

Comparative Determination Of Selected Heavy Metals In Different Brands Of Vegetable Oils Sold At International Market, Lokoja, Nigeria

Mohammed Suleiman¹, Ogedengbe Umezei Victor², Muhammed Karim Abdulrahim³

1Department of Science and Laboratory Technology

Kogi State Polytechnic, Lokoja

mohammedsuleimanozas@gmail.com

2Department of Science and Laboratory Technology

Kogi State Polytechnic, Lokoja

ogedengbevictor555@gmail.com

3Department of Science and Laboratory Technology

Kogi State Polytechnic, Lokoja

evernationswealth@gmail.com

Abstract: This study investigated the comparative determination of selected heavy metals in different brands of vegetable oils sold at International Market, Lokoja, Nigeria. Three brands of vegetable oil samples were analyzed for iron (Fe), copper (Cu), chromium (Cr), cadmium (Cd), and lead (Pb) using Atomic Absorption Spectrophotometry (AAS). The results showed varying concentrations of the heavy metals among the samples. Sample B recorded the highest concentration of iron (1.2400 ppm), while Sample C had the highest concentrations of copper (0.2200 ppm) and lead (0.0800 ppm). Cadmium was detected only in Sample A (0.0800 ppm) and was below the detection limit in the other samples. The variations observed suggest differences in environmental conditions, agricultural practices, processing methods, and storage conditions. Although the concentrations detected were generally low, continuous consumption of contaminated vegetable oils may pose health risks due to bioaccumulation of heavy metals in the body. The study recommends regular monitoring of vegetable oils by regulatory agencies and strict adherence to good manufacturing practices to ensure food safety.

Keywords: Heavy metals, vegetable oils, Atomic Absorption Spectrophotometry, food safety, contamination, bioaccumulation

1. Introduction

1.1 Background to the Study

Vegetable oils are among the most widely consumed food products globally and serve as essential components of human diets. They are primarily derived from plant sources such as seeds, nuts, and fruits, and are valued for their nutritional benefits, including the provision of essential fatty acids, fat-soluble vitamins, and energy. Due to their extensive use in cooking, food processing, and industrial applications, vegetable oils play a significant role in food security and nutrition, particularly in developing countries like Nigeria.

Despite their nutritional importance, concerns have been raised regarding the safety and quality of vegetable oils, especially in relation to contamination by heavy metals. Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are toxic elements that can accumulate in food products through environmental pollution, agricultural practices, and industrial processing. These metals are non-biodegradable and persist in the environment, making them capable of entering the food chain and posing serious health risks to consumers (Barau et al., 2025).

Food consumption is recognized as one of the primary routes through which humans are exposed to heavy metals. Contamination of edible oils can occur at various stages, including cultivation of oil-bearing crops, harvesting, processing, storage, and transportation. Environmental factors such as polluted soil, irrigation with contaminated water, industrial emissions, and the use of agrochemicals contribute significantly to the accumulation of heavy metals in plant materials (Yohannes et al., 2024).

Additionally, processing techniques such as extraction, refining, bleaching, and packaging may introduce or increase the concentration of heavy metals in vegetable oils. Equipment used in processing, as well as storage containers, can serve as sources of contamination. Studies have shown that certain locally produced and marketed vegetable oils may contain heavy metal concentrations exceeding recommended safety limits, thereby posing potential risks to human health (Yohannes et al., 2024).

Heavy metals are classified into essential and non-essential elements. While some metals like iron (Fe), zinc (Zn), and copper (Cu) are required in trace amounts for normal physiological functions, excessive concentrations can be harmful. On the other hand, non-essential metals such as lead, cadmium, and mercury are highly toxic even at low concentrations and have no known beneficial role in the human body (Negassa et al., 2025).

The health implications of heavy metal exposure are severe and may include neurological disorders, kidney damage, liver dysfunction, cardiovascular diseases, and cancer. Chronic exposure, even at low levels, can lead to bioaccumulation in body tissues over time, resulting in long-term health complications. This is particularly concerning in developing countries where regulatory monitoring and quality control mechanisms may be inadequate.

In recent years, there has been growing global concern regarding food safety, particularly in relation to contaminants such as heavy metals. Regulatory bodies such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) have established permissible limits for heavy metals in food products, including vegetable oils, to safeguard public health. However, compliance with these standards varies across regions, especially in areas with limited enforcement capacity.

Given the widespread consumption of vegetable oils and the potential health risks associated with heavy metal contamination, it is essential to monitor and evaluate the levels of these metals in different brands of vegetable oil. Comparative studies are particularly important as they provide insights into variations in contamination levels among different products, thereby helping consumers make informed choices and guiding regulatory agencies in enforcing food safety standards.

1.2 Statement of the Problem

The increasing demand for vegetable oils in Nigeria and other developing countries has led to a proliferation of both locally produced and imported brands in the market. While these products are essential for daily consumption, there is growing concern about their safety due to possible contamination with heavy metals.

Heavy metals can enter vegetable oils through multiple pathways, including environmental pollution, agricultural inputs, and industrial processing. In many cases, these contaminants are not easily detectable without laboratory analysis, making it difficult for consumers to assess the safety of the products they consume. Studies have reported that some edible oils contain heavy metals at concentrations exceeding permissible limits, thereby posing potential health risks (Yohannes et al., 2024).

In Nigeria, the situation is further compounded by inadequate monitoring and enforcement of food safety regulations. Many locally produced vegetable oils are processed under conditions that may not meet standard quality control requirements. Additionally, the lack of routine testing for heavy metals in food products increases the likelihood of contaminated products reaching consumers. The continuous consumption of contaminated vegetable oils can lead to the accumulation of toxic metals in the body, resulting in serious health complications over time. Despite these risks, there is limited data on the comparative levels of heavy metals in different brands of vegetable oils available in the Nigerian market.

Therefore, there is a need to investigate and compare the concentrations of selected heavy metals in various vegetable oil brands to determine their safety and compliance with established standards. This study seeks to address this gap by providing empirical data on heavy metal contamination in vegetable oils.

1.3 Aim and Objectives of the Study

1.3.1 Aim of the Study

The main aim of this study is to comparatively determine the levels of selected heavy metals in different brands of vegetable oils.

1.3.2 Objectives of the Study

The specific objectives are to:

- i. Determine the concentration of selected heavy metals (Pb, Cd, Fe, Cu, and Cr) in different brands of vegetable oil.
- ii. Compare the levels of heavy metals among the selected vegetable oil brands.
- iii. Evaluate the concentrations obtained against WHO/FAO permissible limits.
- iv. Assess the potential health risks associated with the consumption of the vegetable oils.

1.4 Significance of the Study

This study is significant in several ways. Firstly, it will contribute to existing knowledge on food safety by providing current data on the levels of heavy metals in vegetable oils. Given the increasing concerns about food contamination, this study will serve as a valuable reference for researchers and scholars in the field of food science and environmental health.

Secondly, the findings of this study will be beneficial to regulatory agencies such as the National Agency for Food and Drug Administration and Control (NAFDAC) in Nigeria. The data generated will assist in monitoring and enforcing food safety standards, ensuring that vegetable oil products in the market meet acceptable quality requirements.

Thirdly, this study will help raise awareness among consumers about the potential risks associated with heavy metal contamination in vegetable oils. By providing comparative information on different brands, consumers will be better equipped to make informed choices regarding the products they purchase and consume.

Furthermore, the study will provide useful information to manufacturers and producers of vegetable oils. It will highlight the importance of adhering to good manufacturing practices and implementing quality control measures to minimize contamination during production and processing.

1.5 Scope of the Study

This study focuses on the comparative determination of selected heavy metals in different brands of vegetable oil. The study involves the analysis of commonly consumed vegetable oil brands available in the study area. The heavy metals to be analyzed include lead (Pb), cadmium (Cd), Iron (Fe), Copper (Cu), and Chromium (Cr), due to their known toxicity and public health significance.

1.6 Limitations of the Study

The study is limited to selected brands and does not cover all vegetable oil products available in the market. Additionally, the research was conducted within a specific geographical location, and the findings may not be generalized to other regions without further investigation.

2. Literature Review

2.1 Conceptual Framework

2.1.1 Overview of Vegetable Oils

Vegetable oils are naturally occurring lipids extracted from various parts of plants, including seeds, nuts, and fruits. They constitute a major component of the human diet and are widely used in both domestic cooking and industrial food processing. Common sources of vegetable oils include oil palm (*Elaeis guineensis*), soybean (*Glycine max*), sunflower (*Helianthus annuus*), groundnut (*Arachis hypogaea*), coconut (*Cocos nucifera*), and rapeseed (*Brassica napus*). These oils are highly valued due to their availability, affordability, and nutritional contributions to human health (Ogunniyi et al., 2021).

Vegetable oils are primarily composed of triglycerides, which consist of glycerol molecules esterified with three fatty acids. The nature and proportion of these fatty acids determine the physicochemical properties and nutritional value of the oil. Fatty acids in

vegetable oils are broadly classified into saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs). Oils rich in unsaturated fatty acids, such as sunflower and soybean oil, are considered healthier due to their role in reducing low-density lipoprotein (LDL) cholesterol levels and promoting cardiovascular health (Aremu et al., 2022).

In addition to triglycerides, vegetable oils contain minor constituents such as phospholipids, tocopherols (vitamin E), sterols, pigments, and trace elements. These minor components contribute to the stability, flavor, color, and nutritional quality of the oils. For instance, tocopherols act as natural antioxidants that help prevent oxidative rancidity, thereby extending the shelf life of oils (Aremu et al., 2022). However, the presence of trace elements, including heavy metals, may negatively affect both the quality and safety of vegetable oils.

The extraction of vegetable oils can be carried out using different methods, including mechanical pressing and solvent extraction. Mechanical pressing, also known as cold pressing, involves physically squeezing oil from plant materials without the use of chemicals. This method is often preferred for producing high-quality oils with minimal chemical alteration. On the other hand, solvent extraction involves the use of organic solvents such as hexane to extract oil more efficiently, especially on an industrial scale. While solvent extraction yields higher quantities of oil, it may introduce contaminants if not properly managed (Ogunniyi et al., 2021).

Following extraction, vegetable oils often undergo refining processes to improve their quality, safety, and consumer acceptability. The refining process typically includes several stages: degumming, neutralization, bleaching, and deodorization. Degumming removes phospholipids and mucilaginous substances; neutralization eliminates free fatty acids; bleaching removes pigments and impurities; while deodorization eliminates undesirable odors and flavors. Although these processes enhance the sensory qualities of oils, they may also alter their nutritional composition and, in some cases, influence the concentration of contaminants such as heavy metals (Aremu et al., 2022).

Vegetable oils are classified based on their level of processing into crude oils, refined oils, and specialty oils. Crude oils are unrefined and retain most of their natural components, including impurities. Refined oils are processed to meet safety and quality standards and are the most commonly consumed. Specialty oils, such as extra virgin oils, are minimally processed and are often marketed for their superior nutritional and sensory qualities.

In terms of functionality, vegetable oils serve multiple purposes. In cooking, they are used for frying, baking, and sautéing due to their ability to transfer heat efficiently. In food processing, they are used in the production of margarine, mayonnaise, salad dressings, and snack foods. Industrially, vegetable oils are utilized in the manufacture of soaps, cosmetics, biodiesel, and pharmaceuticals (Ogunniyi et al., 2021).

Globally, the production and consumption of vegetable oils have increased significantly over the years due to population growth, urbanization, and changing dietary patterns. In developing countries like Nigeria, vegetable oils are staple food items and are consumed daily in various forms. Palm oil, in particular, is widely consumed due to its affordability and local availability. However, the high demand for vegetable oils has led to increased production activities, some of which may not adhere to strict quality control standards, thereby increasing the risk of contamination.

One of the major concerns associated with vegetable oils is their susceptibility to contamination by heavy metals. These contaminants can be introduced at various stages, including cultivation, harvesting, processing, storage, and distribution. Environmental factors such as polluted soil, water, and air contribute significantly to the contamination of oil-bearing crops. Additionally, the use of metal equipment during processing and storage can lead to leaching of metals into the oil (Barau et al., 2025).

The presence of heavy metals in vegetable oils not only affects their quality but also poses serious health risks to consumers. Unlike microbial contaminants, heavy metals are not destroyed by heat or processing and can accumulate in the human body over time. This makes their presence in widely consumed products like vegetable oils a significant public health concern (Negassa et al., 2025).

In recent years, there has been increasing attention on the need to ensure the safety and quality of vegetable oils through proper monitoring and regulation. International organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) have established guidelines and permissible limits for contaminants in food products, including vegetable oils. Compliance with these standards is essential to protect public health and ensure consumer confidence.

2.1.2 Composition and Nutritional Importance of Vegetable Oils

Vegetable oils are complex mixtures of chemical compounds, primarily composed of lipids that play essential roles in human nutrition and overall health. The major component of vegetable oils is triglycerides, which typically constitute about 95–98% of the total composition. Triglycerides are formed from one molecule of glycerol esterified with three fatty acid chains. The structural diversity of these fatty acids largely determines the physical, chemical, and nutritional properties of the oil (Aremu et al., 2022).

1. Fatty Acid Composition of Vegetable Oils

Fatty acids present in vegetable oils are broadly categorized into saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs). Saturated fatty acids, such as palmitic acid and stearic acid, contain no double bonds and are typically solid at room temperature. Oils with high saturated fat content, such as palm oil and coconut oil, are more resistant to oxidation but may contribute to increased cholesterol levels when consumed excessively (Ogunniyi et al., 2021).

Monounsaturated fatty acids, such as oleic acid, contain one double bond and are considered beneficial for cardiovascular health. They help reduce low-density lipoprotein (LDL) cholesterol while maintaining or increasing high-density lipoprotein (HDL) cholesterol levels. Oils such as olive oil and groundnut oil are rich in MUFAs and are often recommended for healthy diets (Aremu et al., 2022).

Polyunsaturated fatty acids, including linoleic acid (omega-6) and alpha-linolenic acid (omega-3), contain two or more double bonds and are essential fatty acids that must be obtained from the diet. These fatty acids play critical roles in brain development, immune function, and inflammation regulation. Oils such as sunflower oil and soybean oil are rich sources of PUFAs (Lievens-Corneille et al., 2024).

2. Minor Components of Vegetable Oils

In addition to triglycerides, vegetable oils contain minor components that significantly influence their nutritional quality, stability, and functionality. These include:

- i. **Phospholipids:** Important for cell membrane structure and function.
- ii. **Tocopherols (Vitamin E):** Act as natural antioxidants that protect the oil from oxidative damage and also provide health benefits by reducing oxidative stress in the body.
- iii. **Phytosterols:** Known to lower cholesterol levels by inhibiting its absorption in the intestine.
- iv. **Pigments (e.g., carotenoids and chlorophyll):** Contribute to the color of oils and may have antioxidant properties.

These minor constituents, although present in small quantities, enhance the nutritional and therapeutic value of vegetable oils (Aremu et al., 2022).

2.1.3 Nutritional Importance of Vegetable Oils

Vegetable oils are vital sources of dietary energy, providing approximately 9 kcal per gram, which is higher than that of carbohydrates and proteins. This makes them an important energy source, particularly in regions where caloric intake may be inadequate.

They also serve as carriers for fat-soluble vitamins (A, D, E, and K), facilitating their absorption in the body. Without adequate dietary fat, the absorption of these vitamins would be significantly impaired, leading to potential deficiencies and associated health problems (Ogunniyi et al., 2021).

Furthermore, vegetable oils contribute to essential physiological functions. Essential fatty acids derived from vegetable oils are involved in the formation of cell membranes, hormone production, and regulation of metabolic processes. They also play a role in maintaining skin health, supporting brain function, and reducing inflammation (Negassa et al., 2025).

2.1.4 Health Implications of Vegetable Oil Consumption

The health effects of vegetable oils largely depend on their fatty acid composition and the presence of other bioactive compounds. Diets rich in unsaturated fats, particularly MUFAs and PUFAs, have been associated with reduced risk of cardiovascular diseases,

improved lipid profiles, and better overall health outcomes. Conversely, excessive consumption of saturated fats has been linked to increased risk of heart disease and obesity.

However, the nutritional benefits of vegetable oils can be compromised by contamination with harmful substances such as heavy metals. These contaminants can interfere with metabolic processes and negate the health benefits of the oils. For instance, heavy metals may induce oxidative stress, damage cellular structures, and impair organ function (Negassa et al., 2025).

2.1.5 Effect of Processing on Nutritional Composition

Processing methods, including refining, bleaching, and deodorization, can significantly affect the composition and nutritional quality of vegetable oils. While refining improves the sensory properties and removes impurities, it may also lead to the loss of beneficial components such as tocopherols and phytosterols. Additionally, high-temperature processing can result in the formation of undesirable compounds that may affect health (Aremu et al., 2022).

In contrast, minimally processed oils, such as cold-pressed oils, tend to retain more of their natural nutrients and bioactive compounds. However, they may also contain higher levels of impurities if not properly handled.

2.2 Heavy Metals in Food

Heavy metals are naturally occurring elements characterized by relatively high atomic weight and density, which are toxic or poisonous at low concentrations. In the context of food safety, heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) are of major concern due to their persistence in the environment, non-biodegradable nature, and potential to accumulate in living organisms. These metals enter the food chain through natural processes and anthropogenic activities, thereby posing significant risks to human health (Lievens-Corneille et al., 2024).

2.2.1 Definition and Characteristics of Heavy Metals

Heavy metals are defined as metallic elements with a density greater than 5 g/cm³ that exhibit toxic effects even at low concentrations. Unlike organic contaminants, heavy metals cannot be degraded into harmless substances and therefore remain in the environment for long periods. Their persistence allows them to accumulate in soils, water bodies, and living organisms, leading to increased exposure through the food chain (Negassa et al., 2025).

One of the key characteristics of heavy metals is their ability to undergo bioaccumulation and biomagnification. Bioaccumulation refers to the gradual accumulation of substances in an organism over time, while biomagnification refers to the increase in concentration of these substances as they move up the food chain. This means that even low levels of heavy metals in the environment can result in high concentrations in food products consumed by humans.

2.2.2 Classification of Heavy Metals in Food

Heavy metals present in food are generally classified into two categories:

1. Essential Heavy Metals

These are metals required in trace amounts for normal physiological functions. Examples include iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn). They play important roles in enzymatic activities, oxygen transport, and immune function. However, excessive intake of these metals can lead to toxicity and adverse health effects (Aremu et al., 2022).

2. Non-Essential Heavy Metals

These metals have no known biological function and are toxic even at very low concentrations. Examples include lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As). These metals interfere with biological processes and can cause severe health problems, making them the primary focus of food safety studies (Negassa et al., 2025).

2.2.3 Sources of Heavy Metals in Food

Heavy metals can enter food systems through both natural and anthropogenic sources:

1. **Natural Sources:** Weathering of rocks, volcanic eruptions, and natural soil composition contribute to the presence of heavy metals in the environment.
2. **Industrial Activities:** Mining, smelting, manufacturing, and waste disposal release heavy metals into the environment, contaminating soil and water.
3. **Agricultural Practices:** The use of fertilizers, pesticides, and sewage sludge can introduce heavy metals into agricultural soils.
4. **Environmental Pollution:** Air pollution from industrial emissions and vehicular exhaust can deposit heavy metals onto crops.
5. **Food Processing and Packaging:** Contamination may occur during processing through the use of metallic equipment or packaging materials (Barau et al., 2025).

These sources collectively contribute to the presence of heavy metals in food products, including vegetable oils.

2.2.4 Occurrence of Heavy Metals in Edible Oils

Vegetable oils are particularly susceptible to contamination by heavy metals due to their origin from plant materials that absorb metals from the soil. During oil extraction and processing, these metals may be transferred into the final product. Additionally, contamination may occur through contact with processing equipment, storage containers, and environmental pollutants (Yohannes et al., 2024).

Studies have shown that the concentration of heavy metals in vegetable oils varies depending on factors such as geographical location, agricultural practices, processing methods, and environmental conditions. In some cases, the levels of heavy metals detected in edible oils exceed recommended safety limits, raising concerns about their safety for consumption (Yohannes et al., 2024).

2.2.5 Toxicological Effects of Heavy Metals in Food

Heavy metals exert toxic effects on the human body through various mechanisms, including enzyme inhibition, oxidative stress, and disruption of cellular processes. The specific health effects depend on the type of metal and the level of exposure.

- **Lead (Pb):** Affects the nervous system, causing cognitive impairment, especially in children. It can also lead to kidney damage and hypertension.
- **Cadmium (Cd):** Primarily affects the kidneys and bones, leading to renal dysfunction and osteoporosis.
- **Mercury (Hg):** Causes neurological and developmental disorders, particularly in fetuses and young children.
- **Arsenic (As):** Associated with skin lesions, cardiovascular diseases, and various forms of cancer (Lievens-Corneille et al., 2024; Negassa et al., 2025).

Chronic exposure to these metals, even at low levels, can result in bioaccumulation in body tissues, leading to long-term health complications.

2.2.6 Regulatory Standards and Permissible Limits

To protect public health, international organizations have established maximum permissible limits for heavy metals in food. Agencies such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the European Food Safety Authority (EFSA) provide guidelines for acceptable levels of heavy metals in food products.

These standards are based on toxicological assessments and are designed to minimize health risks associated with dietary exposure. However, compliance with these standards varies across regions, particularly in developing countries where regulatory enforcement may be weak (EFSA, 2021).

Regular monitoring and analysis of food products are essential to ensure that heavy metal concentrations remain within safe limits. This is particularly important for widely consumed products such as vegetable oils.

2.3 Sources of Heavy Metal Contamination in Vegetable Oils

Heavy metal contamination in vegetable oils can occur at various stages of production and distribution. The major sources include:

2.3.1 Environmental Pollution

Environmental pollution is one of the most significant contributors to heavy metal contamination in vegetable oils. It involves the introduction of harmful substances, including heavy metals, into the natural environment—particularly soil, water, and air—through both natural processes and human activities. These pollutants are subsequently absorbed by plants and transferred into the food chain, ultimately affecting the quality and safety of vegetable oils derived from such plants (Barau et al., 2025).

1. Contamination of Soil

Soil serves as the primary medium through which plants obtain nutrients; however, it can also act as a reservoir for heavy metals. Environmental pollution arising from industrial activities such as mining, smelting, oil exploration, and manufacturing leads to the deposition of heavy metals like lead (Pb), cadmium (Cd), and arsenic (As) in the soil. Once present in the soil, these metals bind to soil particles and persist for long periods due to their non-biodegradable nature (Adesina et al., 2022).

Oil-bearing crops cultivated in contaminated soils absorb these heavy metals through their root systems. The extent of absorption depends on factors such as soil pH, organic matter content, and the specific characteristics of the plant species.

2. Water Pollution and Irrigation Practices

Water used for irrigation is another major pathway for heavy metal contamination. In many developing regions, irrigation water may be sourced from rivers, streams, or groundwater contaminated by industrial effluents, sewage discharge, and agricultural runoff. These water sources often contain significant levels of heavy metals, which are taken up by crops during growth (Yohannes et al., 2024).

Continuous use of contaminated water for irrigation leads to the gradual accumulation of heavy metals in agricultural soils and crops. This not only affects crop yield but also increases the concentration of heavy metals in food products, including vegetable oils.

3. Air Pollution and Atmospheric Deposition

Air pollution is another important route through which heavy metals enter the environment. Industrial emissions, vehicular exhaust, and combustion of fossil fuels release heavy metals into the atmosphere in the form of particulate matter. These particles eventually settle on soil and plant surfaces through a process known as atmospheric deposition (Barau et al., 2025).

Oil-producing plants can absorb these deposited metals either directly through their leaves or indirectly through contaminated soil. This contributes to the overall accumulation of heavy metals in plant tissues, which may subsequently be transferred to vegetable oils during extraction.

4. Impact of Oil Spillage and Industrial Waste

In regions where oil exploration and industrial activities are prevalent, such as parts of Nigeria, oil spills and improper disposal of industrial waste significantly contribute to environmental pollution. Crude oil contamination introduces heavy metals into the soil and water, creating long-term environmental hazards. Studies have shown that agricultural soils affected by crude oil spills contain elevated levels of heavy metals, which are readily absorbed by crops (Adesina et al., 2022).

Similarly, improper disposal of industrial and municipal waste leads to the release of heavy metals into the environment. Open dumping and landfill leachates can contaminate nearby agricultural lands, further increasing the risk of heavy metal uptake by plants.

5. Persistence and Bioavailability of Heavy Metals

One of the major challenges associated with environmental pollution is the persistence of heavy metals. Unlike organic pollutants, heavy metals do not degrade over time. Instead, they remain in the environment and may even increase in concentration due to continuous deposition.

The bioavailability of heavy metals—i.e., the extent to which they can be absorbed by plants—depends on environmental conditions such as soil composition, pH, and temperature. Acidic soils, for example, tend to increase the solubility and mobility of heavy metals, making them more available for plant uptake (Negassa et al., 2025).

6. Implications for Vegetable Oil Safety

The contamination of soil, water, and air directly affects the safety of vegetable oils. Since oil-bearing crops act as intermediaries between the environment and the final food product, any contamination in the environment is likely to be reflected in the oil produced from these crops. This highlights the importance of environmental monitoring and pollution control in ensuring the safety of vegetable oils.

Furthermore, the widespread nature of environmental pollution means that even oils produced under seemingly controlled conditions may still be at risk of contamination. Therefore, regular testing and adherence to environmental and food safety standards are essential to minimize the risks associated with heavy metal contamination.

2.3.2 Agricultural Practices

Agricultural practices play a crucial role in the introduction and accumulation of heavy metals in vegetable oils. The methods and inputs used during crop cultivation significantly influence the level of contamination in oil-bearing plants. These practices, although aimed at improving crop yield and productivity, can inadvertently introduce toxic metals into the soil-plant system, thereby affecting the safety of derived food products such as vegetable oils (Barau et al., 2025).

1. Use of Chemical Fertilizers

The application of inorganic fertilizers is a common agricultural practice used to enhance soil fertility and improve crop yield. However, many phosphate-based fertilizers contain trace amounts of heavy metals such as cadmium (Cd), lead (Pb), and arsenic (As) as impurities. Continuous and excessive application of these fertilizers leads to the gradual accumulation of these metals in the soil (Adesina et al., 2022).

Over time, the concentration of heavy metals in fertilized soils may reach levels that are harmful to plants and humans. Oil-bearing crops grown in such soils absorb these metals through their root systems, and the metals are subsequently transferred into the oil extracted from the crops. This makes fertilizer application a significant contributor to heavy metal contamination in vegetable oils.

2. Application of Pesticides and Herbicides

Pesticides and herbicides are widely used to control pests, diseases, and weeds in agricultural production. Some of these agrochemicals contain heavy metals or are contaminated with metallic residues during manufacturing. For example, certain fungicides and insecticides may contain copper (Cu), arsenic (As), or mercury (Hg) compounds.

Frequent use of these chemicals can lead to the accumulation of heavy metals in agricultural soils. Additionally, these substances may directly deposit on plant surfaces, where they can be absorbed into plant tissues. This contributes to the overall metal load in oil-producing crops and increases the risk of contamination in vegetable oils (Negassa et al., 2025).

3. Use of Contaminated Irrigation Water

Irrigation is essential for crop production, especially in regions with limited rainfall. However, the use of contaminated water for irrigation is a major pathway for heavy metal introduction into agricultural systems. Water sources such as rivers, lakes, and groundwater may be polluted with industrial effluents, sewage, and agricultural runoff containing heavy metals (Yohannes et al., 2024).

When such water is used for irrigation, heavy metals are deposited into the soil and subsequently taken up by crops. Continuous irrigation with contaminated water leads to the buildup of heavy metals in both soil and plant tissues, thereby increasing the likelihood of contamination in vegetable oils derived from these crops.

4. Use of Sewage Sludge and Organic Manure

In some agricultural systems, sewage sludge and animal manure are used as organic fertilizers to improve soil fertility. While these materials are rich in nutrients, they may also contain significant levels of heavy metals, especially when derived from urban or industrial sources.

The application of contaminated sludge or manure introduces heavy metals into the soil, where they may persist and accumulate over time. Oil-producing crops grown in such conditions can absorb these metals, which may eventually be detected in the extracted oils (Barau et al., 2025).

5. Poor Agricultural Practices and Land Management

Improper land management practices, such as over-cultivation, deforestation, and lack of soil conservation measures, can exacerbate the problem of heavy metal contamination. Soil erosion, for instance, can redistribute contaminated soil particles, spreading heavy metals to previously uncontaminated areas.

Additionally, the cultivation of crops on lands previously exposed to industrial activities or waste disposal sites increases the risk of contamination. Such lands often contain elevated levels of heavy metals, which can be readily taken up by plants (Adesina et al., 2022).

6. Bioaccumulation in Oil-Bearing Crops

Oil-bearing crops such as soybean, sunflower, and groundnut have the ability to absorb and accumulate heavy metals from the soil and surrounding environment. The extent of accumulation depends on factors such as plant species, soil properties, and the type of metal involved.

Some plants are known as hyperaccumulators, meaning they can absorb high concentrations of heavy metals without showing visible signs of toxicity. While this characteristic may be beneficial for phytoremediation, it poses a risk for food safety when such plants are used for oil production. The accumulated metals can persist through the oil extraction process and contaminate the final product (Negassa et al., 2025).

7. Implications for Vegetable Oil Safety

The impact of agricultural practices on heavy metal contamination highlights the importance of adopting safe and sustainable farming methods. The use of contaminated inputs, poor land management, and inadequate monitoring can lead to increased levels of heavy metals in vegetable oils, thereby posing health risks to consumers.

To minimize contamination, it is essential to regulate the use of fertilizers, pesticides, and irrigation water. Implementing good agricultural practices (GAP), including soil testing, controlled use of agrochemicals, and proper waste management, can significantly reduce the risk of heavy metal accumulation in crops.

2.3.3 Processing and Refining

Processing and refining of vegetable oils are important industrial stages that transform crude oil extracted from oil-bearing plants into a consumable product with improved taste, appearance, stability, and shelf life. However, these processes can also contribute significantly to the introduction or alteration of heavy metal concentrations in vegetable oils. This occurs due to equipment contact, chemical usage, and inadequate processing conditions (Yohannes et al., 2024).

1. Oil Extraction Processes

Vegetable oil extraction is commonly carried out using two major methods: mechanical pressing and solvent extraction. Mechanical pressing involves the physical squeezing of oil from oil seeds using hydraulic or screw presses. While this method is considered relatively natural, contamination may still occur if the machinery used is made of metal alloys that can leach trace elements into the oil during processing, especially under high pressure and temperature conditions (Aremu et al., 2022).

Solvent extraction, on the other hand, involves the use of organic solvents such as hexane to dissolve oil from crushed seeds. Although this method yields higher oil quantities, improper handling, incomplete solvent removal, or contamination of solvents may

introduce impurities into the final product. In some cases, industrial-grade solvents may contain trace metallic residues that contribute to heavy metal contamination in oils.

2. Use of Processing Equipment and Machinery

One of the major sources of heavy metal contamination during processing is the use of metallic equipment such as grinders, crushers, pipelines, storage tanks, and refining vessels. These machines are often made of metals like iron, copper, and stainless steel, which may corrode or wear out over time.

When corrosion occurs, trace amounts of metals can leach into the oil, especially under conditions of high temperature, acidity, or prolonged contact. Poor maintenance of equipment further increases the likelihood of contamination. In small-scale or informal processing facilities, where equipment quality may be substandard, the risk of heavy metal contamination is even higher (Barau et al., 2025).

3. Refining Processes and Chemical Treatments

The refining of vegetable oils involves several stages, including degumming, neutralization, bleaching, and deodorization. Each stage is designed to remove impurities and improve oil quality; however, these processes can also influence the concentration of trace metals.

- i. **Degumming:** This process removes phospholipids and mucilaginous substances. If not properly controlled, residual metals bound to these compounds may remain in the oil.
- ii. **Neutralization:** Free fatty acids are removed using alkaline substances. Chemical reactions during this stage may cause redistribution of metal ions within the oil matrix.
- iii. **Bleaching:** Activated clays or bleaching earths are used to remove pigments and impurities. These materials may themselves contain trace amounts of heavy metals if not properly purified.
- iv. **Deodorization:** High-temperature steam distillation is used to remove volatile compounds. However, exposure to high temperatures may promote chemical reactions that affect metal stability in the oil (Aremu et al., 2022).

4. Contamination from Additives and Processing Aids

During refining, various additives and processing aids are used to improve efficiency and product quality. These include bleaching earth, filtration aids, and antioxidants. If these materials are not properly regulated or sourced from contaminated suppliers, they may introduce heavy metals into the oil.

For example, bleaching clays used in oil purification may naturally contain trace metals such as lead, cadmium, or arsenic. When used repeatedly or in large quantities, these materials can contribute to the overall heavy metal content of the final oil product (Negassa et al., 2025).

5. Packaging and Storage during Processing

After refining, vegetable oils are stored and packaged for distribution. The materials used for packaging, such as metal drums, plastic containers, or tins, can also influence contamination levels. Metal containers that are not properly coated or lined may corrode over time, especially when exposed to moisture or acidic conditions, leading to leaching of metals into the oil.

Storage conditions such as temperature, light exposure, and duration of storage may also affect the stability of oil and its interaction with packaging materials. Poor storage practices in informal markets increase the risk of contamination and quality deterioration (Yohannes et al., 2024).

6. Impact of Small-Scale Processing Units

In many developing regions, a significant proportion of vegetable oil production is carried out in small-scale or local processing units. These facilities often lack advanced technology, proper quality control systems, and strict hygiene standards. As a result, the risk of contamination from equipment, environment, and poor handling practices is higher compared to industrial-scale production.

Such small-scale processors may reuse old machinery, utilize unregulated chemicals, and operate under inadequate sanitary conditions, all of which contribute to increased heavy metal contamination in vegetable oils (Barau et al., 2025).

7. Implications for Food Safety

The presence of heavy metals introduced during processing and refining poses serious concerns for food safety. Unlike microbial contaminants, heavy metals are not eliminated through heat treatment or refining processes. Once present in the oil, they remain stable and can accumulate in the human body upon consumption.

This highlights the importance of strict quality control measures during oil processing, including regular monitoring of equipment, use of certified processing materials, and adherence to international safety standards such as those recommended by WHO and FAO.

2.3.4 Storage and Packaging

Storage and packaging are critical stages in the post-processing handling of vegetable oils. Although these stages occur after extraction and refining, they significantly influence the final quality, safety, and shelf stability of vegetable oils. Improper storage and packaging conditions can introduce or increase the concentration of heavy metals in vegetable oils, thereby posing potential health risks to consumers (Yohannes et al., 2024).

1. Packaging Materials as Sources of Contamination

Vegetable oils are commonly packaged in materials such as plastic containers, glass bottles, tin cans, and metal drums. Among these, metal-based packaging materials present a higher risk of heavy metal contamination due to possible corrosion and leaching. When oils are stored in metal containers that are not properly coated or lined, chemical reactions between the oil and the container surface may lead to the release of metals such as lead (Pb), iron (Fe), copper (Cu), and cadmium (Cd) into the oil (Aremu et al., 2022).

The risk of leaching is increased under conditions of high temperature, humidity, or prolonged storage. Acidic components naturally present in vegetable oils may also accelerate the corrosion of metallic containers, thereby increasing the likelihood of contamination over time.

2. Plastic Containers and Additive-Related Risks

Plastic containers are widely used for packaging vegetable oils due to their affordability and light weight. However, certain plastics may contain additives such as stabilizers, plasticizers, and colorants, some of which may contain trace amounts of heavy metals. Under unfavorable storage conditions, especially exposure to heat and sunlight, these additives may degrade and release harmful substances into the oil (Negassa et al., 2025).

Although plastic containers generally pose a lower risk of heavy metal contamination compared to metals, poor-quality plastics or recycled materials can still contribute to chemical contamination, particularly when regulatory standards are not strictly enforced.

3. Storage Conditions and Environmental Exposure

Storage conditions play a vital role in maintaining the quality and safety of vegetable oils. Oils stored in poorly ventilated, high-temperature, or humid environments are more susceptible to chemical degradation and contamination. Exposure to direct sunlight can accelerate oxidation processes, which may alter the chemical structure of oils and increase their interaction with storage materials.

In addition, storage facilities located near industrial areas or polluted environments may expose packaged oils to airborne contaminants, including heavy metal particles. These particles can settle on packaging surfaces and, in some cases, penetrate poorly sealed containers (Barau et al., 2025).

4. Duration of Storage and Shelf Life Effects

The length of time vegetable oils are stored before consumption also influences their susceptibility to contamination. Extended storage periods increase the likelihood of chemical interactions between the oil and its packaging material. Over time, these interactions may lead to gradual accumulation of trace metals in the oil.

Furthermore, prolonged storage can lead to oxidation and rancidity, which may alter the oil's chemical properties and increase its reactivity with contaminants. This is particularly important in markets where vegetable oils are stored for long periods under uncontrolled conditions before being sold to consumers (Yohannes et al., 2024).

5. Poor Packaging Practices in Informal Markets

In many developing countries, including Nigeria, a significant proportion of vegetable oils are distributed through informal markets. In such settings, packaging standards are often not strictly regulated. Oils may be sold in reused containers, unlabelled bottles, or improperly sealed packaging materials.

The reuse of containers that previously held industrial chemicals or other non-food substances poses a serious risk of contamination. Such containers may retain residues of heavy metals, which can leach into the vegetable oil during storage. Additionally, lack of proper labeling makes it difficult to track production and storage conditions, further increasing food safety concerns (Aremu et al., 2022).

6. Transportation and Handling During Storage

Transportation of packaged vegetable oils from production sites to markets also contributes to contamination risks. During transportation, oils may be exposed to extreme weather conditions, mechanical stress, and environmental pollutants. Poor handling practices, such as improper stacking or use of open vehicles, can increase exposure to dust and airborne contaminants containing heavy metals (Negassa et al., 2025).

Repeated transfer of oils between containers during distribution further increases the risk of contamination, especially when hygienic standards are not maintained.

7. Implications for Heavy Metal Contamination

Storage and packaging are often overlooked sources of heavy metal contamination in vegetable oils. However, evidence shows that these stages can significantly influence the final metal content of oils available for consumption. Since heavy metals are stable and non-degradable, once introduced during storage or packaging, they remain in the oil and may accumulate in the human body upon consumption.

This highlights the importance of using food-grade packaging materials, maintaining proper storage conditions, and enforcing strict regulatory oversight to minimize contamination risks.

2.4 Review of Empirical Studies

Several studies have investigated the presence of heavy metals in vegetable oils across different regions.

Yohannes et al. (2024) analyzed edible vegetable oils in Ethiopia and found varying concentrations of heavy metals, with some samples exceeding permissible limits. The study highlighted the need for regular monitoring and quality control.

Similarly, Aremu et al. (2022) reported the presence of trace metals in commonly consumed vegetable oils, emphasizing that contamination levels depend on processing methods and environmental conditions.

Barau et al. (2025) conducted a global review and concluded that heavy metal contamination in food crops is a widespread issue influenced by industrialization and poor environmental management.

Adesina et al. (2022) found that crude oil contamination significantly increases the concentration of heavy metals in agricultural soils, which subsequently affects food safety.

Negassa et al. (2025) emphasized the health risks associated with long-term exposure to heavy metals and called for stricter regulatory measures to ensure food safety.

Despite these studies, there is still limited data comparing heavy metal concentrations across different brands of vegetable oils within specific local markets, particularly in Nigeria. This gap underscores the need for the present study.

2.5 Summary of Literature Review

The literature reviewed indicates that vegetable oils are essential dietary components but are susceptible to contamination by heavy metals. The sources of contamination include environmental pollution, agricultural practices, and industrial processing. Heavy metals such as lead, cadmium, mercury, and arsenic pose serious health risks due to their toxic and bioaccumulative nature. Previous studies have demonstrated the presence of heavy metals in vegetable oils, with some exceeding recommended safety limits. However, there is a lack of comparative studies focusing on different brands within local markets.

This study, therefore, aims to fill this gap by providing a comparative analysis of heavy metal concentrations in selected vegetable oil brands.

3. Materials and Methods

3.1 Apparatus and Equipment

The following equipment were used:

- i. Atomic Absorption Spectrophotometer (AAS)
- ii. Hot plate
- iii. Analytical balance
- iv. Conical flasks (250 mL and 500 mL)
- v. Beakers
- vi. Measuring cylinders
- vii. Pipettes
- viii. Funnels
- ix. Digestion tubes
- x. Volumetric flasks
- xi. Whatman filter paper

3.2 Chemicals and Reagents

The following analytical grade reagents were used:

- i. Nitric acid (HNO_3)
- ii. Perchloric acid (HClO_4)
- iii. Hydrochloric acid (HCl)
- iv. Distilled/deionized water
- v. Standard solutions of Pb, Cd, Cr, Fe, and Cu

All reagents were of analytical grade to ensure accuracy and reliability of results.

3.3 Study Area

The study was carried out at International Market, Lokoja, where different brands of vegetable oil are commonly sold. The laboratory analysis was conducted in a chemistry laboratory equipped for heavy metal determination using Atomic Absorption Spectrophotometry (AAS). The study area was chosen based on accessibility of samples and availability of laboratory facilities.

3.4 Sample Collection

3.4.1 Selection of Samples

Different brands of commercially available vegetable oils were purchased randomly from markets within the study area. A total of 3 different brands were selected depending on availability.

3.4.2 Sampling Procedure

Samples were purchased in their original sealed containers. Each sample was properly labeled (Sample A, B, C). Samples were stored in clean polyethylene bottles to avoid contamination. All samples were transported to the laboratory for analysis.

3.5 Sample Preparation

Vegetable oil samples were homogenized by shaking thoroughly to ensure uniform distribution of components before analysis.

3.6 Heavy Metal Determination

Heavy metals analyzed include lead (Pb), cadmium (Cd), chromium (Cr), iron (Fe), and copper (Cu).

3.6.1 Preparation of Aqua Regia

The aqua regia was prepared using two concentrated acids: hydrochloric acid (HCl) and nitric acid (HNO₃) in the ratio 3:1.

3.6.2 Digestion of Samples

5 mL of each sample was weighed using an analytical weighing balance into a digestion beaker. 10 mL of aqua regia was measured into the beaker containing the samples and heated. As heating continued, some quantity of distilled water was added to avoid drying of the mixture until the mixture changed to colorless. The mixture was brought down and allowed to cool. The mixture was filtered using filter paper and a little distilled water was added to make up to 10 mL. The procedure was repeated for all the samples. The clear filtrate was put into sample bottles for AAS analysis for the determination of heavy metals.

3.7 Atomic Absorption Spectrophotometry (AAS)

The instrument was calibrated using standard solutions for each metal. Triplicate readings were taken for each sample to ensure precision. Blanks and certified reference materials were used to validate results. Detection limits: The method allowed detection of metals at concentrations as low as 0.001 mg/L.

3.8 Data Analysis

Data obtained from laboratory analysis were subjected to statistical analysis using descriptive and inferential methods. Results were compared with WHO/FAO permissible limits for heavy metals in food.

4. Results and Discussion

4.1 Results

4.1.1 Heavy Metal Concentration in Vegetable Oil

Table 4.1: Heavy Metal Concentration in Vegetable Oil Samples

Sample	Fe (ppm)	Cu (ppm)	Cr (ppm)	Cd (ppm)	Pb (ppm)
Blank	0.1000	0.1000	0.0100	0.0300	0.0100
A	0.1900	0.1100	0.0100	0.0800	0.0600
B	1.2400	0.1900	0.0700	BLD	0.0400
C	0.3300	0.2200	0.0300	0.0100	0.0800
Standard 1	0.1356	-	-	-	-
Standard 2	0.5067	-	-	-	-

BLD = Below Limit of Detection

The results showed that all the vegetable oil samples contained detectable amounts of iron (Fe), copper (Cu), chromium (Cr), and lead (Pb), while cadmium (Cd) was detected only in Sample A and was below the detection limit (BLD) in Samples B and C.

Sample B recorded the highest concentration of iron (1.2400 ppm), indicating a greater possibility of contamination from processing equipment or environmental sources. Sample C had the highest concentration of copper (0.2200 ppm) and lead (0.0800 ppm), suggesting possible contamination during storage or packaging.

Chromium concentration was highest in Sample B (0.0700 ppm), followed by Sample C (0.0300 ppm), while Sample A had the lowest value (0.0100 ppm).

Cadmium was only detected in Sample A (0.0800 ppm), indicating that this particular brand may have been exposed to contaminated raw materials or processing conditions.

Generally, the concentrations of the heavy metals varied among the vegetable oil brands, indicating differences in their sources of production, processing techniques, and storage conditions.

4.2 Discussion of Results

The presence of iron, copper, chromium, cadmium, and lead in the vegetable oil samples confirms that vegetable oils can act as carriers of heavy metal contaminants. This finding agrees with the study of Yohannes et al. (2024), who reported varying concentrations of heavy metals in edible vegetable oils marketed in Ethiopia.

The high concentration of iron in Sample B may be attributed to corrosion of metallic processing equipment or contamination from soil and water during cultivation. This observation supports the findings of Aremu et al. (2022), who reported that processing methods significantly influence metal contamination levels in vegetable oils.

The detection of lead in all samples is a matter of public health concern because lead is a toxic metal with no biological function in the human body. The result is consistent with the findings of Negassa et al. (2025), who reported that continuous exposure to lead may cause neurological disorders, kidney damage, and cardiovascular diseases.

Cadmium was only detected in Sample A and was absent in Samples B and C. This suggests variations in agricultural practices and environmental conditions during production. Similar observations were reported by Yohannes et al. (2024), who found that heavy metal concentrations differ among vegetable oil brands due to differences in processing and environmental exposure.

The occurrence of chromium in all samples may have originated from industrial pollution or processing equipment. According to Barau et al. (2025), environmental pollution and poor waste management contribute significantly to heavy metal contamination in food products.

Overall, the results indicate that although the concentrations of most metals were relatively low, continuous consumption of contaminated vegetable oils could lead to bioaccumulation and adverse health effects over time.

5. Conclusion and Recommendations

5.1 Conclusion

This study comparatively determined the concentrations of selected heavy metals in different brands of vegetable oils available in International Market, Lokoja. The results showed the presence of iron, copper, chromium, cadmium, and lead in varying concentrations.

Iron had the highest concentration among the metals analyzed, particularly in Sample B, while cadmium was only detected in Sample A. The variations in metal concentrations among the samples indicate differences in environmental conditions, agricultural practices, processing methods, and storage systems.

This study concludes that vegetable oils marketed in the study area contain trace levels of heavy metals and therefore require continuous monitoring to ensure consumer safety and compliance with WHO and FAO standards.

5.2 Recommendations

Based on the findings of this study, the following recommendations are made:

- i. Regulatory agencies such as the National Agency for Food and Drug Administration and Control (NAFDAC) should conduct routine monitoring of heavy metal concentrations in vegetable oils.
- ii. Manufacturers should adopt good manufacturing practices and use food-grade processing equipment to minimize contamination.
- iii. Farmers should avoid the use of contaminated irrigation water and excessive application of agrochemicals.
- iv. Proper packaging and storage conditions should be maintained to prevent contamination during distribution.
- v. Consumers should purchase vegetable oils from reputable manufacturers that comply with safety standards.
- vi. Further studies should be conducted using a larger number of samples and additional heavy metals.

References

- Adesina, F. P., Akinnifesi, O. J., Akinyemi, M. I., & Adesina, T. F. (2022). Occurrence and uptake of heavy metals in soil and plants associated with crude oil contamination. *Trends in Sciences*, 19(10), 1-10.
- Aremu, M. O., Adebayo, O. R., & Oladipo, I. C. (2022). Quality assessment and contamination profile of vegetable oils: A food safety perspective. *Journal of Food Science and Nutrition Research*, 5(3), 45-58.
- Barau, B. W., Abdulhameed, A., & Nayaya, J. (2025). Global heavy metal contamination trend in vegetables: A systematic review. *Research Journal of Environmental and Earth Sciences*, 11(2), 63-74.
- European Food Safety Authority (EFSA). (2021). Scientific opinion on the risks to public health related to the presence of heavy metals in food. *EFSA Journal*, 19(4), 1-50.
- Lievens-Corneille, M. M., Jocelyn, M. K., Patrick, N. M., Yannick, N. B., & Josaphat, N. P. (2024). Contamination levels of heavy metals and assessment of potential health risks in food samples: A systematic review. *International Journal of Toxicology and Risk Assessment*, 10, 1-15.

Negassa, D., Kebede, A., & Tesfaye, B. (2025). Health risks associated with heavy metal exposure in food systems: A review. *Environmental Health Insights*, 19, 1-12.

Ogunniyi, L. T., Akinyemi, S. O., & Bello, M. O. (2021). Composition and utilization of vegetable oils in food systems. *African Journal of Food Science*, 15(2), 22-34.

World Health Organization (WHO). (2021). *Guidelines for drinking-water quality and food contaminants*. WHO Press.

Yohannes, L., Feleke, H., Melaku, M. S., & Amare, D. E. (2024). Analysis of heavy metals and minerals in edible vegetable oils produced and marketed in Gondar City, Northwest Ethiopia. *BMC Public Health*, 24, 2204. <https://doi.org/10.1186/s12889-024-19695-0>