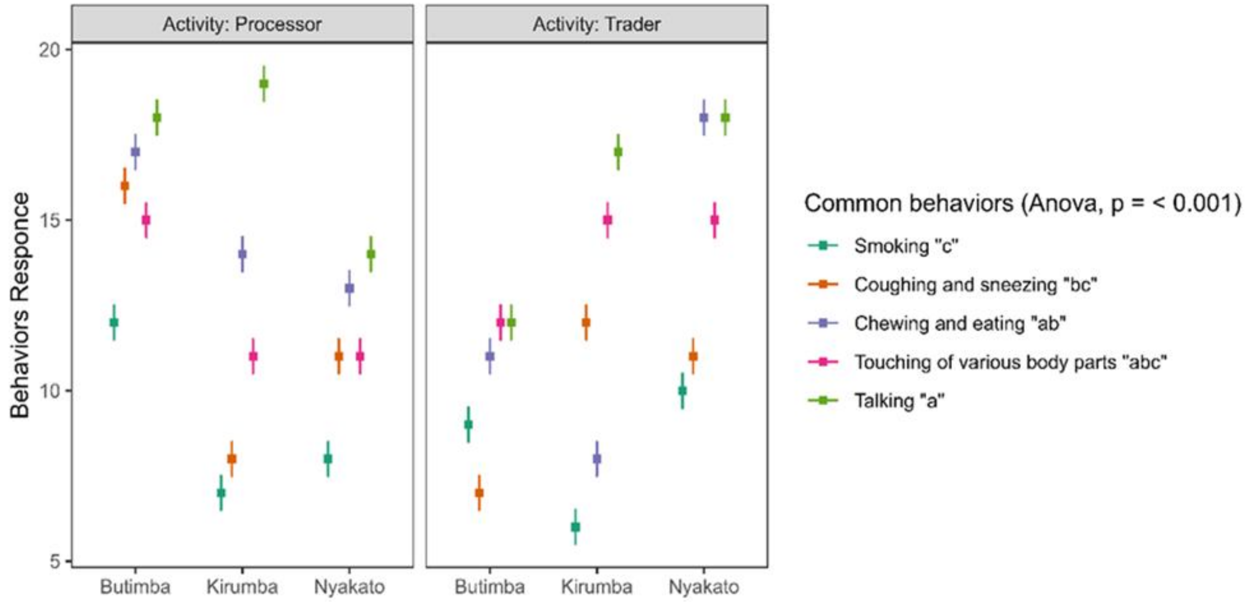

Fig 2.Common behaviors of Nile perch processors and traders in Mwanza markets

3.3.Factors associated with various food safety practices

A chi-square test analysis showed the association of several factors such as income, training, inspection, education level, experience, number of employees, inspection, and the presence of enough facilities as determinants of several hygienic practices by fried Nile perch vendors and processors (Table 4).

Table 4: Association between determinants of various hygienic practices of fried fish processors and traders

Activity	Factors	Practices	Chi-square	P-value
Processors and Traders	Training	Temperature of raw material transport	6.032	0.014
	Inspection	Temperature of storage of fried fish	12.041	0.002
	Education level	Different waste disposal containers for soft and hard waste	9.403	0.024
	Experience	What clothes do you wear during processing?	26.115	0.025
	No of employees	What clothes do you wear during processing?	23.085	0.002
	Enough facilities to implement GHP's	Do you take any measures to control pest infestation	6.829	0.009
		Frequency of cleaning the waste disposal containers	9.107	0.011

The results in Table 4 indicate that several factors were significantly associated with various hygienic practices. For instance, income was directly associated with a clear separation between storage and processing areas(X^2 = 16.201, p = 0.013) while training was associated with the temperature of raw materials transportation (X^2 = 6.032, p = 0.014). Inspection was associated with the storage temperature of fried fish (X^2 = 12.041, p = 0.002). Furthermore, education level was directlyassociated withthe availability of different waste disposal containers for soft and hard wastes (X^2 = 9.403, p = 0.024). The experience was associated with clothes worn during processing or trading(X^2 = 26.115, p = 0.025).

3.4.Microbial contaminants in fried Nile perch sold in Mwanza City retail markets

The total plate count (TPC), coliforms, *E. coli*, and *S. aureus* levels in fried Nile perch found in the retail markets of Mwanza City are detailed in Table 5. Findings show a significant difference (p<0.001) in markets on the levels of assessed microorganisms. Nonetheless, the levels of microbiological contamination (TPC, coliforms, *E. coli*, and *S. aureus*) exhibited no significant differences (p>0.05) between Nile Perch processors and traders across various markets.

Table 5. Showing the mean total count of pathogenic microorganisms in fried Nile Perch

Variable Activity	Market	TPC Mean ± sd	Coliforms Mean ± sd	*E. coli* Mean ± sd	*S. aureus* Mean ± sd
Processors	Butimba	7.79 ± 1.51^{ab}	6.62 ± 1.19^{b}	3.76 ± 0.28^{a}	1.63 ± 2.24^{d}
	Kirumba	6.93 ± 0.16^{b}	2.83 ± 0.44^{c}	0.99 ± 1.14^{b}	3.25 ± 1.82^{c}
	Nyakato	9.53 ± 0.52^{a}	8.64 ± 0.79^{a}	1.01 ± 1.19^{b}	4.57 ± 0.05^{b}
Traders	Butimba	6.88 ± 0.51^{b}	6.25 ± 1.22^{b}	3.74 ± 0.17^{a}	4.57 ± 0.02^{b}
	Kirumba	6.90 ± 0.48^{b}	3.15 ± 0.00^{c}	2.04 ± 1.42^{b}	5.52 ± 0.05^{a}
	Nyakato	8.79 ± 1.04^{a}	8.74 ± 0.59^{a}	2.06 ± 1.44^{b}	5.51 ± 0.08^{a}

Means with similar superscripts are not significantly different (p>0.05), while those with different superscripts are significantly different (p<0.05)

The Nyakato market had the highest TPC contamination for traders (8.79±1.04 log CFU/g) and processors (9.53±0.52 log CFU/g). Moreover, high coliform contamination was observed in the Nyakato market with the highest mean of 8.64±0.79 log CFU/g and 8.74±0.59 log CFU/g for processors and traders, respectively. The fried fish samples from Butimba market were highly contaminated with *E. coli*, the level of contamination being significantly higher (p<0.05) than other markets, measuring 3.76±0.28 log CFU/g and 3.74±0.17 log CFU/g for processors and traders, respectively. Furthermore, Nyakato and Kirumba markets had the highest mean levels of S. aureus contamination at 5.51±0.08 log CFU/g and 5.52±0.05 log CFU/g, respectively, but these values were not statistically different (p>0.05) from that of Butimba market.

The levels of microbial contamination; (TPC), coliforms, *E. coli*, and *S. aureus* were compared between processors and traders in Kirumba, Nyakato, and Butimba markets by

Principal Component Analysis (PCA) as illustrated in figure 3. The first PCA1 explains the variation by 46.2% while PCA 2 explains the variation by 34%. From the plots, fried Nile perch from the Nyakato market are highly contaminated with coliforms, total plate count, and *S. aureus* while fried fish samples from the Butimba market are contaminated with *E. coli*.On the other hand, there was no significant difference between the traders and processors of fried Nile perch. Therefore, the level of microbial contamination in fried fish samples is independent of the activity of fried Nile perch traders and processors.

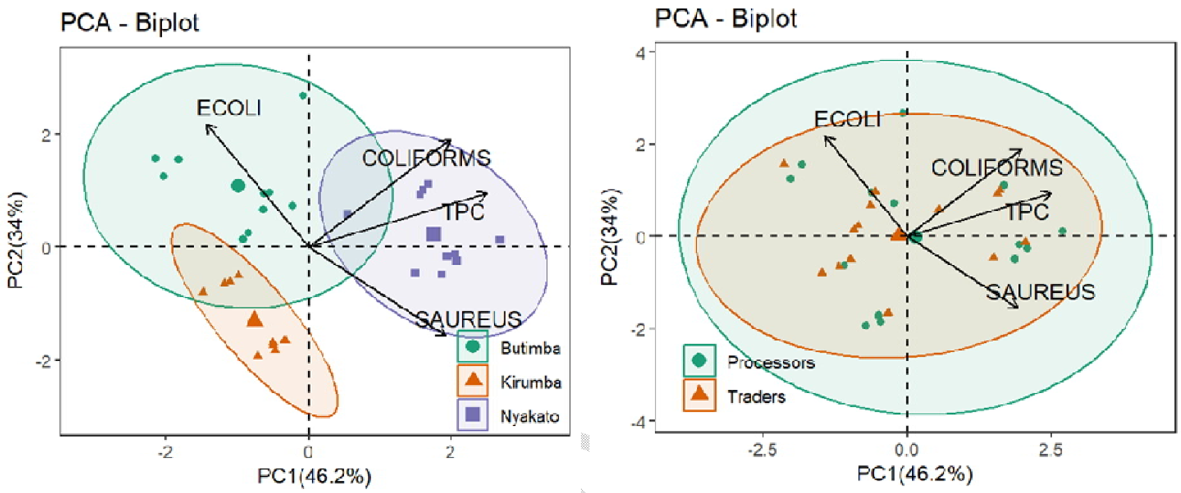

Figure 3. A PCA plot showing variation between activities and markets (Kirumba, Kamanga, and Butimba).

4. DISCUSSION

4.1.General food safety practices of fried Nile perch processors and traders

This study indicates that fried fish sellers, including processors and traders, maintain cleanliness in their food premises despite unfavorable conditions. The findings of the current study align with those of [25]who characterized fish vending locations as inadequately constructed, with fried fish sellers functioning in exposed environments. [28]observed that over 20% of individuals in South Africa sold food on roadsides without any shelters. Potential dangers linked to this approach encompass food-borne infections resulting from environmental contamination, particularly due to fly proliferation. This study identified flies as the primary pests impacting processors and sellers across all markets in Mwanza City. These findings align with those of[25], whereby flies affected 100% of the respondents. Another study by [29]revealed that meat samples were exposed to flies throughout the sales environments. Flies are recognized as mechanical vectors for various pathogenic microorganisms, including bacteria, protozoa, and viruses, contributing to the spread of infectious foodborne diseases such as cholera, dysentery, shigellosis, and salmonellosis [30]. Their presence around vending places indicates poor environmental and sanitation conditions, often worsened by inadequate waste management practices [29], [31]. Houseflies can be controlled by removing their breeding sites, preventing their interaction with disease-causing organisms, and protecting humans and utensils from fly contact [32]. Cleaning up materials that attract flies especially those producing enticing aromas, removing materials such as garbage that harbor the growth of maggots that grow into houseflies, preventing flies from entering buildings by the use of fans blowing across fly congregation sites and emphasizing overall sanitation processes in urban areas by minimizing materials that are attractive to adult house fly population are some methods that can be used to control the presence of houseflies[33]. A study by[34] in Ghana showed that food vendors in Ghana applied fly screens and nets as recommended by authorities to prevent housefly infestation in their food premises.

In line with that, food business operators need to maintain the microbiological quality of the processing water to guarantee the safety of food products[35]. According to [36], contact with contaminated water may lead to the dissemination of microbial contaminants into other fresh or heat-treated fishery products. The current study identified tap water as the main source of water in the Butimba (88.9%), Kirumba (90%), and Nyakato (100%) markets. The findings align with [37], demonstrating that the majority of respondents used tap water for food preparation. In contrast, [38]identified boreholes or well-water as the primary sources of water at vending sites in Nigeria, both of which provided untreated water.The observed use of lake water in the current study was notably low, yet it was associated with potential health risk factors. A study by[18] observed fish being washed with lake water, posing a risk of contamination with pathogenic microorganisms. It has been documented that treated tap water is safe for food processing since its pathogenic microbial load is reduced significantly.

Water plays a significant and fundamental role in food preparation and cleaning operations. Water quality depends on its source and application in food production [39]. Most food-borne illnesses including travelers' diarrhea, dysentery, and typhoid fever can occur due to contaminated water use. According to the WHO, (2015),water-borne diseases account for about 1.8 million human deaths worldwide and 4% of the total disability-adjusted life years. Water can be treated and disinfected to make it safe for use in food preparation operations. The most common disinfectants used in drinking water and wastewater treatment are oxidizing chemicals such as chlorine, chloramines, ozone and chlorine dioxide, and UV-light irradiation [41].

Temperature is the most crucial factor affecting the rate of fish and shellfish deterioration and multiplication of microorganisms [36][36]. Raw fish should be transported and stored at frozen or refrigerated temperatures to prevent decay. Moreover, processed fish products should also be stored at refrigeration temperatures to inhibit bacterial growth and the proliferation of other harmful microorganisms. The findings of the current study reveal a significant association between the temperature of transporting raw materials and market conditions. In Kirumba market, all processors (100%) transported fish at ambient temperature, while a minority of processors in Butimba (22.8%) and Nyakato (28.6%) employed cold temperatures for transporting raw fish. A study by [11]emphasized that ready-to-eat fried fish products should be consumed immediately or kept hot at or above 60°C. If not, they should be quickly cooled to 4.4°C in the refrigerator, as bacteria can increase between 5°C and 60°C. Sufficient and adequate icing or chilled or refrigerated water systems ensure that fish, shellfish, and other aquatic invertebrates are kept chilled as close as possible to 0□[36].According to the[36], inadequate waste management attracts pests, which can lead to contamination and the spread of diseases. Improper waste management can lead to breeding grounds for disease-carrying vectors like mosquitoes, houseflies, and rodents. This exacerbates consequences to public health such as diseases including malaria and dengue fever [42]. Enhancing public awareness about the importance of proper waste collection services is essential to ensure effective disposal, thereby reducing the risk of foodborne illnesses [32].

4.2. Personal hygiene and behaviors of fried Nile perch processors and traders

Food handlers can contaminate food either by carrying pathogens or practicing poor hygiene. Therefore, they must maintain good personal cleanliness and implement safe and hygienic food-handling practices [5]. According to the [36], handwashing should be carried out by all personnel working in a processing area at the start of the fish or shellfish handling activities and upon re-entering a processing area. The present study found that about 92.2% of Nyakato processors and 55.6% of Butimba processors wear home attire, while 55% of Kirumba processors utilize a clean apron during processing. The results of our study differ from those of [25], who reported that a larger proportion of respondents wore clean aprons (64.5%), while only a small percentage (9.7%) lacked protective clothing. Protective clothing prevents cross-contamination from potential contaminants like hair, clothes, and hands. Moreover, food handlers are not supposed to handle food when sick or suffering from disorders such as cholera, typhoid, rashes, and other diseases. About 50% of traders from Butimba and 42.1% from the Nyakato market continue with work even when sick, and when suffering from disorders like diarrhea and flu. Sick individuals risk transmitting pathogens and contaminating food; however, most food handlers prefer to continue the business for economic reasons rather than food safety issues. Similar to our findings, [43] reported that most fish vendors did not abstain from food businesses when sick, even though they agreed that it is necessary to prevent the contamination of fish.

Hand washing with soap and water is a critical hygienic practice in preventing the contamination of the handled food.Insufficient handwashing facilities were noted, resulting in poor hygiene practices, where 55.6% of processors and traders at Butimba and 64.3% of processors and traders and Nyakato market, respectively, failed to wash their hands. Additionally, 55% of establishments in Kirumba provided means for handwashing.[28] revealed that street food vendors had poor hand-washing practices due to the non-availability of potable water at the vending sites. The results of our study are comparable to those of[44], who highlighted that food handlers worked in kitchen areas that did not have hand-washing facilities at all, but contrary to those of [45], where the majority of respondents (77.8%) had access to hand washing stations with soap and water. This was also the case in our study.[46] explained that anaerobic mesophilic bacteria such as *Clostridium*, *S. aureus*, and *E. coli* were isolated in all samples taken from the hands of food handlers. This is a threat to the safety of the food that is being handled.Therefore, food handlers must ensure that their hands are kept clean by washing them with soap and water after handling contaminated matter such as waste and raw fish and visiting the toilet to prevent contamination of fried fish products.Fried Nile perch processors and traders should be trained on pest control methods, like using fly swats or flaps instead of chemicals, implementing proper waste management to avoid public hazards, prohibiting unhygienic behaviors such as sneezing, spitting, and nose-blowing near food, and maintaining the correct temperature for handling processed foods.

4.3.Factors associated with compliance to food safety practices in Mwanza Nile perch retail markets

Fried fish processors and traders generally practice poor hygienic practices, and several factors influence their practices directly or indirectly. These factors are such as access to training, income level, education status, experience in the business, inspection, access to training programs, and whether they have enough facilities to implement the required food safety practices.The association of the aforementioned parameters with compliance to food safety practices was noted in the current study and identified as a determinant of various sanitary practices among fried Nile perch vendors and processors. Previous studieshave shown that food safety knowledge, formal education, income experience, and training are positively associated with food hygiene practices [47]. The current research investigation indicates that the majority of respondents lacked training in proper food safety standards, resulting in the transportation and temporary storage of raw materials at ambient temperatures. Fried fish must be preserved at low temperatures; yet, without proper training in food handling protocols, individuals responsible for handling fried fish may remain ignorant of this necessity. Research by [45], and [47] explained that food handlers who had received food safety training had higher probabilities of having good hygienic and food handling practices. According to[48], training enhances a better understanding of safe food handling practicesby food handlers, hence good performance in safe food handling practices. It also allows knowledge acquisition that may change attitudes and work practices, thus contributing to adopting good hygiene practices [49]. Moreover, most respondents who attained primary school education only did not have different waste disposal containers. A higher education level results in a deeper knowledge of food handling practices compared to lower education levels. Minimizing the risk of contaminating food can be achieved by educating food handlersto higher levels[45].[50] elaborates that, the low education level of food handlers negatively impacts their knowledge and attitude, and therefore may not apply basic food safety principles like separating soft and hard wastes to prevent cross-contamination risks to the fried Nile perch fish samples. Additionally, our study comprised most processors and traders who had less than five years of experience in the business. They mainly put on their home clothes, especially during trading activities. This is not in line with the food safety practice requirements. [50] found that good hygienic practices are influenced by many years of experience in the food business. Likewise, [47] explained that experienced food handlers acquire skills in food hygiene. This is because behavior can be learned through practice facilitated by continuous practice, hence food handlers who have more experience are in a better position to enhance their skills in food hygiene practices. Another factorwas the availability of enough facilities to implement good food safety practices. This was associated ($X^2 = 6.829, P = 0.009$) with measures taken to control pest infestation. Most of the Nile perch processors and traders did not have enough required facilities to control pest infestation. Non-accessibility to adequate sanitation facilities impends appropriate food safety behavior, hence non-compliance with basic hygiene principles [51]. In their review article, [52]argued that the availability of facilities is a prerequisite for putting knowledge into practice and helps to prevent food handling errors. Therefore, fried Nile perch vendors and traders need to have enough facilities to be able to control pests that contaminate the fried fish samples. Income was directly associated ($X^2 = 16.201, P = 0.013$) with a clear separation between storage and processing areas. Most of our respondents earned less than 20,000 TZS per day. This low income helps them provide basic needs in their households. The low-income level makes it difficult for them to establish proper working areas, with clear distinctions between the storage and processing areas. Similarly, [53]highlighted that food handlers with less monthly income were likely to have poor food safety practices compared to those with a high monthly income. Equally important, higher income is associated with good educational status, hence good knowledge and attitude towards food handling practices. Finally, Inspection was associated ($X^2 = 12.041, P = 0.002$) with the storage temperature of fried fish and if the waste disposal site is located away from the food establishment ($X^2 = 6.24, P = 0.44$). In our study, the fried Nile perch processors and traders were not inspected for adherence to food safety practices. Moreover, most of them preserved their waste for later disposal after vending activities at the nearby areas/pits. Thewastewater from raw fish preparation before frying, was just poured out into the open space. Inspection of food vending sites is indispensable as it facilitates the adoption and compliance of food safety practices. Without regular inspection, fried fish traders and processors may not regularly handle food well at required temperature conditions and may dispose of wastes anyhow. These are all risk factors that may contribute to the contamination of fried Nile perch fish ready for sale.

4.4.Microbial contamination of fried Nile perch species in Mwanza City

Microorganisms play a crucial and unique role in fish and fish product safety[54]. Contamination of fish with microorganisms of public health significance remains a significant global public health concern that affects consumers. Therefore, serious attention has to be given to ready-to-eat fish products that act as a vector for human pathogenic bacteria [11].The levels of microbial contamination in Nile perch, including total plate count (TPC), coliforms, E. coli, and Staphylococcus aureus, were generally higher and exhibited variation across different markets. The Nyakato market exhibited the highest total plate count (TPC) contamination levels, with traders showing 8.79±1.04 log CFU/g and processors 9.53±0.52 log CFU/g. Additionally, the mean total coliform contamination levels were recorded at 8.64±0.79 log CFU/g for processors and 8.74±0.59 log CFU/g for traders in the same market. Table 5 highlights the microbial criteria for dry fish and fishery products.

Table 5. Microbial criteria for dry fish and fishery products

Parameter	Criteria (max limit)	Source
Total Viable Count	1.5×10^5CFU/g	TZS 118:2007

(TVC)		EAS 828:2016
E. Coli	1×10^{1}MPN/g	TZS 731: 2007
	Absent	EAS 828:2016
Total coliforms	4×10^{2} MPN/g	TZS 119:2002
S. aureus	1×10^{3}CFU/g	TZS 125:2002
	2×10^{3}CFU/g	EAS 828:2016

According to the East African and Tanzanian Standards [55], dried fish's total viable plate count bacteria should not exceed 5 log CFU/g (Table 5). A substantial level of total plate count contamination was observed across all three markets (Kirumba, Butimba, and Nyakato). The contamination levels exceeded those documented by [7], [56], [57]. This condition could result from inadequate environmental conditions affecting processors and traders, along with their failure to adhere to hygienic practices in the handling of fried fish. Generally, most of the traders and processors fromNyakato market, with the highest contamination rate are located along the roadside, thus posing a significant risk for pathogenic microorganisms to contaminate the fried fish. Moreover, most of the fried Nile Perch traders and processors from Nyakato market did not adhere to good hygienic practices such as hand washing, as there are no adequate means for maintaining the general sanitary practices when operating in the fried fishvending business. On the other hand, coliforms indicate fecal contamination and thus pose a serious food safety risk when consumed above limits. The East African standards for fish and fish products stipulate that the total coliform count must not exceed 100 CFU/g, corresponding to 2 log units [55].The findings of this study indicate significant coliform contamination in Nyakato and Butimba markets, with Nyakato market exhibiting the highest mean coliform contamination (8.74 log CFU/g) in fried fish across both processors. Interestingly, the lowest recorded coliform contamination in Kirumba market was 2.83 log CFU/g, which exceeds the limits established by East African and Tanzanian Standards [55].These findings are quite higher than those reported by[58]. Coliforms in fried fish products signify fecal contamination and show the potential presence of other enteric pathogens [25].In line with that, the East African standard of fried fish and fishery products requires that *E. coli* should be absent from dried fish products [55].Interestingly, the fried fish samples from the traders and processors were positive for *E. coli*, with the Butimba market leading in contamination levels for both traders and processors. *E. coli*is a harmful pathogenic microbe that causes gastroenteritis when consumed in food. *E. coli* in cooked and fried ready-to-eat street foods depicts secondary contamination because it is found in the gastrointestinal tract of warm-blooded animals but not in the environment as natural flora [59]. The contamination in fried fish samples is due to unsanitary environmental conditions in which the processing and trading operationsare conducted. Therefore, due to poor waste management practices, houseflies are seen everywhere and these vectors around the vending centers exacerbate the high levels of *E. coli*. This threatens the safety of the fried Nile Perch sold and consumed by the people around the area. Another pathogenic microorganism, *S. aureus*, is of primary concern worldwide due to its comprehensive reports of inhabiting human respiratory passages, skin, and superficial wounds [11]. The traders from all markets had the highest mean contamination compared to processors.This is mainly attributed to traders operating in open places, hence prone to various contaminants such as dust, hands of clients when buying fish, and personal behaviors such as scratching of body parts. Traders from Nyakato and Kirumba markets was reported to have the highest mean levels of S. aureus contamination at 5.51±0.08 log CFU/g and 5.52±0.05 log CFU/g. The findings of this study were similar to the values noted by[57]. This may be due to poor handling of fish, especially the serving of fried fish with bare hands, other non-hygienic practices such as scratching hair and skin when processing and trading, and non-adherence to good hygienic practices like covering hair.*S. aureus* survives under harsh conditions such as high salt concentration and reduced water activity.Inadequate hygiene procedures and insufficient food handling might lead to the spread of *S. aureus*[7].

5. Conclusion

Most Mwanza people and Tanzanians eat fried Nile perch from city market vendors. They are generally low-income ladies. Most of them lack suitable food venues and, therefore sell on roadsides and in open spaces. Fried Nile perch vendors and processors follow similar food safety measures despite market variances. Clothing, pest management, and raw material transportation temperature were affected by income, training, inspection, education, experience, and inspection. Fly infestation and poor waste management increased fried Nile perch's dangerous microorganisms. Total plate count (TPC), coliforms, *E. coli*, and *Staphylococcus aureus* were found in fried Nile perch in Nyakato, Kirumba, and Butimba, calling for better hygiene by traders and processors. To avoid microbial contamination, reheat fried Nile perch fish before eating.

6. Recommendations

To help these enterprises, the government should provide food handling and environmental cleanliness training. Low-interest loans would also help them build safe food facilities to supply safe fried Nile perch to consumers. To decrease foodborne pathogens, the government, legislators, and food safety legislative authorities should ban roadside food retail. Fried Nile perch must be prepared in a clean, hygienic setting to avoid food illness and biological pollutants.

7. Data availability

The data generated and analyzed in this study are available from the corresponding author upon reasonable request.

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