



EVALUATION OF COPPER, ZINC, AND IRON CONTAMINATION IN SELECTED FROZEN FISH SPECIES MARKETING IN ONDO CITY, SOUTHWESTERN NIGERIA

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Abstract: This study assessed the levels of concentration of copper (Cu), iron (Fe), and zinc (Zn) in the gill, liver, and muscle tissues of Mackerel (*Scomber scombrus*), Herring (*Clupea harengus*), and Hake (*Merluccius merluccius*), sourced in Ondo City, Southwest, Nigeria, and values were compared with WHO and FEPA regulatory limits. Tissues were digested using aqua regia, a mixture of nitric acid (HNO₃) and hydrochloric acid (HCl) in a 3:1 ratio, and an atomic absorption spectrophotometer (AAS) was used to determine the metal concentration level. The results revealed no significant differences in the levels of Cu, Fe, or Zn among the three fish species across the various tissues ($p > 0.05$). The trace metal concentration order in the fish was Zn > Fe > Cu. While the concentrations of Cu and Fe in the tissues of all three fish species studied were within the WHO and FEPA-prescribed limits for food fish, the concentrations of Zn in the muscles of *Merluccius merluccius* (0.262 ± 0.052 ppm), *Clupea harengus* (0.327 ± 0.099 ppm), and *Scomber scombrus* (0.362 ± 0.119 ppm) were above the prescribed limit (0.075 ppm) set by FEPA, indicating potential health risks. Regular monitoring of essential metals in fish, along with stricter regulatory enforcement, is necessary to safeguard public health.

Keywords: trace metal bioaccumulation, food safety, contamination, health risk, analytical toxicology

1. Introduction

Fish is widely recognized as a highly nutritious food, providing high-quality protein, essential fatty acids, vitamins, and minerals. Its consumption has increased in both developing and developed countries due to growing awareness of its nutritional and health-promoting benefits [1]. Fish is available and affordable relative to other animal protein sources [2][3]. Major sources of animal protein in Nigeria are livestock and poultry meat. However, the market prices of livestock and poultry meat have recently gone up; hence, many Nigerians could not afford them, and this resulted in many citizens suffering protein deficiency due to low protein intake, as reported by Fawole et al. [4]. Consumption of fish accounts for

around 40 percent of Nigerian's protein intake, with fish consumption at 13.3 kg/person/per year. Adesina et al. [5] and Odioko & Becer [6] reported that over 3.6 million metric tons of fish were demanded for consumption in Nigeria. Due to an increase in demand, fish culture received a lot of attention in the country. New cultivation techniques were introduced and adopted with a view to meeting the demand of the ever-increasing population, but still, the production is inadequate. Nigeria was only able to produce about 1.2 million metric tons. The deficit of 2.4 million metric tonnes of frozen fish was imported to the country yearly [7]. Fish meal (FM) has been a significant component of the human diet for a long time before civilization [8] [9].

Compared to other animal protein sources, fish is more widely available and more reasonably priced, making it a viable option for human consumption even in rural areas. It is beneficial for people's health because it contains proteins, oils, vitamins, and minerals [10]. Fish meals are a naturally balanced feed ingredient that is rich in minerals (such as calcium and phosphorus) and is also high in protein and calories. FM also contains other trace elements, including selenium and iodine, and is a natural source of vitamins such as choline, biotin, and vitamin B12, as well as vitamins A, D, and E [11]. Knap [12] reported that when fish meat is compared to the meat of goats, lambs, and poultry, fish has a higher protein-to-fat ratio, making it advantageous to consume it whole. Essential amino acids (EAAs) and polyunsaturated fatty acids (PUFAs), which are found in fish, are necessary for the development and maintenance of fetuses, neonates, and infants' brains [13]. Fish consumption is rising, and it is essential for the security of food and nutrition worldwide. As a nutrient-dense diet, fish is highly recommended for children and expectant mothers to support healthy growth and development [14]. Therefore, it could be a valuable tool in the fight against food insecurity and malnutrition.

However, Jinadasa and Fowler [15] reported that fish are highly susceptible to contamination by hazardous organic and inorganic substances, and this is of public health concern. Heavy metals and biogenic amines (BAs) have been shown to have detrimental effects when ingested in contaminated fish, with the effects being more severe for youngsters [16]. Therefore, even if eating fish is highly advised, it is always advisable to examine the product's quality and safety to protect the general public's health. The quality of fish and fish products is complex. It encompasses a wide range of factors, including safety and freedom from health risks, nutritional value or quality, convenience, availability, and

integrity, as well as the freshness of fish, sensory qualities, physical features, type, and quantity of products. Additionally, catching, handling, processing, and techniques, along with environmental elements like time and temperature that affect the fish products' safety and quality, are important considerations [17]. There is a growing awareness of harmful metal contamination in the environment due to the increased use of a variety of metals in industry and our daily lives. Many of these metals linger in the environment and eventually move from one section of the food chain to another. To be confident about health and safety, it is essential to maintain high levels of fish quality throughout the whole food chain, from catch to consumption. King et al. [18] have reported that global demand from consumers for nutritious and secure foods is rising. Statutory bodies, including the WHO and FEPA, establish maximum allowable concentrations for inorganic substances in fish food.

The question that came to mind was, "Did the imported frozen fish vended in Ondo City, Ondo State, Nigeria, have an overabundance of heavy metals that are necessary? Hence, this study aimed to determine the contamination of essential heavy metals in the imported frozen fish commonly sold at the open markets in Ondo City, Southwest Nigeria. Specifically, the levels of essential heavy metals (Cu, Fe, and Zn) in the randomly selected fish purchased from the open markets in Ondo City, Southwest Nigeria, were determined. This revealed whether essential heavy metals were excessive in the fish sold to consumers, which could be transferred to humans via consumption. Fish play an important role in human nutrition, and they must be thoroughly screened to consume wholesome fish.

2. Materials and methods

2.1. Study site

Ondo City, the study site, is the second largest city in Ondo state, Nigeria, second to

Akure, the capital city of Ondo State. It has a Latitude of 7° 05' 35.38' N and a Longitude of 4° 50' 77.01' (Fig. 1)

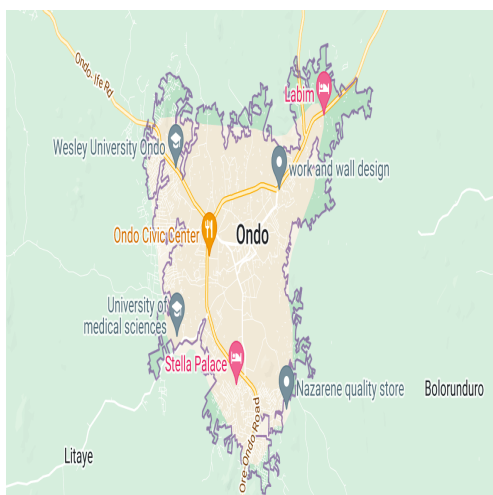


Fig 1. Map showing Ondo City, Southwest, Nigeria. (Google, 2025) (accessed August 18, 2025) <https://www.google.com/maps>

The city is the trade centre for the surrounding region. It is the largest producer of cocoa in the southwest region of Nigeria. Other agricultural products, such as yams, cassava, grain, and tobacco, are produced in commercial quantities.

The major markets in the city are Iyalaje, Sabo, and Igele, and all the major markets were used as sampling units. The major markets in the city are Iyalaje, Sabo, and Igele, and all the major markets were used as sampling units.

The three most popular imported frozen fish sold in these markets, and those fish that were usually hawked around the city by the fish vendors, are: Mackerel (*Scomber scombrus*), commonly known as Titus's fish among the natives, Herring (*Clupea harengus*), commonly known as Shawa among Yoruba indigenes, and Hake (*Merluccius merluccius*) fish, commonly known as Panla, are shown in Figs. 2 a, b, and c.

The most widely sold among the three was Hake fish, being the cheapest. Hake fish was also common among the natives, used to entertain visitors during ceremonies. The major forms of preservation for the fish are freezing, drying, and smoking.

2.2. Sample collection and preparation

Fish were bought in May 2022 from open marketplaces for the investigation.



(a) *Scomber scombrus*, (b) *Clupea harengus*, (c) *Merluccius merluccius*

Fig. 2. Frozen fish vended in Ondo City markets

A polythene bag that had been previously cleaned was used to gather the frozen fish. Immediately after purchasing, the samples were put in a chilled box with ice to maintain their freshness. During shipping, ice was used to keep the surroundings moist and stop tissue degeneration. After rinsing the samples with water to get rid of any foreign objects, extra water was drained from the fish using a paper towel. Each species' nine specimens were acquired and transported to the Department of Biological Sciences laboratory at the University of Medical Sciences in Ondo City, Southwest Nigeria. After that, the samples were kept in a freezer until metal analysis could be done. After allowing the fish to defrost at room temperature, each fish's weight (g) and standard length (cm) were determined using an electric weighing balance and a standard ruler, respectively. After the fish were dissected, the target tissues, the muscle, liver, and gills, were removed. After being extracted, the tissues were labelled appropriately, wrapped in clean foil, and stored in the freezer to undergo acid digestion.

2.3. Digestion of samples

The samples (wet) were digested by measuring 2 g of each organ and placing them in a conical flask that had been previously well-washed and soaked with acid. Ten millilitres of distilled water were added, and a glass rod was used for the homogenization of the tissues before digestion. The mixture of nitric acid (HNO₃) and hydrochloric acid (HCl) at a 3:1 ratio was

used for digestion [19]. The mixtures were swirled gently using another glass rod and then placed and allowed to digest on a hot plate in a fume cupboard for about 2 hours at a temperature of 140 °C. The digest was then allowed to cool. Twenty millilitres of double-distilled water was added, then Whatman No.1 filter papers, which were also earlier rinsed with distilled water, were used to filter the digested samples. Once the digested sample was filtered, it was transferred to the sample bottle and labelled appropriately. The analyses were performed in triplicate. A blank determination was carried out to establish the level of blank metals by digesting the reagents only. The digested samples were analyzed for heavy metal concentration using an Atomic Absorption Spectrophotometer (AAS). The procedure was based on the Ghaedi et al. [20] procedure.

2.4. Quality control for heavy metal analysis

All equipment and glassware used in the present study were acid-washed to avoid external contamination. Along with the digested samples, procedure blanks, and quality control samples produced from the

standard solution for Cu, Fe, and Zn were analyzed. After every 5 - 10 samples, this standard solution was re-analysed to verify the correctness of the samples analysed.

2.5. Statistical analysis

Data obtained were subjected to descriptive statistical evaluation, Pearson Correlation, and one-way ANOVA using GraphPad Prism 10. The results were compared with the permissible levels of the WHO and FEPA guidelines.

3. Results and discussion

The descriptive statistics of different species of fish purchased from the open markets, investigated for the level of concentration of trace metals was shown in Table 1. The analysis showed that the average weights (g) of *S. scombrus* (245.3±21.24) and *M. merluccius* (214.0±22.88) were significantly higher ($p<0.05$) than the average weight (g) of *C. harengus* (163.3±11.53). The average standard length measured in centimeters showed that the average lengths of *S. scombrus* (27.93±0.51) and *C. harengus* (27.57±1.01) were significantly higher than the average length of *M. merluccius* (24.47±1.58).

Table 1.
Descriptive statistics of morphometric parameters of different species of fish purchased from local markets in Ondo City for the present study

Parameters	Mackerel (<i>S. scombrus</i>)	Herring (<i>C. harengus</i>)	Hake (<i>M. merluccius</i>)
Mean Weight (g)	245.3±21.24**	163.3±11.55	214.0±22.88*
CV (Weight)	8.7%	7.1%	10.7%
Mean Standard Length (cm)	27.93±0.51*	27.57±1.01*	24.47±1.58
CV (Length)	1.84%	3.65%	6.49%

SD= Standard Deviation; CV = Coefficient of variation; *Significant at $p < 0.05$; **Significant at $p < .001$

The levels of concentration of metals in different fish species are shown in the figure.

3-5. Fig. 3 showed that the highest Cu concentration is in hake, followed by

herring, while mackerel showed the lowest values. Liver Cu concentrations were generally higher in herring and mackerel compared to hake, suggesting greater hepatic accumulation in these species. Muscle tissues showed comparatively lower Cu levels across all species, though hake presented the highest concentration in this tissue, followed by herring and mackerel.

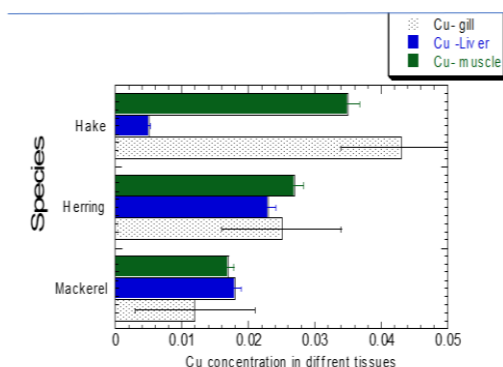


Fig. 3. Concentration (mean $\pm$ SD, ppm wet weight) of Cu in the gill, liver, and muscle of Mackerel, Herring, and Hake. Data are presented as an average of nine samples (N=9)

These findings highlight species-specific differences in Cu bioaccumulation patterns, with hake showing higher overall muscular Cu retention and herring exhibiting greater hepatic uptake. Fig. 4 shows a clear hierarchy of iron accumulation within the tissues of each species, following the order of muscle > liver > gills.

The liver, a central organ for metabolism and nutrient storage, showed a considerable concentration of iron, consistent with its physiological role. In contrast, the gills, primarily responsible for gas exchange, exhibited the lowest iron levels. Interspecies comparison highlighted that mackerel demonstrated the highest overall iron concentration across all tissue types, with its muscle tissue reaching the highest level recorded in the study. Hake also displayed a unique pattern with a relatively high iron concentration in its gills compared to the other two species. These findings suggest species-specific

differences in iron uptake, metabolism, and storage, which could be influenced by a variety of factors, including diet, habitat, and physiological differences.

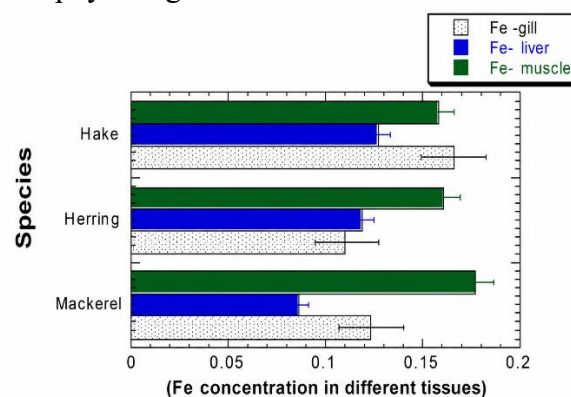


Fig. 4. Concentration (mean $\pm$ SD, ppm wet weight) of Fe in the gill, liver, and muscle of Mackerel, Herring, and Hake. Data are presented as an average of nine samples (N=9)

Fig. 5 reveals distinct patterns of zinc concentration bioaccumulation across the three fish species and their tissues. Contrary to the common pattern for iron, zinc was not preferentially accumulated in muscle tissue. Instead, the highest zinc concentrations were consistently found in the gills and liver of all three species. Specifically, the gills of hake and the liver and gills of herring showed the highest recorded zinc levels. This pattern is physiologically plausible, as the gills are the primary entry point for waterborne metals, while the liver acts as the main organ for detoxification and storage of excess or toxic substances. In all species, the muscle tissue consistently contained the lowest concentration of zinc. This finding is significant from a public health perspective, as it suggests that zinc, unlike some other contaminants, is not readily stored in the edible portions of these fish. The high levels in herring, for example, may reflect a greater exposure to zinc-rich environments or a more efficient uptake mechanism compared to hake and mackerel. These results provide a valuable base for future studies on trace metal contamination and bioaccumulation in marine ecosystems. The bioaccumulation, tissue-specific distribution, and inter-metal

relationships are shown in Table 2 and Fig. 6 (heatmap).

The analysis highlights that the distribution of metals (copper, iron, and zinc) was not random but rather interconnected both within and between different organs of the organism.

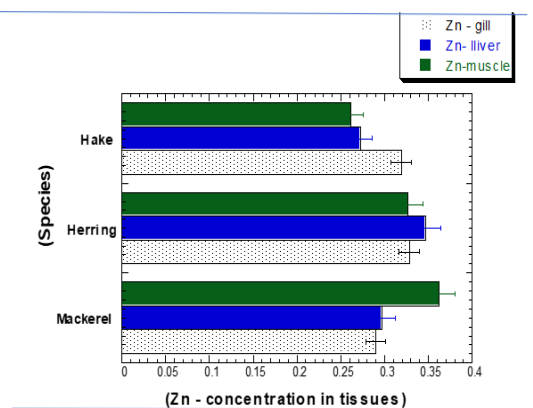


Fig. 5. Concentration (mean $\pm$ SD, ppm wet weight) of Zn in the gill, liver, and muscle of Mackerel, Herring, and Hake. Data are presented as an average of nine samples (N=9).

Some metal concentrations were strongly related to the fish's overall size (weight and length), while others showed complex inter-organ and inter-metal relationships. Based on Pearson's Correlation matrix provided, the data revealed several key relationships, particularly concerning the bioaccumulation and distribution of metals (copper, iron, and zinc) in different tissues (gills, liver, and muscle) of the experimental fish. As expected, a significant positive correlation exists between weight and length ($r = 0.749$), indicating that longer individuals tend to be heavier. Regarding metal distribution, strong positive correlations were observed for the same metal across different tissues, suggesting a consistent bioaccumulation pattern. For instance, copper concentration in the gills was highly correlated with its concentration in the liver ($r = 0.983$), and iron concentration in the gills was strongly correlated with its concentration in the muscle ($r = 0.950$). This implies systemic distribution and regulation of these metals within the organism. Interestingly, several

negative correlations were also present, highlighting potential antagonistic relationships. A notable finding was the strong negative correlation between iron in the liver and the organism's weight ($r = -0.615$), suggesting that heavier individuals have lower iron concentrations in their liver. A similar but weaker negative relationship was seen between zinc in the liver and weight ($r = -0.466$). Additionally, an inverse relationship was observed between zinc in the liver and iron in the gills ($r = -0.528$), which could indicate an interaction or competitive uptake mechanism between these two metals. Van der Oost et al. [21] reported that the correlation matrix provided a comprehensive overview of the interdependent relationships between physiological characteristics and metal bioaccumulation in the fish's tissues. These findings have several significant implications for public health, particularly concerning the consumption of this organism. The data revealed strong correlations between the organism's size (weight and length) and the concentration of certain heavy metals in its tissues, as well as complex relationships between the metals themselves. The implications were that human consumption suggests that larger, older fish may have lower concentrations of iron in their livers. This could be beneficial from a public health perspective if iron in this context is a contaminant, but it might also indicate a deficiency or redistribution of a vital nutrient. The bioaccumulation and tissue distribution of the strong positive correlations for metals within different organs (e.g., Cu_Gill and Cu_Liver, Fe_Gill and Fe_Muscle) indicate that these metals are not isolated to a single tissue. Instead, they are systematically distributed throughout the organism. This means that consuming any part of the fish, particularly the liver, could expose a person to elevated levels of these metals.

The liver is a known site for metal detoxification and storage, making it a

potential public health concern if the metal levels are high [22]. Concerning the environmental and regulatory implications, the strong correlations between metal concentrations in different tissues suggest that one tissue could serve as a reliable biomarker for overall metal contamination in the organism. For example, a single measurement of copper in the gills could be used to predict the copper concentration in the liver, simplifying environmental monitoring efforts. This could streamline regulatory testing and help determine if fish from a certain area are safe for consumption.

The correlations between different metals, such as the negative relationship between Fe_Liver and Zn_Muscle ($r = -0.357$), could indicate complex physiological interactions. Wang et al. [23] concluded that the interactions of one metal in the presence of another might influence the toxicity. Therefore, public health risk assessments should consider these multi-metal interactions rather than evaluating each metal in isolation. It could be possible that the presence of one metal might either enhance or mitigate the harmful effects of another.

Table 2.

Pearson's correlation coefficients (r) and their corresponding p -values for the relationship between morphometric parameters and the concentration of metals in the different tissues of the studied fish species.

Variables	Weight (g)	Length (cm)	Cu_Gill	Cu_Liver	Cu_Muscle	Fe_Gill	Fe_Liver	Fe_Muscle	Zn_Gill	Zn_Liver	Zn_Muscle
Weight (g)	—										
Length (cm)	0.125 (0.749)	—									
Cu_Gill	-0.284 (0.458)	-0.428 (0.250)	—								
Cu_Liver	-0.207 (0.592)	0.538 (0.135)	-0.008 (0.983)	—							
Cu_Muscle	0.020 (0.959)	0.142 (0.715)	0.502 (0.169)	0.076 (0.845)	—						
Fe_Gill	0.394 (0.294)	-0.369 (0.328)	0.469 (0.203)	-0.522 (0.150)	0.581 (0.101)	—					
Fe_Liver	-0.615 (0.078)	-0.675 (0.046)	0.641 (0.063)	-0.146 (0.708)	0.015 (0.970)	0.100 (0.799)	—				
Fe_Muscle	0.262 (0.496)	0.382 (0.311)	0.239 (0.536)	0.580 (0.102)	0.027 (0.944)	0.025 (0.950)	-0.274 (0.476)	—			
Zn_Gill	0.064 (0.870)	-0.112 (0.775)	-0.312 (0.414)	-0.531 (0.141)	-0.316 (0.407)	0.130 (0.740)	0.202 (0.602)	-0.336 (0.377)	—		
Zn_Liver	-0.466 (0.206)	0.330 (0.386)	0.171 (0.659)	0.335 (0.379)	0.182 (0.640)	-0.528 (0.144)	-0.012 (0.975)	-0.038 (0.922)	-0.506 (0.164)	—	
Zn_Muscle	0.127 (0.745)	0.472 (0.199)	-0.094 (0.810)	0.604 (0.085)	-0.351 (0.354)	-0.345 (0.363)	-0.357 (0.346)	0.892 (0.001)	-0.206 (0.595)	0.031 (0.938)	—

Note: Correlation coefficients, with their corresponding p -values in parentheses below each value. Statistically significant correlations ($p < 0.05$) are bolded

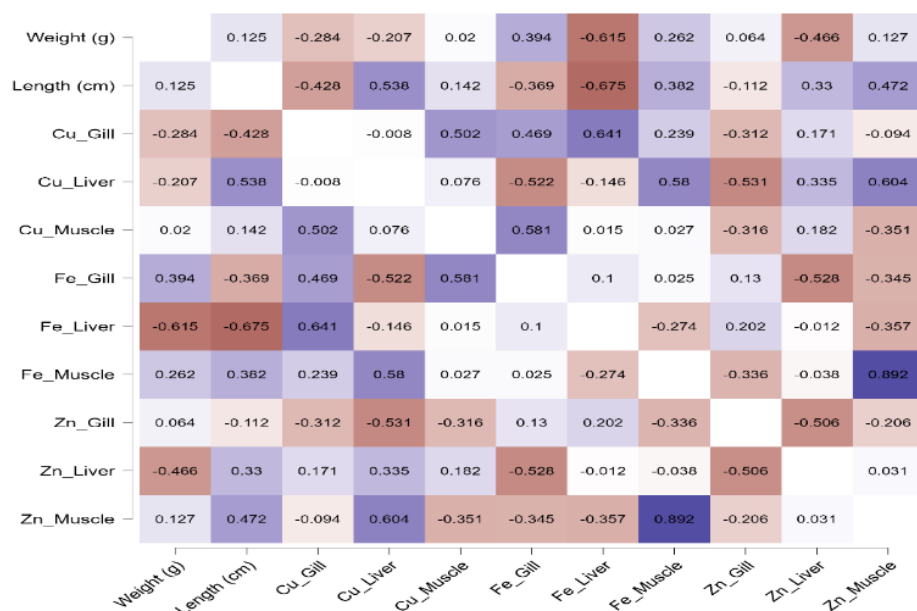


Fig. 6. Heatmap showing Pearson's correlation coefficients (r) and their corresponding p -values for the relationship between morphometric parameters and the concentration of metals in the different tissues of the fish species studied

The descriptive analysis of the morphometric parameters of the fish investigated showed that the fish were not homogeneous. *S. scombrus* investigated were bigger than *M. merluccius* and *C. harengus*. This could explain the different levels of accumulation of the metals in their different tissues observed in this study. The observed differences were properly described by comparing the morphometric and the level of different concentrations of metals in different tissues of the experimental fishes (Table 3), and the ANOVA results are summarised in Table 4. The table showed the biometrics (weight and length) and the concentration of three metals (copper, iron, and zinc) in different tissues (gill, liver, and muscle) of three species of frozen fish (mackerel, herring, and hake) studied. The biometric analysis showed that mackerel had the highest mean weight at 245.3g, a statistically significant finding ($p < 0.05$), indicating a notable difference compared to the other species. In contrast, herring exhibited the greatest mean length at 27.57 cm. The Standard Error (SE) values, which indicate the precision of the mean, varied across measurements; for example,

the SE for mackerel weight (12.27) was higher than that for herring (6.67), suggesting more variability in the weights of the mackerel samples. The hake gills had the highest mean copper concentration at 0.043 ppm. The lowest was in mackerel gills at 0.012 ppm. The highest iron concentration was found in the muscle tissue of hake at 0.166 ppm, while the lowest was in the liver tissue of mackerel at 0.087 ppm. The highest concentration of zinc was found in the liver tissue of herring at 0.347 ppm. The lowest concentration was in the muscle tissue of hake at 0.262 ppm.

These findings highlight that metal accumulation is not uniform and varies significantly by both fish species and tissue type. These data provide important insights into the potential health implications of consuming these different fish species sold in the open markets in Ondo City. Sharma and Agrawal [24] pointed out that while some of these metals are essential for biological function, they can become toxic at elevated levels. The observed concentrations, particularly the variations across different species and tissues, have several key implications. The presence of

these metals in edible fish tissues, especially the muscle, raises a public health concern. The liver and gills often act as primary sites for heavy metal accumulation and detoxification. The levels found in the muscle tissue, which is the primary part consumed by humans, are particularly important for assessing the risk of dietary exposure. The varying concentrations across different fish tissues (gills, liver, and muscle) indicate the process of bioaccumulation, where metals accumulate in an organism over time. The gills, being the site of respiration, often have higher concentrations because of direct exposure to metals in the water. The liver, a key organ for detoxification, also tends to accumulate high levels of metals. More so, the presence of heavy metals in the fish suggests that the aquatic environment from which these fish were harvested is contaminated. This makes the fish a bio-indicator for environmental pollution, likely from industrial, agricultural, or domestic waste runoff. Previous studies in various Nigerian water bodies, such as the Ose River and other coastal waters in Ondo State [25], consistently report that fish tissues accumulate heavy metals. Squadrone et al. [26] also confirm that metal concentrations are generally highest in organs like the gills and liver compared to the muscle tissue, which aligns with the provided data. This pattern is widely recognized in ecotoxicology.

The concentration of Cu and Fe in the tissues of all three fish species studied was within the WHO and FEPA-prescribed limits for food fish, an indication that these fish were free from copper and iron toxicity and are safe for human consumption. When fish containing low amounts of copper and iron are ingested, it helps in the overall health of the human body [27]. Copper cannot be produced by the human body and therefore needs to be added from external food sources [28]. The right development of the body, effective iron usage, and better connective

tissue, hair, and eye health are just a few of copper's health advantages. Additionally, it is essential for improving energy production and delaying the onset of old age [29]. Cu also maintains the integrity of your immune system, nerve cells, and the production of red blood cells in your body. Collagen, a crucial component of bones and connective tissue, is also formed with the aid of this substance. By lowering free radicals that can harm DNA and cells, copper may also function as an antioxidant [30]. The cupric (Cu^{2+}) form of copper, which is frequently found in fish [31], is largely responsible for its harmful toxicity, which can cause cellular abnormalities like oxidative stress, Huntington's disease, and impairments in osmo/ion regulatory functions [32]. Copper can also be toxic to humans when consumed in high doses. Al-Samarrai et al. [33] described the symptoms of copper deficiency in people as anemia, a low body temperature, brittle bones, a low white blood cell count, and an irregular heartbeat.

The value obtained for Fe in all the fish species investigated in the gills, muscles, and liver was below the 0.3 ppm and 0.3 ppm prescribed by WHO and FEPA, respectively, as the recommended limits for food fish, thereby indicating that these fish were free from iron toxicity and are safe for human consumption. Some other studies by some researchers [34], [35] revealed low iron content in the food fish. People suffering from iron overload disorder, called hemochromatosis, could be advised to consume fish species that are relatively low in iron. Iron is a mineral that the body needs for growth and development. The human body utilizes iron to create myoglobin, a protein that oxygenates muscles, and hemoglobin, a protein found in red blood cells that delivers oxygen from the lungs to all areas of the body [35]. Iron is also required by the human body to create several hormones, but too much iron can have fatal consequences due to liver damage and other serious side effects [36]. The symptoms

appear gradually and start with nausea, diarrhoea, and stomach pain before progressing to liver failure in the later days. The concentration of Zn in the samples (gill, liver, and muscles) of all the fishes investigated was within the permissible level, 1.0 ppm, set by WHO; however, the values obtained in all the fish specimens were above the prescribed limit of 0.075 ppm set by FEPA. Zinc is an important part of a healthy and complete diet. Zinc is a mineral that is essential for many of the body's normal functions and systems, including the immune system, wound healing, blood clotting, thyroid function, and the senses of taste and smell. Zinc also supports normal growth and development during pregnancy, childhood, and adolescence, but taking too much can lead to acute or chronic zinc toxicity [37]. Signs of too much zinc include nausea, dizziness, headaches, upset stomach, vomiting, and loss of appetite. Sandstead [38] reported that taking too much zinc for a long time could have led to problems such as lower immunity, low levels of HDL ("good") cholesterol, and low copper levels. The negative effects of too much zinc in the body include a lack of appetite, headaches,

vomiting, and reduced immunity [39]. The value obtained for Zn in all the fish species in the gills, muscles, and liver is below 1.0 ppm, prescribed by WHO as the recommended limit for food fish, thereby indicating that these fish were free from Zn toxicity and are safe for human consumption.

This trend agrees with other studies carried out by Okogwu et al. [40].

However, the values obtained in the fish investigated were above the permissible limits for Zn prescribed by FEPA, though within the WHO safety limit; consumers must exercise caution in consumption. Only two of zinc's many health benefits include increased metabolism and a robust immune system. Bhowmik et al. [41] reported that zinc promotes wound healing, combats the common cold, and lessens the severity of children's diarrhoea. Additionally, zinc is essential for preventing age-related illnesses like arthritis and muscle deterioration, according to [42]. Rahimzadeh et al. [43] also concluded that eating a lot of these fish that contain more zinc may cause acute adverse effects such as nausea, vomiting, loss of appetite, cramping in the abdomen, diarrhoea, and headaches.

Table 3.
Comparison of biometric and the level of metal concentration in different tissues of randomly selected frozen fish sold at the open market in Ondo City, Southwest, Nigeria

Species		Weight (g)	Length (cm)	Cu- concentration (ppm)			Fe -concentration (ppm)			Zn- concentration (ppm)		
				Gill	Liver	Muscle	Gill	Liver	Muscle	Gill	Liver	Muscle
Mackerel	Mean	245.3**	27.93	0.012	0.018	0.017	0.124	0.087	0.178	0.29	0.297	0.362
	SE	12.27	0.3	0.069	0.004	0.01	0.012	0.01	0.02	0.07	0.049	0.069
Herring	Mean	163.3	27.57	0.025	0.023	0.027	0.111	0.119	0.161	0.328	0.347	0.327
	SE	6.67	0.581	0.014	0.012	0.014	0.005	0.000578	0.027	0.104	0.051	0.057
Hake	Mean	214*	24.47	0.043	0.005	0.035	0.166	0.127	0.158	0.319	0.272	0.262
	SE	13.21	0.917	0.01	0.005	0.019	0.024	0.015	0.012	0.021	0.2	0.03
WHO (ppm)				0.2.25			0.3			1.0		
FEPA (ppm)				1.3-3.0			0.3			0.075		

Key: WHO = World Health Organization, FEPA = Federal Environmental Protection Agency limit, *Significant

Table 4.

Summary of one- way ANOVA results of biometric and level of metal concentration in different tissues of the fishes

Values	Weight	Length	Cu-concentration			Fe- concentration			Zn-concentration		
			Gill	Liver	Muscle	Gill	Liver	Muscle	Gill	Liver	Muscle
F	13.920	8.590	2.202	1.280	0.347	3.488	4.181	0.275	0.073	0.806	0.870
P value	0.005	0.017	0.191	0.344	0.719	0.098	0.072	0.768	0.929	0.489	0.465
R squared	0.8227	0.822	0.423	0.299	0.103	0.537	0.582	0.083	0.0239	0.211	0.224

*p value < 0.05 is significant

4. Conclusion

This study had shown that Atlantic Herring (*Clupea harengus*), Mackerel (*Scomber scombrus*), and Hake (*Merluccius merluccius*), which are the commonly consumed frozen fish vended in Ondo City, Ondo State, Nigeria, contained essential heavy metals that were within the range or below the range prescribed by the WHO and FEPA, except for zinc, which was above the recommended levels prescribed by FEPA across all three organs investigated in all three species of the fish. However, levels of zinc should be monitored as this metal could pass to humans and predispose consumers to possible health hazards. In view of the importance of fish to the human diet, it is necessary that regular biological monitoring of the fish meant for consumption should be done to ensure the continuous safety of fish food. It's not enough to simply measure a single metal in a single tissue; regulators must consider the organism's size, the distribution of metals across different tissues, and the potential interactions between various metals to provide accurate and safe consumption guidelines for the public. Hence, further studies on the concentration of heavy metals in other fish tissues (brain, liver, kidney, intestines, and heart) are recommended.

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6. References

- [1]. Smith, M., Love, D. C., Rochman, C. M., & Neff, R. A. (2018). Microplastics in seafood and the implications for human health. *Current Environmental Health Reports*, 5, 375-386.
- [2]. Kawarazuka, N., & Béné, C. (2011). The potential role of small fish species in improving micronutrient deficiencies in developing countries: building evidence. *Public Health Nutrition*, 14(11), 1927-1938.
- [3]. Tiarniyu A.M., Adesina I.A. (2021). Benefits and risks of aquaculture foods in primary health care: a mini review. *Journal of Food Quality and Hazards Control*. 8: 52-56.Doi: 10.18502/jfqhc.8.2.6468.
- [4]. Fawole, O. O., Ogundiran, M. A., Ayandiran, T. A., & Olagunju, O. F. (2007). Proximate and mineral composition in some selected freshwater fishes in Nigeria. *Internet Journal of Food Safety*, 9, 52-55.
- [5]. Adesina, A. J., Asaolu, S. S., Adefemi, S. O., Olaleye, A. A., Akinsola, A. F., & Idowu, K. A. (2021). Polycyclic Aromatic Hydrocarbons in Fresh and Smoked *Clupea harengus* and Hake Fish Consumed in Ekiti State, Nigeria, and their Health Implications. *Indian Journal of Public Health Research & Development*, 12(1), 545-555.
- [6]. Odioko, E., and Becer, Z. A. (2022). The economic analysis of the Nigerian fisheries sector: A Review. *Journal of Anatolian Environmental and Animal Sciences*, 7(2), 216-226.
- [7]. Olukunle, O. T. (2017). Profitability analysis of small-scale fishery enterprise in Nigeria. *Journal of Agricultural Science*, 9(3), 107-116.

- [8]. Pal, J., Shukla, B. N., Maurya, A. K., Verma, H. O., Pandey, G., & Amitha, A. (2018). A review on role of fish in human nutrition with special emphasis to essential fatty acids. *International Journal of Fisheries and Aquatic Studies*, 6(2), 427-430.
- [9]. Ringø, E., Olsen, R. E., Jensen, I., Romero, J., & Lauzon, H. L. (2014). Application of vaccines and dietary supplements in aquaculture: possibilities and challenges. *Reviews in Fish Biology and Fisheries*, 24, 1005-1032.
- [10]. Balami, S., Sharma, A., & Karn, R. (2019). Significance of nutritional value of fish for human health. *Malaysian Journal of Halal Research*, 2(2), 32-34.
- [11]. Chanda, S., Paul, B. N., Ghosh, K., & Giri, S. S. (2015). Dietary essentiality of trace minerals in aquaculture: A Review. *Agricultural Reviews*, 36(2), 100-112.
- [12]. Knap, P. W. (2022). Drivers of Animal Source Food Consumption: A Biophysical Approach. *Frontiers in Sustainable Food Systems*, 5, 532.
- [13]. Maulu, S., Nawanzi, K., Abdel-Tawwab, M., & Khalil, H. S. (2021). Fish nutritional value as an approach to children's nutrition. *Frontiers in Nutrition*, 1090.
- [14]. Gibson, E., Stacey, N., Sunderland, T. C., & Adhuri, D. S. (2020). Dietary diversity and fish consumption of mothers and their children in fisher households in Komodo District, eastern Indonesia. *PloS one*, 15(4), e0230777.
- [15]. Jinadasa, B. K. K. K., & Fowler, S. W. (2019). Critical review of mercury contamination in Sri Lankan fish and aquatic products. *Marine Pollution Bulletin*, 149, 110526.
- [16]. Omer, A. K., Mohammed, R. R., Ameen, P. S. M., Abas, Z. A., & Ekici, K. (2021). Presence of biogenic amines in food and their public health implications: A review. *Journal of Food Protection*, 84(9), 1539-1548.
- [17]. Al-Busaidi, M. A., Jukes, D. J., & Bose, S. (2016). Seafood safety and quality: An analysis of the supply chain in the Sultanate of Oman. *Food Control*, 59, 651-662.
- [18]. King, T., Cole, M., Farber, J. M., Eisenbrand, G., Zabar, D., Fox, E. M., & Hill, J. P. (2017). Food safety for food security: Relationship between global megatrends and developments in food safety. *Trends in Food Science & Technology*, 68, 160-175.
- [19]. Shaibur, M. R., Hasnat, A., Shamim, M. D., Huq, S. M., & Kawai, S. (2010). Comparison of digesting capacity of nitric acid and nitric acid-perchloric acid mixture and the effect of lanthanum chloride on potassium measurement. *Nature and Science*, 157 – 162.
- [20]. Ghaedi, M., Mortazavi, K., Montazerzohori, M., Shokrollahi, A., & Soyak, M. (2013). Flame atomic absorption spectrometric (FAAS) determination of copper, iron, and zinc in food samples after solid-phase extraction on Schiff base-modified duolite XAD 761. *Materials Science and Engineering: C*, 33(4), 2338-2344.
- [21]. Van der Oost, R., Beyer, J., & Vermeulen, N. P. (2003). Fish bioaccumulation and biomarkers in environmental risk assessment: a review. *Environmental toxicology and pharmacology*, 13(2), 57-149.
- [22]. Roberts, E. A., & Sarkar, B. (2008). Liver as a key organ in the supply, storage, and excretion of copper. *The American Journal of Clinical Nutrition*, 88(3), 851S-854S.
- [23]. Wang, X., Liu, J., Tan, Q., Ren, J., Liang, D., & Fan, W. (2018). Development of multi-metal interaction model for *Daphnia magna*: Significance of metallothionein in cellular redistribution. *Ecotoxicology and Environmental Safety*, 151, 42-48.
- [24]. Sharma, R. K., & Agrawal, M. (2005). Biological effects of heavy metals: an overview. *Journal of Environmental Biology*, 26(2), 301-313.
- [25]. Olayinka-Olagunju, J. O. (2022). Heavy metal bioaccumulation and histopathological studies of fish tissues from Ose River, Ondo State, Nigeria. *European Journal of Environment and Earth Sciences*, 3(4), 70-78.
- [26]. Squadrone, S., Prearo, M., Brizio, P., Gavinelli, S., Pellegrino, M., Scanzio, T., ... & Abete, M. C. (2013). Heavy metals distribution in muscle, liver, kidney and gill of European catfish (*Silurus glanis*) from Italian Rivers. *Chemosphere*, 90(2), 358-365.
- [27]. Saha, N., Mollah, M. Z. I., Alam, M. F., & Rahman, M. S. (2016). Seasonal investigation of heavy metals in marine fishes captured from the Bay of Bengal and the implications for human health risk assessment. *Food Control*, 70, 110-118.
- [28]. Koyande, A. K., Chew, K. W., Rambabu, K., Tao, Y., Chu, D. T., & Show, P. L. (2019). Microalgae: A potential alternative to health supplementation for humans. *Food Science and Human Wellness*, 8(1), 16-24.
- [29]. Bhattacharya, P. T., Misra, S. R., & Hussain, M. (2016). Nutritional aspects of essential trace elements in oral health and disease: an extensive review. *Scientifica*, 2016.
- [30]. Osredkar, J., & Sustar, N. (2011). Copper and zinc, biological role and significance of copper/zinc imbalance. *Journal of Clinical Toxicology S*, 3(2161), 0495.
- [31]. Ogundiran, M. B., & Ojo, A. S. (2012). Determination of fat contents, iodine values, trace and toxic metals in commonly consumed frozen fish in Nigeria. *American Journal of Food Technology*, 7(1), 34-42.
- [32]. Engwa, G. A., Ferdinand, P. U., Nwalo, F. N., & Unachukwu, M. N. (2019). Mechanism and health

effects of heavy metal toxicity in humans. *Poisoning in the modern world-new tricks for an old dog*, 10, 70-90.

[33]. Al-Samarrai, M. K. O., Al-Samarraie, M. Q., & Alelyan, U. A. A. (2019). Estimation of white blood cells, hemoglobin, and copper levels in bakery workers. *Biochemical and Cellular Archives*, 19, 2327-2330.

[34]. Yilmaz, F., Özdemir, N., Demirak, A., & Tuna, A. L. (2007). Heavy metal levels in two quality and public health of selected towns in Southwestern Nigeria. *Water Quality, Exposure and Health*, 6, 143-153.

[35]. Abbaspour, N., Hurrell, R., & Kelishadi, R. (2014). Review on iron and its importance for human health. *Journal of research in medical sciences: The Official Journal of Isfahan University of Medical Sciences*, 19(2), 164.

[36]. Kontoghiorghes, C. N., & Kontoghiorghes, G. J. (2016). Efficacy and safety of iron-chelation therapy with deferoxamine, deferiprone, and deferasirox for the treatment of iron-loaded patients with non-transfusion-dependent thalassemia syndromes. *Drug Design, Development and Therapy*, 465-481.

[37]. Lokuruka, M. N. (2012). Role of zinc in human health with reference to the African elderly: A review. *African Journal of Food, Agriculture, Nutrition and Development*, 12(6).

[38]. Sandstead, H. H. (1995). Requirements and toxicity of essential trace elements, illustrated by zinc and copper. *The American Journal of Clinical Nutrition*, 61(3), 621S-624S.

[39]. Kopparapu, R. K., Ramirez, R., Kasting, J. F., Eymet, V., Robinson, T. D., Mahadevan, S., ... & Deshpande, R. (2013). Habitable zones around main-sequence stars: new estimates. *The Astrophysical Journal*, 765(2), 131.

[40]. Okogwu, O. I., Nwani, C. D., & Ugwumba, A. O. (2009). Seasonal variations in the abundance and biomass of microcrustaceans in relation to environmental variables in two shallow tropical lakes within the cross-river floodplain, Nigeria. *Acta Zoologica Lituanica*, 19(3), 205-215.

[41]. Bhowmik, D., Chiranjib, K., & Kumar, S. (2010). A potential medicinal importance of zinc in human health and chronic. *Int J Pharm*, 1(1), 05-11.

[42]. Mocchegiani, E., Costarelli, L., Giacconi, R., Piacenza, F., Basso, A., & Malavolta, M. (2012). Micronutrient (Zn, Cu, Fe)-gene interactions in ageing and inflammatory age-related diseases: implications for treatments. *Ageing Research Reviews*, 11(2), 297-319.

[43]. Rahimzadeh, M. R., Rahimzadeh, M. R., Kazemi, S., & Moghadamnia, A. A. (2020). Zinc poisoning: symptoms, causes, treatments. *Mini reviews in medicinal chemistry*, 20(15), 1489-1498.