Determination of Levels of Selected Heavy Metals and Essential Elements in Rice Bran from Kwale, Kirinyaga and Kisumu Counties, Kenya

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DETERMINATION OF LEVELS OF SELECTED HEAVY METALS AND ESSENTIAL ELEMENTS IN RICE BRAN FROM KWALE, KIRINYAGA AND KISUMU COUNTIES, KENYA

KIPLANGAT PAUL

A THESIS SUBMITTED TO THE BOARD OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE CONFERMENT OF THE DEGREE OF MASTER OF SCIENCE IN CHEMISTRY OF THE UNIVERSITY OF KABIANGA

UNIVERSITY OF KABIANGA

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DECLARATION AND APPROVAL

Declaration by the Student

This thesis is my original work and has not been submitted for the conferment of a degree or award of a diploma in this or any other university.

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DEDICATION

… to my lovely wife Rosphela and our children.

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ABSTRACT

Kenya has, over the years, suffered from perennial food shortages. This is compounded by the dependence on rain-fed agriculture, which is unreliable, poor agricultural practices and low-yielding crop varieties. If this is not mitigated, it leads to malnourishment of the population. Children and even the elderly are most affected. This, therefore, calls for diversification of sources of food and enhancement of the nutritional value of existing ones. Some counties in Kenya, such as Kirinyaga, Kwale and Kisumu, are producing rice under irrigation farming. During milling of rice and a product called rice bran is produced, which is made up of the external layer of the seed, including the pericarp, tegmen and aleurone layer. Rice bran is usually disposed of as waste, though a small fraction is used as animal feeds. Numerous studies have shown that rice bran has positive nutritional and health benefits, including intestinal functions, anti-diabetic, anti-oxidant and anti-inflammatory properties. These benefits result from its ingredients, which include dietary fiber proteins and trace elements, among others. The metal components of rice bran depend on local soil composition; the quality of water used for irrigation and pollutants in that region. Thus, though rice bran is beneficial, there is little information on its safety for use as animal and human food. The purpose of this study was to determine the levels of metal elements: lead, arsenic, cadmium, chromium, mercury, manganese, magnesium, copper, zinc, iron, selenium and potassium in rice bran from Kwale, Kirinyaga and Kisumu counties of Kenya. From six randomly selected farms from each of these Counties, soil samples and rice of two commonly grown varieties were collected in the same farms. Rice was milled and freshly produced rice bran was collected. Rice bran samples were digested by a high-performance microwave digestion system at 200^0C (Ethos Up) using Nitric acid and the metal profile was generated using inductively coupled plasma mass spectrometry (ICP MS) and inductively coupled plasma optical emission spectroscopy (ICP OES). The levels of arsenic in rice bran ranged from 0.43 mg/Kg to 0.92 mg/Kg. 9.7% of the samples contained cadmium ranging from 0.03 mg/Kg to 2.78 mg/Kg. Chromium concentration in rice bran samples ranged from 1.13 mg/Kg to 3.79 mg/Kg. It was also noted that lead and mercury ranged from 0.0013 mg/Kg - 0.0087 mg/Kg and 0.000004 mg/Kg – 0.003 mg/Kg, respectively. The mean concentrations of Zn, Se, Fe, Mn, K, Mg and Cu (in mg/Kg) were 60.64, 1.05, 199.21, 240.15, 13307.77, 5623.26 and 6.07, respectively. Soil samples had Zn and Fe (in mg/Kg) ranging from 76.63 to 268.94 and 5183.63 to 82457.28, respectively. In addition, 11 % of the soil samples had Se levels below the detection limit of the instrument. The data was analyzed using ANOVA to determine variations of metal elements per cultivars and regions. The results of this study will inform farmers, nutritionists, policy makers and the general population on the safety and health benefits of rice bran. From the findings, it is recommended that irrigation water be analyzed to determine the relationship between the levels of metals in water and rice bran.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADB	African Development Bank
ARC	African Rice Centre
BAF	Bioaccumulation Factor
CDC	Centre for Disease Control.
DOM	Degree of Milling
DRB	Defatted rice bran
FFA	Free Fatty Acid
FRB	Fat rice bran
HRY	Head Rice Yield
KALRO	Kenya Agricultural and Livestock Research Organization
LBDA	Lake Basin Development Authority
LBDC	Lake Basin Development Company
MRGM	Mwea Rice Growers Multipurpose Cooperative society
MRM	Mwea Rice Mills
NERICA	New Rice for Africa
NCPB	National Cereals and Produce Board
NIA	National Irrigation Authority
RB	Rice bran
SSA	Sub-Saharan Africa.
WKRRDP	West Kenya Rainfed Rice Development Project
WHO	World Health Organization

OPERATIONAL DEFINITION OF TERMS

Aleurone	Protein stored as granules in the cells of plant seeds.
Cultivar	A plant variety that has been produced in cultivation by selective breeding.
Nutraceutical	Food or part of a food or substance in food that provides medical or health benefits.
Tegmen	A superficial layer or covering, usually of a plant or animal part.

CHAPTER ONE

INTRODUCTION

1.1 Overview

This chapter gives information on the background of the study, statement of the problem, justification of the study, objectives of the research, hypotheses and scope of the study.

1.2 Background of the Study

Rice production has increased significantly in the last three decades of 20th century. Between the 1940s and the late 1960s, the Green Revolution led to a surge in agricultural production in developing nations, mostly through the transfer of several research and technology efforts (Uma et al., 2025).

When the Sustainable Development Goals (SDGs) are phased out in 2030, the UN projects that there will be roughly 8.5 billion people on the globe. For more than half of the world's population, rice is a crucial crop for food and livelihood security (Darko et al., 2025). In comparison with Europe and North America, where population growth is slow, the demand for rice as a food is stronger in Asia and Africa due to their continued population rise.

The African nations that produce the least amount of rice have had low yields; the expansion of agricultural land has led to an increase in production. If nothing is done to lessen the obstacles to rice production, Africa's present lower rice output of roughly 2 t/ha is predicted to drop to 1.4 t/ha in the future (Darko et al., 2025a). China, the world's greatest rice producer, uses 48% less land than India, the second-largest rice producer. The employment of better varieties and climate-smart technology is anticipated to boost global rice output, even if it is anticipated that global rice acreage and yields may decrease in the future if existing issues like climate change are not addressed (Tang et al., 2022). In Asia, rice accounts for up to 50% of their daily caloric intake and a significant portion of their protein consumption. The amount of rice consumed by urban residents in sub-Saharan Africa has increased continuously, with a per capita consumption that has doubled since 1970. People's consumption of rice is steadily increasing in Latin American and Caribbean nations. Therefore, rice is particularly important for the nutrition of a substantial portion of the people in the Asia Pacific region, sections of Latin America and the Caribbean, and increasingly in Africa.

According to the Food and Agriculture Organization of the United Nations (FAO), 34.9 million tonnes of milled rice would be consumed in Africa by 2025. However, the amount and quality of rice produced in Africa today cannot meet consumer demand, and imports— primarily of Asian origin to fill the gap to the extent of about USD 5.5 billion per year (Darko et al., 2025). For many middle-class to upper-class households nowadays, rice is a staple meal. It is the second most significant source of calories in Africa and a significant source of energy for West Africans.

East Africa's consumption of milled rice was expected to be 3.1 million metric tones in 2006. East Africa used 2.8 million metric tones of milled rice annually on average throughout the five-year period from 2001 to 2005. The overall growth rate of sub-regional rice consumption was comparatively high rate of 2.7% annually. Madagascar, Mozambique, and Tanzania stand out as Africa's top rice-consuming countries per capita. Rice is the primary food staple in Madagascar, with a per capita food supply of over 100 kg per year annually (Bwire et al., 2025).

Kenya has experienced persistent food scarcity for many years. This is compounded by crop types that are not drought-resistant, uncertain rain patterns, poor agricultural techniques, and reliance on rain-fed agriculture (Oluoko-Odingo, 2011). Numerous people have suffered as a result of this, including malnourished children, school dropouts, and, in some severe cases, deaths, particularly of the elderly and young. Some Kenyan counties, such as Kirinyaga, Kwale, and Kisumu, use irrigation farming to produce rice (Uma et al., 2025).

Rice is the third most staple food after maize and wheat in Kenya. In Mwea and the coastal region with Arabic and Islamic influences, rice is traditionally consumed (Promar consultancy, 2016). In recent years, the country's rice output has been unable to keep up with the sharp rise in demand. Self- sufficiency of rice was as low as 11% in 2018 (Atera et al., 2018).

In order to produce refined milled rice, the husk (20%), bran layers (10%), clean rice or starchy endosperm (65%), and broken rice (5%) must all be carefully separated throughout the milling process. Cleaning, husking, whitening, polishing, and sorting are some of the crucial phases in the milling process of rice. Rough paddy rice's husk is removed to produce brown rice. As the paddy grains move between two abrasive surfaces at varying speeds, friction removes the husk. The husk is extracted by suction after dehusking and sent to a storage dump outside the mill. A skilled husker should remove 90% of the husk in a single pass, as it makes up 20% of the weight of the paddy. Milling will enhance taste, cooking properties and shelf life of rice.

During milling, rice seed and a product called rice bran are produced. Rice bran is made up of the external layer of the seed, which includes the pericarp, tegmen and aleurone layer (Spaggiari et al., 2021). While rice is mainly used as human food, rice bran, which makes a significant percentage of unprocessed rice, is underutilized (Yilmaz, 2023). A small percentage of rice bran is used as animal feeds, while most of it is disposed of as waste (Sharif et al., 2014). Rice bran is known to possess anti-diabetic, antioxidant, and anti-inflammatory activity and has also been demonstrated to aid human digestive processes (Pateriya & Kumar, 2020).

Despite these good attributes, rice bran can accumulate both essential and toxic metal elements depending on the cultivar and region where the rice is grown (Scutarașu & Trincă, 2023) (Hasan et al., 2022) (Arunrat et al., 2024). Therefore, diversifying the usage of rice bran requires information on its safety. Several recent studies have found stabilized rice bran to be nutritious and of health benefit (Zambrana et al., 2021) and efforts to integrate it into human food is underway (Odingo et al., 2025a); (Saji et al., 2020).

Rice crops are particularly susceptible to heavy metal toxicity since they depend on water for the majority of their growth. In the United States, white rice had median concentrations (in µg/Kg) of 131, 6.5 and 2.8 for arsenic (As), Cadmium (Cd) and lead (Pb), whereas brown rice had median concentrations (in µg/Kg) of 217 for arsenic, 17.4 for Cadmium and 4.5 for lead. White rice in Italy, India and Thailand had median concentrations (in µg/Kg) of 155, 3.6 and 8.4 for As, Pb and Cd (TatahMentan et al., 2020). Similar information on quantities and variation of metal elements in Kenyan rice bran is scanty.

The presence of excessive heavy metals in edible crops has a negative impact on food quality and the health of customers (Murtaza et al., 2015). For example, arsenic is known to induce lung, skin and bladder cancer (Rothenberg et al., 2017). Similarly, long-term consumption of food with acceptable amounts of these metals poses similar risks due to bioaccumulation in the consumer. For example, in China, Arsenic and Cadmium, respectively, have been reported to contribute 64.57 % and 22.38 % of metal health risk (Wei et al., 2023).

Therefore, the purpose of this research was to determine the levels of these metals and some essential elements such as selenium (Se), manganese (Mn), iron (Fe), zinc (Zn) and potassium (K) in rice bran samples from Kenya's Kirinyaga, Kwale, and Kisumu counties. Information obtained formed a solid scientific safety base on the use of rice bran in food and feeds formulation and thus increases its usability.

1.3 Statement of the Problem

While rice is produced mainly by irrigation in some regions of Kenya, its main use is limited to human food. Rice bran, a byproduct that results from rice milling, is known to possess both nutritional and health benefits that include antioxidant activity and aid human digestive processes, among others (Odingo et al., 2025). Due to industrialization, abuse of cultivating area, pollution of irrigation water, fertilizers and pesticides, rice may become contaminated with harmful metals such as arsenic (As), cadmium (Cd), and lead (Pb) (Pateriya & Kumar, 2020). Consuming agricultural products that have been irrigated with contaminated water increases the risk of bioaccumulation of toxins and illness. Due to Kenya's water scarcity, irrigated farming is common in urban and peri-urban regions and is supported by the large and ready market created by the country's growing population. It is impossible to overstate the danger of illness to farmers and consumers who irrigate their crops with water from contaminated streams (Linge et al., 2020). Heavy metals bioaccumulate in rice plants as a result of contamination of rice fields. Because heavy metals tend to accumulate up in crops and eventually make their way into the human body through the food chain, they are hazardous to human health. Certain chemicals have concentrations that rise over time and across the food chain due to bioaccumulation. As opposed to the abundance of chemicals in the environment, these substances are absorbed and retained in crops or bodies. Instead of being broken down or eliminated from crops, heavy metals accumulate up in them (Kong et al., 2018). The flow of heavy metals from the roots of the rice plant to the stem, leaves, and rice grains puts human health at risk (Shi et al., 2020).

However, Kenya is yet to tap these benefits and thus expand its usage from animal feed to human food. Despite these good attributes, rice bran can accumulate both essential and toxic metal elements depending on the region where the rice is grown (de Oliveira et al., 2021). Diversifying the usage of rice bran is in line with Sustainable Development Goals (SDG) number two, whose aim is to achieve 'zero hunger' (Heaphy, 2023). However, data on the safety and nutritional components of Kenyan rice bran are limited. This study evaluated the heavy metals and essential elements and created metal profiles and thus determined the safety and health benefits of Kenyan rice bran.

1.4 General Objective

To determine levels of selected heavy metals and essential elements in rice bran from Kwale, Kirinyaga and Kisumu Counties of Kenya.

1.5 Specific Objectives

The specific objectives of the study were:

i. To determine levels of heavy metals - lead, arsenic, cadmium, mercury and chromium in rice bran from Kwale, Kirinyaga and Kisumu counties of Kenya.
ii. To evaluate levels of essential elements - manganese, magnesium, copper, zinc, potassium, iron and selenium in rice bran from Kwale, Kirinyaga and Kisumu counties of Kenya.
iii. To determine the variation of metal profiles by cultivars and region.
iv. To determine the bioaccumulation of metals in rice bran.

1.6 The hypotheses (H_o)

i. There are no significant differences in levels of heavy metals in rice bran from Kwale, Kirinyaga and Kisumu counties of Kenya.

ii. There are no significant differences in levels of essential elements in rice bran from Kwale, Kirinyaga and Kisumu counties of Kenya.

iii. There is no significant variation in metal profiles by cultivars and region.

iv. There is no significant bioaccumulation of metals in rice bran.

1.7 Justification of the Study

There is potential to use rice bran to fortify human food and as animal feeds. Use of rice bran could only be recommended when safety and nutritional benefits have been established. Agricultural pesticide uses and production of chemicals that accumulate metals in soil and groundwater are examples of human activities that introduce heavy metals into rice and rice bran (Alengebawy et al., 2021). Thus, such rice and rice bran could contain both undesired heavy metals and essential metals that have health benefits. Metal composition of Kenyan rice bran was not adequately known. Thus, there was need to determine levels of selected heavy metals and selected essential elements in rice bran. Determination of this metal profile was used to ascertain the safety and nutritional value of rice bran. The results of this study will form a solid scientific basis for recommendations on the use of Kenyan rice bran.

1.8 Significance of the Study

The findings of this study will provide valuable information on the safety of Kenyan rice bran. This study will inform about the formulation of rice bran as human food and as animal feeds. Resultant new foods and feeds will be enhancing the diversification of rice bran use in Kenya. Subsequently, this, in the long run, contributes to value addition and improvement in food security.

1.9 The scope of the Study

The study narrowed down to the most common rice variety from selected regions. Komboka and Sindano were studied in Kisumu County. Pishori and Komboka were studied in Kirinyaga County while Supa and Pachanga were studied in Kwale County. Secondly, the study focused mainly on irrigation schemes regions. The study was also limited to metal profiles in rice bran (RB), bioaccumulation by cultivars and by region and not the distribution of metals on various parts of a rice paddy.

1.10 Limitations of the Study

The study was limited by the efficiency of the ICP instruments, which were used for analyses that required regular maintenance and servicing. The study also assumed that there was no potential contamination during storage and that there was no effect on seasonal variation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature that has been done on rice bran and existing gaps that have not been researched on.

2.2 Rice Farming in Kenya

Rice is primarily grown using irrigation method by small-scale farmers in Kenya's counties of Kirinyaga (Mwea), Bunyala in Busia, Tana Delta and Bura in Tana River, Vanga cluster in Kwale, Ahero, West Kano, South West Kano smallholder irrigation schemes within Kano Plains in Kisumu (National-Rice-Development-Strategy-2019-2030.Pdf, n.d.). Other areas include Lower Kuja in Migori, Maugo, Oluch Kimira in Homa Bay, Kimorigho and Buluma in Siaya. In Busia, Bungoma, Kakamega, Kwale, Kilifi, Meru, Isiolo, Migori, Baringo, and Murang'a, rice is also cultivated under rain-fed conditions, and over 300,000 rice farmers supply labor in addition to making a living from the crop's production. There is numerous rice mills located all around the nation for the processing and milling of rice, with capacities ranging from 1 to 3.5 tons/hour (Lower Kuja Irrigation Scheme – National Irrigation Authority, n.d.). The Mwea Irrigation Scheme is where the majority of these mills are located; most of them are privately held, with only a small number being publicly owned. The main farmer-run cooperative in Kirinyaga County's Mwea Irrigation System is the Mwea Rice Growers Multipurpose Cooperative Society (MRGM) (National-Rice-Development-Strategy-2019-2030.Pdf, n.d.).

2.2.1 Rice Cultivars

There are a number of rice cultivars available to growers for both upland and irrigated environments. Aromatic rice Basmati 217 is the most prominent variety in Kenya. Sindano and BW196 are varieties of conventionally irrigated rice that are grown by farmers. According to the National Irrigation Authority (NIA), Sindano IR, Basmati 370 and hybrid (Arize Gold & Arize 6444 Gold) are 90 %, 5 % and 5 % respectively in Ahero irrigation scheme (Ahero Irrigation Scheme – National Irrigation Authority, n.d.). In Mwea irrigation scheme, the most popular varieties of rice are Kenyan Pishori and Kwamboka (KALRO, 2018). Kwale County has a higher rice variety. The most popular varieties are Pachanga (44.8 %), Supa (25.4 %) and Kitumbo (22.4 %) (Kengo *et al*., 2021). In Kenya, farmers were given access to the Basmati 370 in the late 1990s as an improved cultivar that was irrigated and scented.

The West Kenya Rain-fed Rice Development Project (WKRRDP) was financed by the African Development Bank (ADB) in order to grow upland rice in Kenya. The WKRRDP initiative included a number of elements, including lending money and offering extension services to farmers, building rice milling areas, and conducting research on adaptation (Lake Basin Development Authority, 1991).

Asian rice (*Oryza sativa*) and African rice (*Oryza glaberrima*) were interspecifically hybridized to create the New Rice for Africa (NERICA), which was a creation of the African Rice Center (ARC). These cultivars created NERICA, which has given Sub-Saharan Africa (SSA) an opportunity to eliminate food shortage. NERICA combines the productivity of Asian rice with the hardiness of African rice. In 2004, ARC released the NERICA cultivars to Kenya for adaptation testing. Four (NERICA 1, NERICA 4, NERICA 10, and NERICA 11) of the eighteen NERICA cultivars examined were deemed appropriate and released to growers in 2008. The NERICAs produced between 3.5 and 5.0 t/ha of yield (Atera et al., 2018).

Komboka rice is distinguished from Pishori rice by having more tillers, a uniform crop stand, even and early maturity, aroma, higher yields, ease of threshing, longer panicles, resistance to diseases like Rice Yellow Mottle Virus (RYMV) and Blast, an attractive grain type, good plant height and no lodged hills as shown in the photo below (Plate 2.1).

Plate 2.1

Komboka rice variety

Google photo: (https://encryptedtbn0.gstatic.com/images?q=tbn:ANd9GcSD9B04Ss)

Supa rice variety is known for high yield, good taste and early maturity of about ninety days (Plate 2.2). It is highly resistant to weed but is susceptible to rice yellow mottle virus (SUPA BC - The Rice Variety with Benefits, 2014).

Plate 2.2

Supa Rice Variety

Google photo: SUPA BC rice growing in Zanzibar (Photo: L. Potterton/IAEA)

Pachanga rice variety is a traditional, local Kenyan variety that has a long maturity period of between three to four months. Its yield is less compared to other varieties like Komboka. It is often grown in rain-fed lowland conditions in coastal areas(Magoti et al., 2019).

2.2.3 Milling of Rice

The objective of rice milling is to create milled, polished, or white rice by removing the hulls and bran from harvested, dried rough rice. Milling has a wide range of meanings, both within the grain sector and throughout the many various industries in which it is used. In the rice industry, "milling" can refer to the entire process of cleaning, shelling, bran removal, and size sorting in a rice mill, or it can just refer to the single process of removing the bran or outer layers from brown rice in order to create a whole grain white rice product.

Rice milling can be done in one step, two step or multistep milling process. A one-step milling method produces milled or white rice straight from paddy by removing the husk and bran in a single pass. Brown rice is produced as an intermediate product after the husk and bran are removed independently in a two-step procedure. Rice will go through several processing stages in multistage milling. Rice milling methods can be divided into two groups based on whether the rice is milled in the village for local use or for marketing: Rice mills in villages and commercial mills.

The "Engleberg" coffee huller from the United States was modified for rice milling to create the single pass rice mill. In the past, this kind of rice mill was widely used in the majority of rice-producing nations. In Bangladesh and many other African nations, it remains the primary method for grinding parboiled paddy. The mills referred to as "iron hullers" or "single pass mills" are known for breaking paddy grain. The head rice recovery is about 30% of the milled rice due to the significant breakage, and the overall milled rice recovery is 53–55%. Two-stage rice mills or two different machines for husking and polishing are the two methods used for two-stage milling as shown in the photo below (Plate 2.3).

Plate 2.3

Two- Stage Milling Machine

Google photo: *(https://www.hayleysagriculture.com/agrotech-mini-combine-rice-mill)*

Their paddy intake capacity is usually between 0.5 and 1 ton per hour. In rural places, they are often utilized for custom milling services. A rubber roller husker plus a friction whitener makes up a standard small rice mill. With the exception of the lack of a husking knife, frictional whitener and the Engleberg have a very similar design. Compared to the single pass Engleberg huller, the small rice mill has better milling performance. Typically, milling recoveries exceed 65%. The use of mobile rice mills is a recent development. These usually comprise of a huller and a polisher mounted on a self-propelled truck or two-stage, single-pass mills.

2.2.4 Effect of milling on dietary composition

The amount of rice bran and germ layers that are removed during processing is determined by the degree of milling, which has an impact on rice quality. Essential elements like dietary fibre, vitamins, minerals, and healthy fats are abundant in these outer layers (Puri et al., 2014). The nutrient-rich layers are peeled away as the bran is removed, which significantly lowers the rice's nutritional value. As a result, a higher degree of milling results in a decrease in the levels of lipids, proteins, fibre, vitamins, and minerals and an increase in carbohydrates (Akter et al., 2025). While friction milling creates bran with higher fat content, abrasive milling produces bran with higher protein, dietary fiber and mineral content (Kalpanadevi et al., 2018). Although starch is absent from the outer layers of rice, it is a key component of the rice endosperm. However, when the degree of milling increases, the endosperm is gradually removed as well, leading to a rise in breakage and the appearance of starch in the bran. The bran will lose some of its nutritional benefits. Friction mill-bran's total starch content ranged from 23.2 to 57.0 %, which was substantially greater than abrasive mill-bran's range of 16.3 to 49.0 %. Both forms of milling produced bran with a decreased nutritional fiber content (Kalpanadevi, 2018).

2.2.5 Rice Bran

The main byproduct of milling rice is rice bran. Rice bran is the outer, brown layer of grain that is separated during polishing (Plate 2.4).

Plate 2. 4

Rice bran

Google photo. *(https://www.annapurna-ricemill.co.in/rice-bran.htm)*

Rice is made up of aleurone, pericarp, sub aleurone layer. Essential fatty acids, dietary fibre, vitamins, minerals, and other sterols are all abundant in rice bran. Numerous health advantages of dietary fibre ingestion are widely acknowledged by scientists. Rice bran is finding more uses in the food, nutraceutical, and pharmaceutical industries. The global market for functional foods is expanding, and consumer attitudes toward health foods are promising (Manzoor et al., 2023). The use of rice bran in animal feed has a long history. Since the early 1900s, rice bran has been used in poultry feed. This suggests that earlier rice bran obtained during polishing was mostly utilized as animal feed, but because of its advantageous nutritional and biological properties, it is becoming more and more important commercially. Numerous investigations have been conducted to assess rice bran's potential as a useful component in a variety of foods to enhance their nutritional value (Manzoor et al., 2023).

In China, a tiny amount of rice bran is used for the extraction and processing of rice bran oil; the majority of rice bran is used as animal feed or boiler fuel (Xuhui & Xiaolin, 2019). The creation of workable stabilization techniques and the value-added processing of the nutrients and active components are required to increase the usage of rice bran. The three main nutrients found in rice bran are oil, proteins and carbohydrates. There are also many other additional nutrients and active ingredients, including phytic acid and non-starch polysaccharides. Most of these substances have anti-inflammatory and anti-cancer properties (Goufo & Trindade, 2014).

2.2.6 Heavy Metals

Heavy metal refers to any metallic element that has a relatively high density and is dangerous or toxic at low concentrations (Heavy Metal - an Overview | ScienceDirect Topics, n.d.). Mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead are a few examples of heavy metals (Sadak, 2023).

2.2.6.1 Sources of heavy metals

Heavy metal pollution can come from a variety of sources. Since some plants may accumulate significant amounts of heavy metals. Toxic metals can also be extracted from soil (Bilo et al., 2015). By the roots or shoots of plants, heavy metals can be passed from the soil to crops. Cereal grains absorb toxic metals from the soil, including lead, cadmium, and arsenic. The bioaccumulation pattern of heavy metals is influenced by their capacity to move from soil to crops (Hu et al., 2014).

2.2.6.2 Lead

Lead is a hazardous element that occurs naturally in the crust of the Earth. Global environmental damage, human exposure, and serious public health issues have resulted from its widespread use.

Lead poisoning can result in kidney, brain damage and anemia. Lead exposure in excess can be fatal. Lead may pass the placental barrier. Thus, pregnant women who are exposed to it run the risk of damaging their growing fetus (RÍsov, 2019). The growing brain of a baby can be damaged by lead. It has been discovered that lead exposure, even at low concentrations, has an impact on a baby's behavior and IQ while they are still growing (Heidari et a*l*., 2022). Lead exposure can cause stillbirths, infertility, and miscarriages in women, as well as infertility in men. Lead generally has more of an adverse influence on children than on adults. Children frequently exhibit severe lead toxicity symptoms at concentrations lower than those felt by adults (Hauptman et al., 2017). Children who are exposed to lead may suffer major health effects. Extremely high lead exposure can seriously harm the brain and central nervous system, resulting in seizures, coma, and even death (Wani et al., 2015). Children who survive severe lead poisoning may develop behavioural issues and an irreversible intellectual impairment. Lead can cause a range of injuries to several body systems at lower exposure levels that may not show any symptoms. Lead, in particular, can have a lasting negative impact on children's brain development, which can lead to decreased IQ, behavioral changes like shorter attention spans and more antisocial behavior, and worse educational attainment (Lead Poisoning, n.d.).

The median concentration of lead in white rice from the United States is 2.8µg/kg, which is below the Codex standard of 200 µg/kg in pulses and cereals. White rice in India, Thailand and Italy contains a median concentration of 3.6 µg/kg (TatahMentan et al., 2020). Whereas there are various studies on quantities of lead in rice, there is hardly any information on quantities of lead in rice bran. It was of paramount importance to determine these quantities to ensure safety in the use of rice bran.

2.2.6.3 Arsenic

Arsenic is a naturally occurring metalloid element with the atomic number 33 and the symbol As. It is toxic. Pure arsenic is poorly absorbed, but its compounds—especially white arsenic—are extremely toxic and can have both immediate and long-term negative health effects, including cancer. Exposure usually happens through contaminated food, drinking water, or dust inhalation. It can cause symptoms like organ damage, skin changes, and gastrointestinal problems (Kuivenhoven & Mason, 2025). Additionally, it is employed in the production of glass, electronics, and certain metals. Both organic and inorganic forms of arsenic can be found in nature. It is a common metalloid. Although arsenic's damaging effects are widely known, its toxicity varies depending on the compound's type (inorganic or organic) and degree of oxidation. It is acknowledged that inorganic arsenic is far more dangerous than organic arsenic (Bakota et al., 2015) because it cannot be excreted so easily by the body.

The bioavailability of various types of arsenic differs as well. The majority of organic chemicals are contained in seafood and when consumed, they almost entirely remain intact after little biotransformation. In contrast, inorganic arsenic, which is primarily to blame for the hazardous consequences, is most commonly found in water in particular geographic areas, as well as in rice and rice-based goods (Ahmad et al., 2018). Beneficial elements in rice bran oil support both the health of customers and the oil's resistance to oxidation (Bakota et al., 2015). However, worries about the presence of heavy metals in rice and items made from rice have emerged in recent years. It is well known that rice absorbs arsenic more quickly than other grain crops.

The UN Food and Agriculture Organization has set an acceptable level of 0.2 μg/g of arsenic in rice, but no restrictions have been established for other edible products like rice bran oil (Bakota et al., 2015). The mean total Arsenic in US rice bran was 0.771 mg/kg and 0.023mg/kg in Guatemala. Thailand rice contained 0.619 mg/kg, while Cambodia rice contained 0.57mg/kg (Weber et al., 2021). It was, however, paramount to determine levels of Arsenic in Kenyan rice bran.

2.2.6.4 Cadmium

The human body's half-life of cadmium, a nephrotoxin and carcinogen, is measured in decades. The grains of wheat and rice are a significant source of cadmium exposure worldwide (Shi et al., 2020). In the European Union, rules governing the highest cadmium amounts permitted in wheat and rice have been established at 200 mg/kg. Processed infant food has even stricter regulations set at 40 mg/kg (Zuwei & Zeng, 2015). Due to the elevated cadmium levels in Chinese rice grains, cadmium intakes are of special concern there (Shi et al., 2020). The average cadmium concentration in Chinese rice bran obtained in eight major growing regions was 0.297 mg/kg (Yao et al., 2020). Levels of Cadmium in Kenyan rice bran need to be ascertained to ensure safety before it can be used for animal feeds or human consumption.

2.2.6.5 Mercury

Mercury is a naturally occurring chemical element that can be found in coal deposits and other rocks in the earth's crust. At room temperature, elemental or metallic mercury is a lustrous, silver-white metal (Mercury, n.d.). Mercury is a hazardous metal because of its persistence, bioaccumulation and neurotoxic nature. It can harm the central nervous systems of mammals and humans even at low exposure levels (Jaishankar et al., 2014). Studies on mercury contamination of rice have been done, especially in mining or contaminated areas (Se et al., 2014). Mercury emission from coal-power plants may affect the accumulation of mercury in rice grown in areas around the plants (Sharma et al., 2013). There is documentation that methyl mercury (MeHg) and inorganic Hg(II) accumulate in rice plant tissue in different ratios. MeHg is more concentrated in rice grain than in roots, stalks, or leaves, but inorganic Hg(II) concentrations are highest in the roots, indicating that MeHg is more efficiently absorbed and loaded into the grain than inorganic Hg(II) (Rothenberg et al., 2017). A study on total mercury and methyl mercury in rice samples collected in 15 provinces across China found them to be 4.74 μgkg^{-1} and 0.682 μgkg^{-1}, respectively (Wei et al., 2023). There was, however, little information on quantities of mercury in Kenyan rice bran. This study aimed to contribute to this knowledge gap.

2.2.6.6 Chromium

Chromium element occurs naturally and can be found in soil, plants, animals, and rocks. It exists in various forms. It can be a liquid, solid, or gas depending on the shape it takes. The three most prevalent types are chromium (0), chromium (III), and chromium (VI). According to the report by Sharma et al (2013); chromium state Cr (VI) has a harmful effect on biological systems (Sharma et al., 2013). Additionally, the most mobile ions in soil and water, which are more readily available to living plants, are Cr (VI) ions. The root tissue of plants that are grown in a Cr (VI)-contaminated environment frequently exhibits a buildup. There is limited understanding of the mechanisms underlying chromium absorption and translocations in plants because it is unknown which ionic species are present in various systems.

Despite the fact that chromium is maintained in the roots, there is evidence that Cr (VI) is converted to Cr (III) at the plant root surface. This element, at concentrations above what vegetables need physiologically, not only has the potential to be poisonous to them but also to enter food chains, become biomagnified and potentially endanger human health (Sharma et al., 2013). Currently, there is a lot of interest in clean, safe and uncontaminated food because of emerging diseases associated with contamination of food. Chromium (Cr) is beneficial for some plants and animals in trace amounts; however, at higher concentrations, it could be a hazardous environmental contaminant (D. Srivastava et al., 2021). Because plant roots absorb and store Cr from the soil, thus causing its availability in aerial plant parts through an inactive pathway, this could have an impact on human health via the food chain (S & Ak, 2017). Rice bran collected in China was found to contain 0.351 mg/kg of chromium (Yao et al., 2020). It was vital to determine the quantities of chromium in Kenyan rice bran before being used as animal feeds or human food.

The Codex- 1995 FAO/ WHO permissible levels for heavy metals for polished rice (in mg/Kg) are 0.2, 0.4, 0.2 and 0.1 for arsenic, cadmium, lead and mercury, respectively.

2.2.7. Essential Metals

Essential metals play important roles in the metabolic reactions that are vital for the human body, such as acting as a cofactor or catalyst for numerous enzymes. They aid in creating the structures that keep proteins and enzymes stable (Ouna, 2025); (Permyakov, 2021). They assist the body in preventing metal deficiency, which is linked to the emergence of numerous disorders (Jomova et al., 2022).

2.2.7.1 Manganese

Manganese is a silvery-gray, hard, brittle chemical element that is necessary for both biological and industrial processes. It is used in batteries, glass, and ceramics, and it is an essential component in the manufacturing of steel and alloys to improve strength.

Manganese is a cofactor of particular enzymes that are necessary for the synthesis of polysaccharides, glycoproteins, fatty acids, urea from ammonia, and fish cholesterol. These enzymes include pyruvate carboxylase, lipase, superoxide dismutase, and others. Red blood cell regeneration, the reproductive cycle, and the production of chondroitin sulfate, a mucopolysaccharide found in the organic matrix of bones, all depend on manganese (Avila et al., 2013). Manganese is oxidized to the transportable Mn^{3+} form after being poorly absorbed in the Mn^{2+} form. While iron shortage promotes Manganese absorption, excess dietary calcium and phosphorus decrease it (Ye et al., 2017).

Manganese levels of rice bran collected across China contained an average of 174.3 mg/kg (Yao et al., 2020). Kenyan rice bran had to be analyzed to determine the levels of manganese and its nutritional value.

2.2.7.2 Zinc

Although the body only needs trace amounts of zinc, approximately 100 enzymes rely on it to carry out crucial chemical processes. It is essential for the creation of DNA, cell growth, protein synthesis, tissue repair, and the upkeep of a robust immune system. Because zinc promotes cell development and multiplication, it is essential during times of fast growth, such as childhood, puberty, and pregnancy. Zinc also has an impact on the senses of taste and smell (Yagi et al., 2013). The human metabolism is impacted by the shortage or buildup of critical amino acids, minerals, and vitamins due to an unbalanced supply of these nutrients. The World Health Organization ranks zinc deficiency as the fifth most significant cause of illness and disease worldwide and the eleventh worldwide (Sharma et al., 2013). The average level of zinc in rice bran from China is 56.4 mg/kg (Chang et al., 2019). Rice bran from India had 60.2 mg/kg of zinc (Bhosale & D.Vijayalakshmi, 2015) while rice bran from Bangladesh had an average of 57.95 mg/kg (Miah et al., 2014). Rice bran from Kenya had to be analyzed to ascertain its levels of zinc, hence its nutritional benefits.

2.2.7.3 Selenium

The health of humans depends critically on the trace mineral selenium. Selenium has structural and enzymatic functions as a component of selenoproteins (B & Ah, 2006). In enzymatic functions, it is well recognized for acting as an antioxidant and a catalyst in the synthesis of active thyroid hormone. In addition to being essential for immune system health, selenium also appears to be a crucial element in preventing the virulence of HIV and AIDS progression (Guillin et al., 2019). In ten representative areas of China, the levels of selenium range between 8.1- 72.6 µg/kg and 7.6-1807.3 µg/kg for common rice and selenium-rich rice in Ankang and Enshi (Zhang et al., 2020). Determination of levels of selenium in Kenyan rice bran was vital to ascertain its nutritional composition.

2.2.7.4 Potassium

Potassium is one of the essential electrolytes, or blood minerals, needed for both cellular and electrical function. The cells, which contain potassium as the primary positive ion or cation as their home, contain more than 90 % of the body's total potassium stores (Zacchia et al., 2016). In addition to regulating the water balance and the acid-base balance in the blood and tissues, potassium is also crucial for the electrical conduction system of the heart, along with sodium. The active transport of potassium into and out of cells is necessary for cardiovascular and neurological function. A sodium-potassium exchange takes place across the cell membrane when potassium enters the cell (Pirahanchi et al., 2024). This creates the electrical potential in the nerve cells that permits the conduction of nerve impulses. When potassium leaves the cell, it restores the cell's repolarization, enabling the nerve impulse to advance. This electrical potential gradient controls heartbeat and facilitates muscular contraction (Pirahanchi et al., 2024). Asian rice bran contains an average of 14850 mg/100g (Kinyuru et al*.,* 2015) (Sapwarobol et al., 2021), while in Rio Grande do Sul Brazil, it is 2110 mg/kg (Pateriya & Kumar, 2020). There was scanty information on levels of potassium in Kenyan rice bran, which informed this research.

2.2.7.5 Iron

Iron is essential for oxygen delivery, short-term oxygen storage and the oxidase and electron transfer functions of haemoglobin-containing enzymes. A lack of it can result in soft nails, mood swings, weak muscles, and weakened immunity, which can also be a complication of other nutritional deficiencies. Plants contain non-heme iron, a dietary type whose absorption by the body involves a number of processes. Stabilized rice bran from India contains 281mg/kg of iron (Bhosale & D.Vijayalakshmi, 2015) while the iron content in white rice from the US was found to be 3 mg/kg. The average iron concentrations in white rice from Italy, Thailand and India are 2 mg/kg (TatahMentan et al., 2020). Studies to determine the levels of iron in Kenyan rice bran were limited, hence the need to analyze the bran.

2.2.7.6 Magnesium

Magnesium is a cofactor in more than 300 enzyme systems that control a wide range of biochemical processes in the body, including protein synthesis, the health of muscles and nerves, blood glucose control, and blood pressure regulation. Magnesium is necessary for glycolysis, oxidative phosphorylation, and the creation of energy (Office of Dietary Supplements - Magnesium, 2022). The mean concentration of magnesium in white rice from the U.S.A. was 57mg/Kg. In Italy, Thailand and India, the mean concentration of magnesium in white rice was 61 mg/Kg. The U.S brown rice had a mean concentration of 87 mg/Kg (TatahMentan et al., 2020). The levels of magnesium in Kenyan rice bran have to be determined to ascertain its health benefits.

2.2.7.7 Copper

Copper is the third most abundant trace element in the human body after zinc and iron. Proteins combine with copper to enhance the normal functioning of blood vessels, skin and bones. Copper also enhances the normal functioning of the central nervous system. The average level of copper from rice fields across China was 3.56 mg/Kg (Yao et al., 2020). Brown rice from the U.S had a median concentration of 18.8 mg/Kg of copper

(TatahMentan et al., 2020). The concentration of copper in Kenyan rice bran has to be obtained for its nutritional benefits to be ascertained.

2.2.8 Bioaccumulation of Metals

Bioaccumulation is the slow accumulation of harmful compounds, such pesticides and heavy metals, in one organism over time. It occurs when an organism absorbs a material more quickly than it can be eliminated or broken down, resulting in concentrations in its tissues that are greater than those in its surroundings or diet. This procedure may have negative effects on reproduction, make people more susceptible to illness, or even result in death. Large concentrations of heavy metals can build up in the tissues of crops cultivated in contaminated soil. Toxic metal buildup in crops like rice is a serious problem in Bangladesh (Marshallet et al., 2007). The primary causes of hazardous metal contamination in the environment include mining, shipbreaking industry waste, industrial waste, and agricultural chemicals (Hasan et al., 2022). It is quite concerning since rice contains a number of hazardous metals, including Cd, Cu, Pb, and Hg. According to three separate investigations, rice in southeast China had an average lead level of 0.69 mg/kg, a maximum concentration of 0.467 mg/kg of Cd, and 0.957 mg/kg of Pb (Zuwei & Zeng, 2015). Heavy metal concentrations in rice are strongly correlated with those in soils and water. In actuality, heavy metals typically enter agricultural soils through a variety of irrigation techniques, and the bioavailable portion of soil elements is transmitted to food and fodder crops, posing a health concern to both humans and animals (Mao et al., 2019). When rice plants obtain essential nutrients like phosphorus, potassium, manganese, selenium, iron, zinc, and copper from the contaminated soil, they may collect unwanted and harmful elements including nickel, chromium, mercury, arsenic, lead, and cadmium (Satpathy et al., 2014).

2.3 Analytical Techniques

Analytical methods are procedures for data analysis and interpretation as well as for the separation, identification, and quantification of chemical compounds. Food and agricultural products can be identified and quantified using a variety of analytical techniques. The structural and elemental compositions as well as quantification are determined by a number of modern methods, such as gas chromatography, gas chromatography-mass spectrometry, High-Performance Liquid Chromatography, Hyperspectral Imaging Techniques, biosensors, and Inductively Coupled Plasma spectroscopy (Bharti et al., 2024). While there are a number of traditional ways for evaluating food quality, spectroscopic and imaging techniques are the most popular since they are quick, dependable, and non-invasive. In particular, the use of near-infrared spectroscopy (NIRS) for origin tracking, adulteration detection, pesticide residue detection, and food safety monitoring has expanded in the food business. One of the key benefits of employing NIRS, among other modern methods, is its useful characteristics, such as its rapid detection speed, minimal or non existent sample preparation requirements, non-invasive or non-destructive sampling and testing, and the capacity to conduct at-line, online, and in-line analysis using adaptable equipment like fibre optic probes (Cozzolino et al., 2006).

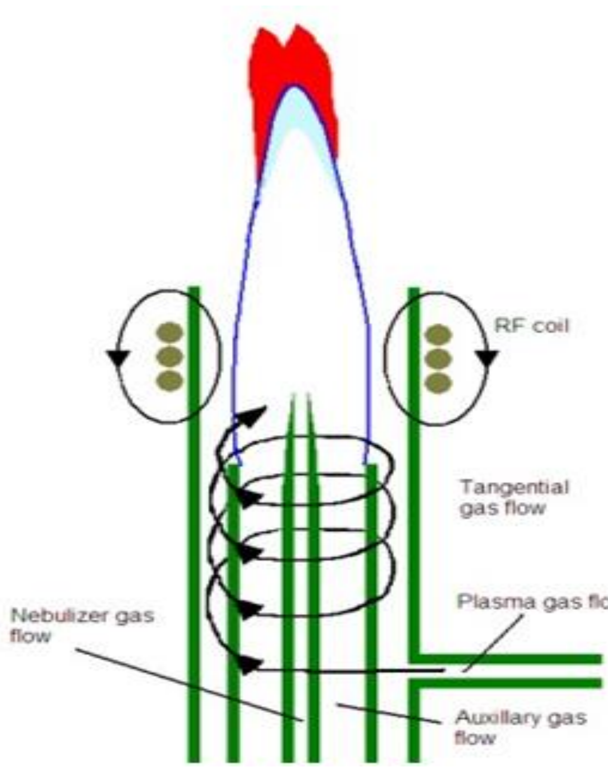
2.3.1 Inductively Coupled Plasma

Inductively Coupled Plasma (ICP) is an ionization source that completely breaks down a sample into its component elements and converts them into ions. Usually made of argon gas, the plasma is created by coupling energy to the gas using an induction coil.

Plasma is a gaseous mixture in which a significant proportion of the gas-phase species are ionized. A high-power radiofrequency induction coil is wrapped around the end of a quartz tube that makes up the apparatus. Argon gas flows quickly down the quartz tube. A magnetic field is created within the quartz tube's end by passing an electric current via the radio frequency coil. Some Ar+ ions are produced when argon is sparked; these ions are now paramagnetic and take in energy from the magnetic field as illustrated by the figure 2.1.

Figure 2. 1

Plasma flame



From: http://www.asdlib.org/learningModules/AtomicEmission/index.html

In the section of the tube that the radio frequency induction coil covers, the argon ions absorb enough energy to produce a plasma. The temperature will rise up to 6000K. High temperature will ensure complete ionization of the samples. New argon entering the plasma gets ionized due to the high temperature, which keeps the plasma going. An additional tangential flow of argon along the quartz tube walls prevents the plasma from melting the walls. Lastly, the sample is nebulized and sprayed into the plasma's centre as an aerosol mist.

2.3.1.1 Inductively Coupled Plasma- Optical Emission Spectroscopy

Inductively Coupled Plasma- Optical Emission Spectroscopy (ICP-OES) is a strong, adaptable, and sophisticated analytical method with superior detection capabilities (Plate 2.5). ICP-OES creates highly excited atoms from the sample by using an inductively coupled plasma (ICP) source. These energized atoms emit light at particular element-specific wavelengths. The elemental concentration in the sample is then determined by measuring the intensity of this light's emission using a detector.

Plate 2.5

ICP-OES Machine

https://pics.equipnet.com/mp_data/images/Oct/2025109153524_1015517_1.jpg

Owing to its exceptional qualities, it has been successfully used in recent years for the investigation of a wide range of chemical elements. It provides less chemical interference, the shortest detection time, lower detection limits, a wider linear dynamic range, and increased matrix tolerance. Proper sample preparation is essential since ICP-OES analyses samples in a liquid form. It guarantees that the sample is totally dissolved, removes matrix interferences, and produces a uniform solution for analysis.

In addition, it can handle a wide range of samples, including solids, organic liquids, inorganic liquids, and aqueous liquids. Its intricate instrumental design allows it to accurately identify up to seventy elements at once (Martínez et al., 2020).

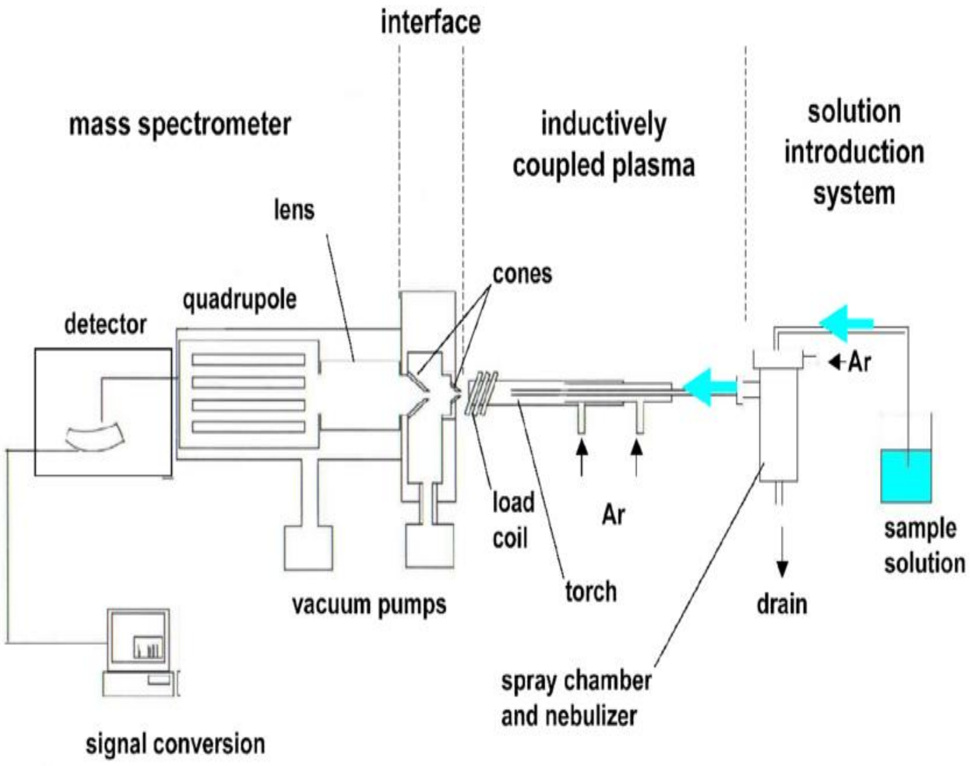
2.3.1.2 Inductively Coupled Plasma- Mass Spectrometry

Inductively coupled plasma mass spectrometry (ICP-MS) is one analytical method for measuring elements at trace amounts in samples. The sample introduction system, plasma, vacuum interface, ion optics with mass analyser, and ion detecting system are the five main components of an ICP-MS system. While the ion optics, mass discrimination, and ion detection sections function in high vacuum, the sample introduction system and plasma are run at atmospheric pressure. A radio frequency (RF) generator that uses an induction coil or load coil to provide energy to the plasma itself. After being ionized by the plasma, samples are moved via a vacuum interface to the mass analyser. In ICP-MS, quadrupole and magnetic sector mass analyzers are the two most used types. Because quadrupole mass analyzers are sequential, every element is measured one after the other. Depending on the shape of the instrument's components, magnetic sector analysers might be sequential or simultaneous. Due to their ease of use and upkeep, quadrupole instruments are commonly employed in standard laboratory settings. Because magnetic sector instruments employ larger ion extraction potentials than quadrupole instruments, they are intrinsically more sensitive. They are therefore employed in more specialized applications or when greater sensitivity is required.

The ICP-MS detection system finds ions after they have been separated so the operator may analyse the data.

There has been a steady shift toward ICP-MS, especially in the past decade, even though some laboratories continue to employ older methods like atomic emission and atomic absorption techniques. This is because of possibility of spectroscopic and non-spectroscopic interference (Wilschefski & Baxter, 2019). The schematic diagram below shows the working of ICP- MS instrument (Figure 2.2).

Figure 2. 2

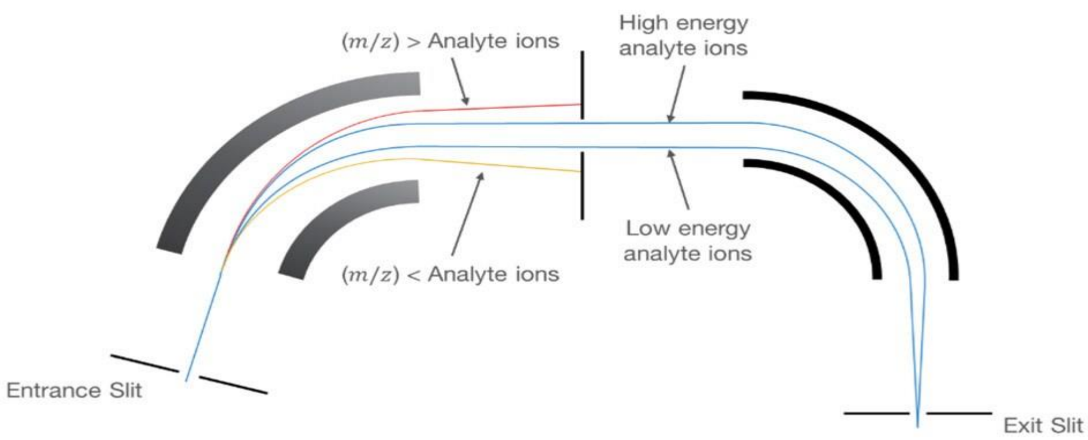


https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net

In order to create the electric field that sample ions travel through, a quadrupole mass analyser combines a direct current (DC) potential over four electrodes, or poles, with a radio frequency (RF) alternating current (AC) potential. The ions accelerate and gain energy as they move through this electric field. Charged ions are subjected to force as they move through a magnetic field in a magnetic sector mass analysers. This force is directly proportional to the ions' momentum and is perpendicular to their flight path. As a result, the ions are deflected, and the radius of that deflection is proportional to both the force and the ions' momentum.

The product of an ion's mass and velocity, which is determined by the kinetic energy it possesses, is its momentum. Ions of different masses may have the same momentum because a plasma generates ions with a broad range of kinetic energy. As a result, two ions with different masses can pass through the magnet with the same radius of curvature. Ions are separated by kinetic energy using an electric sector analyzer (ESA) to counteract this effect as shown in the figure 2.3 below.

Figure 2. 3



Google image: https://www.thermofisher.com/foregroundimg.im539845444.jpg

In order to reject any remaining ions with slightly different masses from the ion beam, the ESA focuses ions with the same mass but slightly different kinetic energy onto the same location in space.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents research design, location of study, flow diagram, sampling and sample collection, sample digestion, sample treatment, sample digestion, preparation of standards, metal profiling and data analysis.

3.2 Research Design

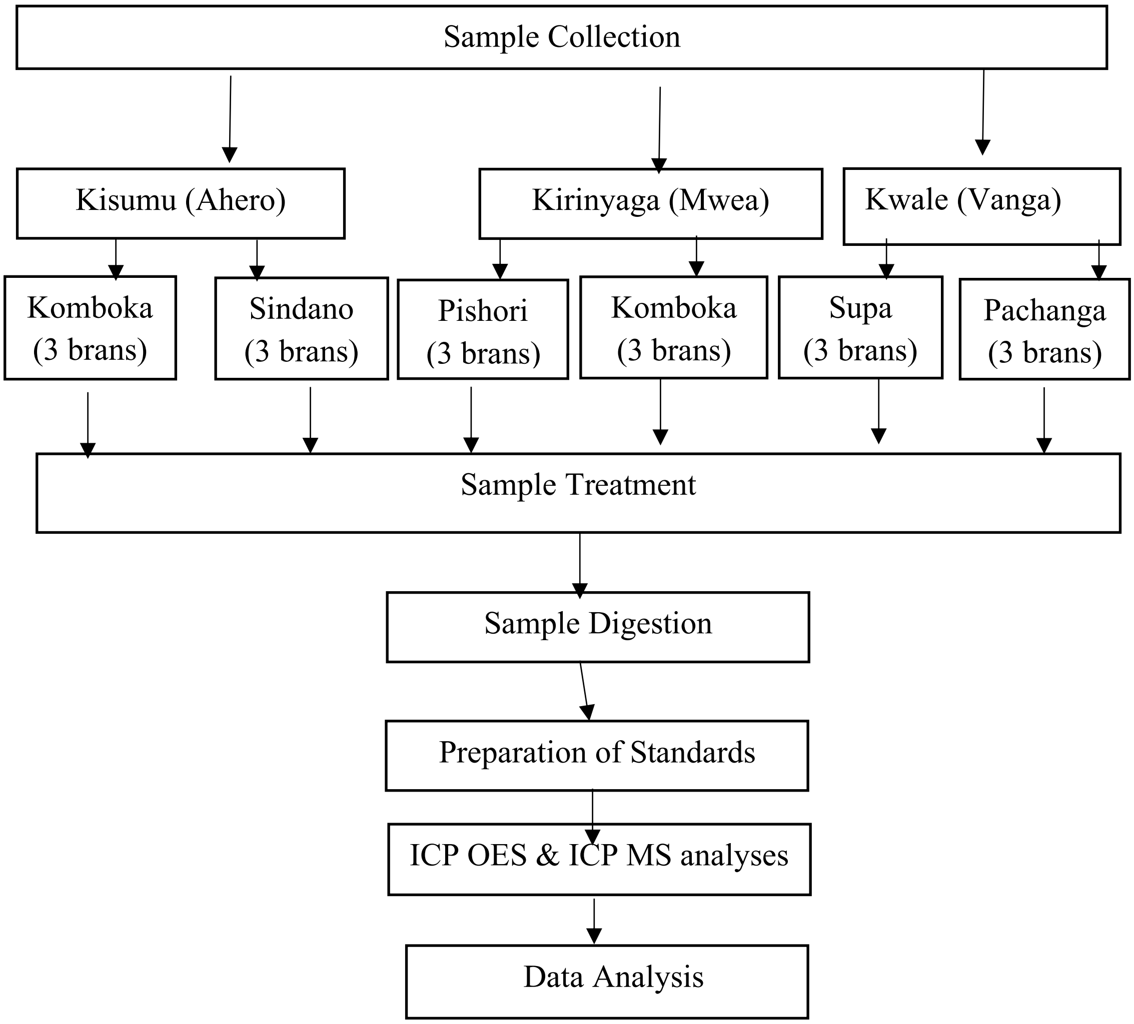
The study used an experimental design, which involved the determination of levels of lead, arsenic, cadmium, chromium, mercury, potassium, iron, manganese, magnesium, copper, zinc and selenium in rice bran from Kwale, Kirinyaga and Nyanza counties of Kenya.

3.3 Location of Study

Sampling was conducted in Mwea irrigation schemes of Kirinyaga County, small-scale rice farms in Vanga of Kwale County and Ahero irrigation schemes in Kisumu County. Mwea falls within two sub-counties, that is Mwea West and Mwea East in Kirinyaga County. It lies at longitude 37^0 30’0’’ E and latitude 1^0 42’ 0’’ S and about 100 km from Nairobi city. Ahero is situated in Kisumu County, about 16 km east of Kisumu City. It lies at longitude 34^0 54’ 60’’ E and latitude 0^0 10’ 60’’ N. It is located in Kano plains between Nyabondo Plateau and Nandi Escarpment. Vanga is located in Kwale County. It lies at a longitude of 39° 13' 6" E and a latitude 4º 39' 34" S and approximately 134 km from Mombasa.

3.4 Flow Diagram

The flow chart below shows the process of sample collection, areas of sample collection, the rice cultivars, sample treatment, sample digestion and data analyses.



3.5 Sampling and Sample Collection

Rice farms from Mwea irrigation schemes in Kirinyaga County, Ahero irrigation schemes in Kisumu County and Vanga rice farms in Kwale County were mapped into six blocks each. In each block, 5 kg of rice paddy of two of the most common varieties in each region and 1 kg of soil samples were collected from the same farms. In Mwea irrigation scheme, three rice bran samples of Komboka and three rice bran samples of Kenyan Pishori were collected. In Ahero irrigation scheme, three rice bran samples, each of Komboka and Sindano-IR varieties, were also collected. Three rice bran samples each of Pachanga and Supa rice varieties were also collected from different farms which were selected randomly in Vanga rice farms, Kwale County.

3.6 Sample Treatment

The rice paddies were milled and polished. The milling machine was cleaned before a different sample was milled and from which about 500 grams each of rice bran were collected in paper bags. The samples were then transported to Kenya Plant Health Inspectorate Services (KEPHIS) for analyses, where 0.25g of each sample was weighed using an analytical weighing balance.

3.7 Sample digestion

Rice bran sample digestion was done as described by Runge et al, 2019. The milled rice bran was grounded into powder after drying to weight of 0.25g. The sample was then mixed with 2 ml of 30 % hydrogen peroxide and 8 ml of concentrated nitric and put in a microwave digestion vessel. The samples were covered and left to stand for 12 hours. The content was then put in a 25 ml volumetric flask and diluted to the mark using grade 2 de-ionized water.

Digestion of soil samples used the protocol of the Ministry of Environment and Ecology in the People's Republic of China (*HJ 832-2017 English PDF*, 2017). In a 50-mL digestion tube, 0.5 g of ground-up soil samples was mixed with 5 mL of 69% concentrated nitric acid. Hydrogen peroxide was applied after the mixture had been heated at 120–130 ºC for 14 hours. Following digestion, the samples were diluted to 50 mL and then further diluted by 1:9 using grade 2 de-ionized water for ICP OES analysis.

3.8 Preparation of standards

Fresh standards were made just before each analysis (Germany Merck KGaA Darmstadt EMD Millipore Corporation) and were prepared in 5% nitric acid. Working standard solutions for each element were prepared from a 1000 ppm stock solution by serial dilution. From the 10ppm standard, other standards of 5 ppm, 1 ppm, 500 ppb, 100 ppb, 10 ppb and 1 ppb were made using the dilution formula. The standard solution for each element was used to calibrate the instrument and optical emissions from ICP instruments. The same procedure for preparing working standards was used to prepare 25 ppb, 50 ppb, 100 ppb and 200 ppb for ICP MS analyses.

3.9 Metal profiling

To determine the presence and quantities of each of the selected metals, ICP-OES was used for profiling. The less abundant metals that were not detected by ICP-OES were analyzed using ICP-MS. Each instrument was set according to the manufacturer's user manuals. Each rice bran sample and one soil sample from each region were analyzed for the presence of Arsenic, Mercury, Lead, Cadmium, Chromium, Zinc, Iron, Selenium, Copper, Manganese, Magnesium and Potassium. In the replication phase, three detected metals in each category (3 heavy metals and 3 essential elements) were selected for replication. Only samples in which any of the six selected metals was detected were injected in the respective instrument two more times for each selected metal, giving a total of three technical replicates for each metal in that particular sample. The obtained data were tabulated and used for statistical analyses.

3.10 Data Analysis

To find out if there were significant differences in metal profiles from different cultivars and regions, data analysis was performed using the SPSS statistical tool. ANOVA was used to do the main comparison of quantities of metal elements per cultivar and region. All these were done at a 95% confidence interval (Girden, 1992).

3.11 Bioaccumulation

To determine the level of bioaccumulation of metals in rice bran from the soil, this formula was used for determination.

$$BAF = \frac{C_{Bran}}{C_{S0il}}$$

Where C_{Bran} and C_{S0il} are the concentrations of metals in rice bran and soil, respectively, in mg/Kg (Hasan et al., 2022).

3.12 Ethical Consideration

This research was done with approval from the University of Kabianga and Kenya Methodist University. The permit to carry out the research was obtained from the National Commission for Science, Technology and Innovation (NACOSTI) and County Governments in the regions under study.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter covers results obtained, data analyses and discussion of the results obtained.

Eighteen rice bran samples collected from all the counties under study were analyzed for presence of selected heavy metals and essential elements. The levels of essential elements in the samples are as shown in table 4.1.

Table 4.1

Levels of Essential metals in Rice Bran Samples (mg/Kg)

		Zn	Cu	Mg	Se	Fe	Mn	K
		Mean	Mean	Mean	Mean	Mean	Mean	Mean
Samples	Komboka 1	68.62	9	6522	0.80	165.55	134.10	14468
	Komboka 2	67.98	10	6631	.	115.13	145.01	14668
	Komboka 3	56.86	9	6136	.	135.99	203.17	14261
	Komboka 4	46.38	10	4178	0.54	200.26	346.23	10215
	Komboka 5	40.73	8	4425	0.40	207.91	220.30	10260
	Komboka 6	47.28	9	3971	1.49	472.55	372.79	9750
	Pachanga 1	75.86	15	6603	0.75	81.19	243.45	15727
	Pachanga 2	81.46	12	7096	.97	105.94	295.09	19221
	Pachanga 3	77.82	10	5497	6.20	106.72	398.44	11890
	Pishori 1	77.78	12	6040	.	545.81	235.79	13647
	Pishori 2	70.07	14	6577	1.52	129.70	219.21	15075
	Pishori 3	70.41	14	6066	1.04	303.58	234.78	15015
	Sindano 1	55.22	9	4756	0.35	316.56	237.91	11668
	Sindano 2	56.36	7	4232	0.35	246.11	161.45	9091
	Sindano 3	48.67	10	4570	0.31	174.42	169.70	10519
	Supa 1	73.85	13	5479	0.22	81.23	278.07	13166
	Supa 2	71.08	8	5759	1.78	95.82	138.23	12729
	Supa 3	79.41	13	6681	.	101.34	288.28	18172

Note:
Data presented as mean concentration of triplicate analyses.
The samples that have dotted (.) results were samples with individual elements below the limit of quantification.

4.2 Results, Presentation and Discussion

Rice bran from Kirinyaga, Kwale and Kisumu Counties are rich in essential elements such as zinc, iron, potassium, magnesium, manganese and trace elements like copper and selenium, as shown in Table 4.1.

A one-way ANOVA was conducted to determine whether there were statistically significant differences in the concentrations of various nutritional elements across the three regions. The results are reported in Table 4.2. Statistically significant differences ($p<0.05$) were observed for Magnesium (Mg) and Zinc (Zn) levels among regions. Iron (Fe) showed a significant difference ($p=0.0486$) but non-significant pairwise differences following a Tukey HSD post hoc test. Other elements, including Potassium (K), Manganese (Mn), Copper (Cu), and Selenium (Se), did not vary significantly ($p>0.05$) across regions.

Table 4.2

Mean Concentration of (± SD) of Nutritional Elements in Rice Bran by County

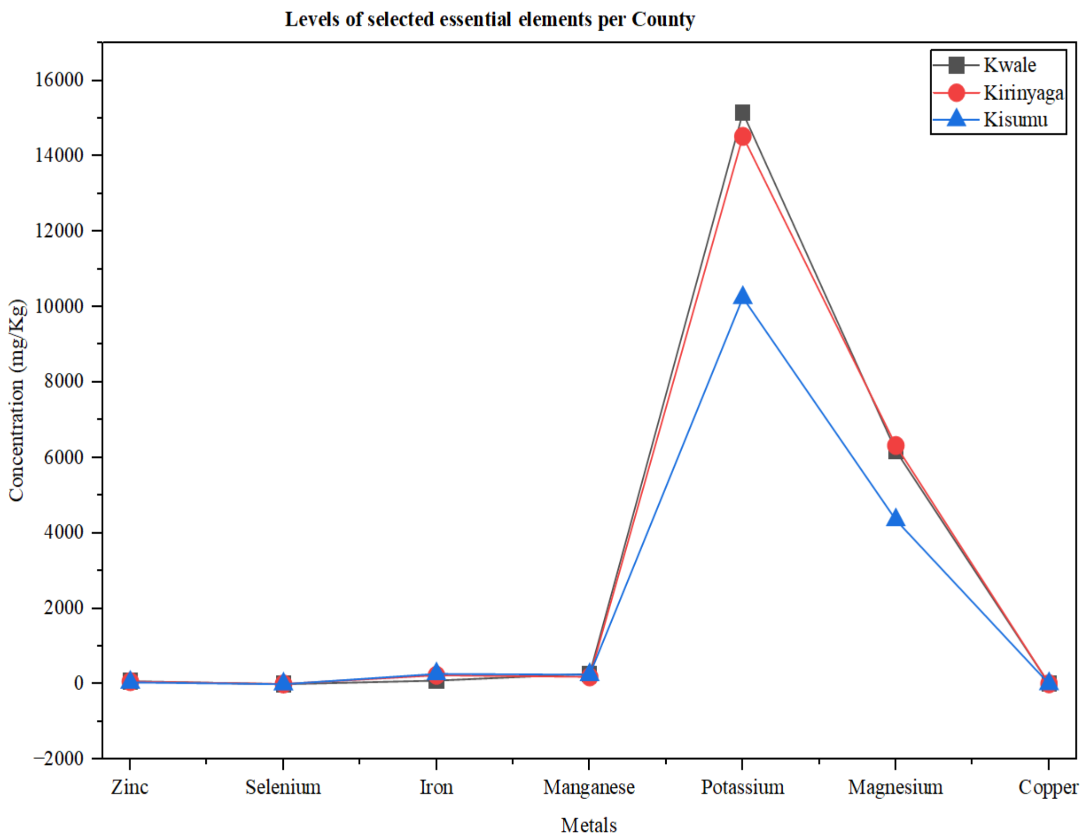
	Kwale	Kirinyaga	Kisumu	*P-value*
K	15148.94 ± 3048.08^{a}	14489.00 ± 525.78^{a}	$11750.38 \pm 3{,}898.92^{a}$	0.1285
Mg	6185.80 ± 693.43^{a}	6628.62 ± 721.75^{a}	4355.38 ± 285.00^{b}	**0.0001**
Mn	290.26 ± 86.97^{a}	243.56 ± 162.02^{a}	251.40 ± 89.04^{a}	0.7670
Fe	95.37 ± 11.64^{a}	232.63 ± 168.14^{a}	269.64 ± 111.02^{a}	**0.0486***
Cu	11.76 ± 2.16^{a}	11.43 ± 2.58^{a}	8.87 ± 1.11^{a}	0.0537
Zn	76.56 ± 3.77^{a}	68.62 ± 6.75^{a}	49.11 ± 5.85^{b}	**0.0001**
Se	1.65 ± 2.31^{a}	2.23 ± 4.58^{a}	0.57 ± 0.46^{a}	0.6287

- The mean values are in mg/kg (ppm) from a minimum 6 samples.
- Means in the same row followed by the same superscript are not significantly different (p>0.05) using the Tukey HSD Post Hoc Test.
- *Fe showed a significant overall ANOVA effect, but the pairwise comparison was not significant in Tukey HSD, suggesting the variance may be spread across groups rather than driven by strong pairwise contrasts.

All tested nutritionally important metal elements (K, Mg, Mn, Fe, Cu, Zn and Se) were detected at various concentrations in various samples. Potassium was detected in all samples (Table 4.2) at between 11889.57-19220.69mg/Kg (Kwale), 13646.77-15074.65mg/Kg (Kirinyaga) and 9091.32-19518.76mg/Kg (Kisumu) and; was the most abundant metal element in all regions with the highest mean value of 15148.94±3048.08mg/Kg (Kwale) followed by 14489.01±525.78mg/Kg (Kirinyaga) and 11750.38±3898.92mg/Kg (Kisumu), though this variation was not significant (p=0.05) across the three regions. Magnesium was also detected in all samples (Table 4.2) at between 5479-7096.05mg/Kg (Kwale), 6065.54-8040.05-mg/Kg (Kirinyaga) and 3970.93-4756.27mg/Kg (Kisumu) and was the second most abundant metal (Fig. 4.1). Its highest mean level of 6628.62±721.75mg/Kg (Fig. 4.2), was detected in rice bran from Kirinyaga followed by 6185.80-±693.43mg/Kg (Kwale) and 4355.38±285.00mg/Kg (Kisumu), which was significantly lower (p=0.05) than the other two. Manganese was also detected in all samples from all regions (Table 4.2) at 138.23-398.44mg/Kg (Kwale), 129.7-545.81mg/Kg (Kirinyaga) and 161.45-372.79mg/Kg (Kisumu). It was the next most abundant metal with a highest mean (Fig. 4.1) value of 290.26±86.97mg/Kg (Kwale) followed by 251.40±89.04mg/Kg (Kisumu) and 243.56±162.02mg/Kg (Kirinyaga). There was no significant difference (p=0.05) among these means. Iron, which was the next most abundant metal was also detected in all samples from all regions (Table 4.2) at concentrations ranging from 174.42-472.56mg/Kg (Kisumu), 115.13-545.81mg/Kg (Kirinyaga) and 81.19-106.72mg/Kg (Kwale). Rice bran from Kisumu had the highest mean (Fig. 4.1) value of 269.64±111.02mg/Kg, followed by 232.63±168.14mg/Kg and 95.37±11.64mg/Kg in rice bran from Kirinyaga and Kwale, respectively. These variations in means were not significant (p=0.05) across these regions. The concentration of Zinc, which was also detected in all samples (Table 4.2), ranged from 71.08-81.45mg/Kg (Kwale), 56.86-77.78mg/Kg (Kirinyaga) and 40.73-56.36 (Kisumu). It had the next highest concentration with the highest mean (Fig. 4.1) of 76.56±3.77mg/Kg in rice bran from Kwale, followed by 68.62±6.75mg/Kg (Kirinyaga) and 49.11±5.85mg/Kg (Kisumu). The mean levels in rice bran from Kisumu were significantly lower (p=0.05) than those in the other two regions. On the other hand, Copper, which was also detected in all samples (Table 4.2) from all regions, had its levels ranging from 8.67-14.49mg/Kg (Kirinyaga), 8.36-14.52mg/Kg (Kwale) and 7.46-10.33mg/Kg (Kisumu). It was the next most abundant with the highest mean of 11.76±2.16mg/Kg (Fig. 4.1) in rice bran from Kwale with no significant difference (p=0.05) compared to 11.43±2.58mg/Kg and 8.87±1.11mg/Kg in rice bran from Kirinyaga and Kisumu, respectively.

Figure 4. 1

Levels of essential elements per county

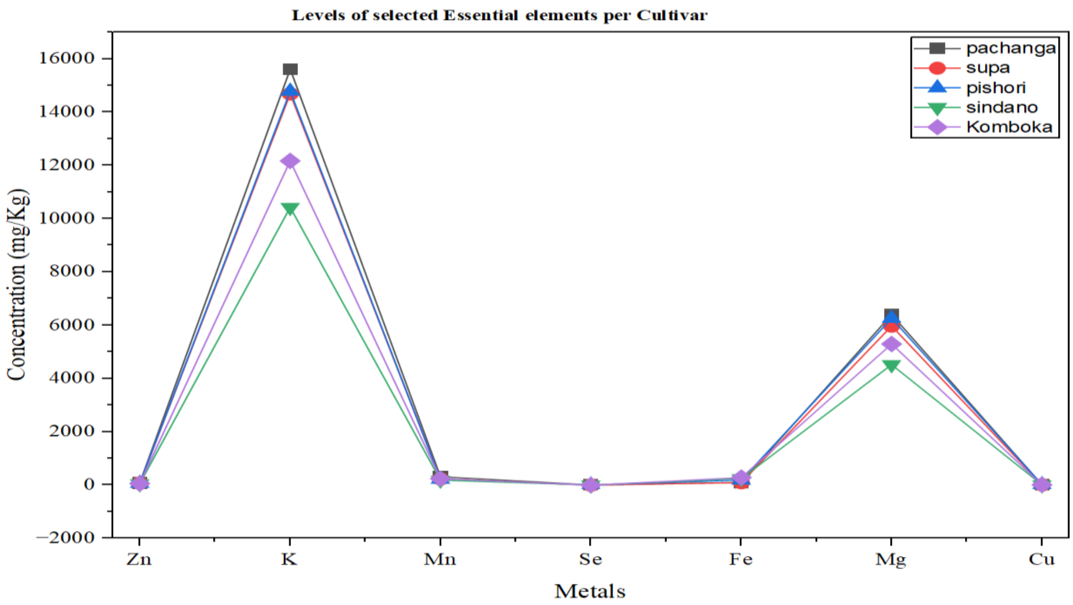


Note: The data were mean triplicate concentrations of all metal cultivars from the Counties.

Selenium which was the least abundant metal in this category (Fig. 4.2) was detected in the range of 0.8-11.52mg/Kg, 0.22-6.2mg/Kg, 0.8-11.52mg/Kg respectively in 50%, (n=6), 83.3%, (n=6) and 100%, (n=6) of samples from Kirinyaga, Kwale and Kisumu. There was no significant difference (p=0.05) among the means of 2.23±4.58, 1.65±2.31 and 0.57±0.46mg/Kg in rice bran from Kirinyaga, Kwale and Kisumu (Fig. 4.2), respectively.

Figure 4. 2

Levels of essential elements per cultivar



A one-way ANOVA was conducted to compare the concentrations of each element across five rice varieties (Table 4.3). Only Zn showed statistically significant differences (p=*0.0298*) among rice varieties. No other nutrient had significant variation, though trends in Fe and Se were notable.

Table 4.3.

Mean Concentration of (± SD) of Nutritional Elements in Rice Bran by Cultivar

Variety type	Landrace		Improved Variety			
Name	**Supa**	**Pachanga**	**Komboka**	**Basmati**	**Sindano***	**p-value**
K	13870.41± 1613.64[a]	16427.46± 3964.75[a]	12134.44± 2283.12[a]	14783.86 ± 453.39[a]	13426.02± 5431.48[a]	0.4048
Mg	5947.11± 585.39[a]	6424.48± 829.77[a]	5594.44± 1646.26[a]	6259.61± 277.05[a]	4519.50 ± 265.85[a]	0.2830
Mn	253.25± 104.84[a]	327.27± 61.73[a]	294.04± 158.46[a]	212.15± 87.29[a]	189.69 ± 41.97[a]	0.5516
Fe	86.08± 8.44[a]	104.67± 2.91[a]	284.54± 178.58[a]	189.76± 98.62[a]	245.70 ± 71.07[a]	0.1560
Cu	11.89± 3.18[a]	11.62± 1.25[a]	9.55± 1.60[a]	12.67± 2.94[a]	8.83 ± 1.19[a]	0.1352
Zn	73.60± 2.40[a]	79.53± 1.87[a]	58.13± 15.18[a]	65.78± 7.73[a]	53.42 ± 4.15[a]	**0.0298**
Se	0.92± 0.79[ab]	2.39± 3.34[a]	0.54± 0.56[ab]	4.19± 6.37[ab]	0.34 ± 0.02[b]	0.4150

- The mean values are in mg/kg (ppm) from a minimum of 3 samples.
- *Sindano is also known as IR273-80.
- Means in the same row followed by the same superscript are not significantly different (p>0.05) using the Tukey HSD Post Hoc Test.

These findings indicate that rice bran mineral composition, particularly Zn and Mg, varies by both growing region and rice variety. Since rice bran is a functional food and a nutritional supplement, this variability has implications for nutrient fortification, dietary planning, and value-added rice products.

The data reveal meaningful regional and varietal effects on mineral concentrations in rice bran, particularly for zinc and magnesium**.** Zinc, essential for immune function and enzyme activity, was highest in Kwale and in the variety Pachanga. Magnesium, vital for bone health and metabolic processes, also showed significant variation by region.

The lack of statistical significance in some elements (like potassium, manganese, and selenium) suggests their concentrations may be less influenced by geography or genotype, or that natural variation within samples masks underlying trends.

Interestingly, iron levels, while varying across samples and regions, showed inconsistent statistical support—highlighting the complexity of mineral uptake and translocation in rice and the need for further agronomic or genetic investigations.

Kwale County demonstrated consistently higher zinc and magnesium levels in rice bran, making it a strategic region for harvesting bran for fortification programs targeting micronutrient deficiencies. Zinc is particularly vital for immune function and gut health, offering potential benefits in combating diarrhea-related morbidity, especially in children under five.

Kirinyaga County, known for its high rice production, showed intermediate levels of minerals, including iron. However, the variation in iron levels suggests a need for soil management and variety selection to enhance nutrient density in future crops.

Kisumu County, while having lower zinc concentrations, showed relatively higher iron levels, which could be leveraged in anemia mitigation programs, particularly among women of reproductive age and adolescents.

Analysis of toxic metal elements (Cr, As, Cd, Hg and Pb) detected Chromium, lead and Arsenic in all tested rice bran samples from all studied regions (Table 4.4). Chromium was the most abundant (Fig. 4.3) with sample concentrations (Table 4.4) ranging from 1.58-3.79mg/Kg, 1.13-1.85mg/Kg and 1.14-1.58mg/Kg in samples from Kisumu, Kirinyaga and Kwale, respectively.

Table 4.4

Levels of toxic metal elements in rice bran from different counties of Kenya

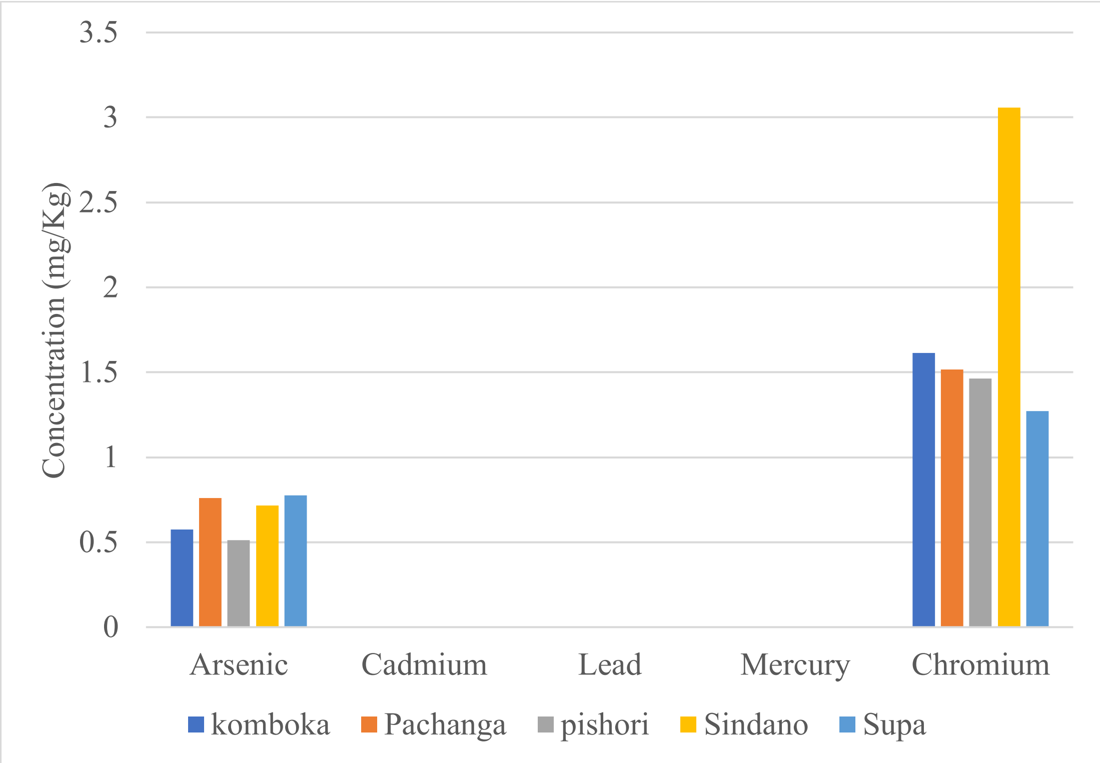
County	Toxic metals Min- Max in mg/Kg (%; n)				
Metal	**Cr**	**As**	**Cd**	**Hg**	**Pb**
Kwale	1.14 - 1.58 (100; 6)	0.64 - 0.92 (100; 6)	0.02–0.04 (33.33; 6)	0.00003-0.00067 (100;6)	0.00021-0.00086 (100;6)
Kirinyaga	1.13 – 1.85 (100; 6)	0.43 – 0.72 (100; 6)	0.00007-0.00069 (100; 6)	nd (0; 6)	0.00002-0.00027
Kisumu	1.58 – 3.79 (100; 6)	(0.50 – 0.83 (100; 6)	0.00015 (17; 6)	nd (0; 6)	0.000032 (17; 6)

NB: % is the percentage of samples in which a metal element was detected; n is the total number of tested samples in that region and; nd is not detected,

The highest mean was 2.41±0.84mg/Kg (Fig. 4.3) in rice bran from Kisumu followed by 1.47±0.25mg/Kg and 1.39±0.20mg/Kg in rice bran from Kirinyaga and Kwale, respectively. The variation between mean concentrations in samples from Kisumu and Kirinyaga was statistically significant at ($p=0.05$). The levels of Arsenic (Table 4.4) ranged from 0.64-0.92mg/Kg, 0.50-0.83mg/Kg and 0.43-0.72mg/Kg in samples from Kwale, Kisumu and Kirinyaga, respectively. The highest mean level of 0.77±0.10mg/Kg (Fig. 4.3) was detected in rice bran from Kwale followed by 0.61±0.13mg/Kg and 0.58±0.11mg/Kg from Kisumu and Kirinyaga, respectively.

Figure 4. 3

Concentration of heavy metals in rice bran per cultivar (mg/Kg)



The difference among these means was not significant (p=0.05). Cadmium was detected (Table 4.4) at an average of 0.03±0.01mg/Kg in a few samples (33.3%, n=6) from Kwale at between 0.02-0.04mg/Kg. All the samples in Kirinyaga had Cadmium at an average of 0.0007 mg/Kg, whereas Kisumu samples had one sample (17%; n= 6) at 0.00015 mg/Kg. Mean concentrations of arsenic and chromium were compared per cultivar. Sindano was found to have a higher concentration of chromium (3.06 mg/Kg), whereas arsenic was found to be higher (0.85 mg/Kg) in Pachanga, as shown in figure 4.3, compared to other cultivars. Lead, Mercury and Cadmium levels were below Codex FAO/WHO permissible levels of heavy metals of 0.2 mg/Kg, 0.4 mg/Kg and 0.1 mg/Kg for Lead, Mercury and Cadmium respectively.

Studies on both white and brown rice in countries like the US, Thailand, Italy, and India have reported the presence of various metals, including Arsenic (As), Lead (Pb), Cadmium (Cd), Manganese (Mn), Copper (Cu), Zinc (Zn), Iron (Fe), Magnesium (Mg), Calcium (Ca), and Potassium (K), The ranges in concentrations of these metals on brown rice which harbor rice bran was: As- 139-403µg/Kg, Pb- 1.4–34µg/Kg, Cd- 7.7-65µg/Kg, Zn- 15-23mg/Kg, Cu- 2.24-4.77mg/Kg, Mn- 18-35mg/Kg, Fe- 7-16mg/Kg, Mg- 937-1410mg/Kg, Cd- 64-116mg/Kg and K- 1981-3003mg/Kg (TatahMentan *et al*., 2020). Similarly, in rice bran, K (14850.0mg/Kg), Mg (7810.0mg/Kg), Mn (142.1mg/Kg), Zn (60.4mg/Kg), Fe (185.4mg/Kg), and Se (0.156mg/Kg) have been reported (Sapwarobol *et al*., 2021). In addition, As (<5µg/Kg), Cd (<50µg/Kg), Pb (<500µg/Kg) and; Cr (30µg/Kg) were reported in rice bran in Bangladesh (Haque *et al*., 2021). Earlier studies on rice bran sampled from Kenya and the USA reported Fe at 75mg/Kg (Mwea) and 97mg/Kg (RiBran USA); Zn at 46mg/Kg (Mwea) and 53mg/Kg (RiBran USA); As at 0.12mg/Kg (Mwea) and 0.86mg/Kg (RiBran USA); Cd and Pb each at <0.1mg/Kg (Mwea and RiBran USA) (Kinyuru et al., 2015).

Soil analyses for three essential and three heavy metals were done and the results were obtained according to Table 4.5 as shown. Soil from Kisumu County was found to have a significantly higher level of zinc (239.94 mg/Kg) compared to other counties. Soil from Kirinyaga has a higher level of iron (75,206.00 mg/kg), while soil from Kwale has a significantly lower level of iron (7232.42 mg/Kg)

Table 4. 5

Selected metal composition of selected soil (mg/kg)

		As	Cr	Zn	Cd	Se	Fe
					<LOQ	<LOQ	
		Mean	Mean	Mean	Count	Count	Mean
County	Kwale	.99	25.54	107.12	1	1	7232.42
	Kirinyaga	4.45	149.15	172.33	1	1	75206.00
	Kisumu	6.04	90.38	239.94	1	1	50056.70

Note: The data was a mean triplicate analysis of different soil samples selected randomly from the same County. Cd and Se were below the limit of quantification.

The levels of iron in the bran are proportional to the levels of iron in the soil in which the rice paddy was established (Table 4.6). The levels of selenium in the soil from these counties are below the limit of quantification of the ICP OES instrument used.

There was no significant relationship between the metal compositions of rice bran and the region in which the rice was grown ($p = 0.5$). This implies that there was no significant variation in the metal composition and rice cultivars.

Table 4. 6

Levels of metal elements among soil and bran samples (mg/kg)

	As	Fe	Zn	Cr	Cd	Se			
					<LOQ	<LOQ	0.06a	0.31a	2.51a
	Mean	Mean	Mean	Mean	Count	Count	Count	Count	Count
Kirinyaga Bran	.73	282.45	67.75	1.33	1	0	1	0	0
Kirinyaga Soil	4.45	75205.96	172.32	149.15	1	1	0	0	0
Bioaccumulation	16%	0.38%	39%	0.89%					
Kisumu Bran	.61	174.42	48.67	3.79	1	0	0	1	0
Kisumu Soil	6.04	50056.70	239.94	90.38	1	1	0	0	0
Bioaccumulation	10%	0.34%	20%	3.3%					
Kwale Bran	.85	97.95	78.38	1.97		0	0	0	1
Kwale Soil	.99	7232.42	107.12	25.54	1	1	0	0	0
Bioaccumulation	85%	1.4%	73%	7.7%					

Note: The data tabulated is the average metal composition of various rice brans and the average composition of various soil samples from different counties. Cd was below the limit of detection, whereas Se was below the detection limit in all soil samples.

Arsenic bioaccumulated most (85%) in rice bran (Pachanga and Supa) from Kwale County (Table 4.6), whereas bran from Kirinyaga (Pishori and Komboka) and bran from Kisumu (Sindano and Komboka) bioaccumulated 16% and 10 % respectively. Whereas iron concentration is significantly higher in the soil, rice bran does not significantly bioaccumulate it.

Rice bran from Kwale (Pachanga and supa) bioaccumulated 1.4 % of iron, whereas bran from Kisumu and Kirinyaga bioaccumulated 0.34% and 0.38% respectively (Table 4.6). Zinc bioaccumulation was 73%, 20% and 39% from Kwale, Kisumu and Kirinyaga counties, respectively (Table 4.6). Though chromium bioaccumulated the least compared to other metals under this study, it was higher (7,7%) in rice bran from

Kwale county. Kirinyaga and Kisumu bran bioaccumulated 0.89% and 3.3% of chromium, respectively. It's noticeable that Pachanga and Supa rice bran bioaccumulate metal elements more than other rice bran varieties (Table 4.6).

The Rising consumption of rice in Kenya presents a valuable opportunity to transform rice bran—traditionally discarded or used as animal feed—into a nutritious, functional food ingredient. The findings highlight the need for investments in rice milling technologies that preserve the nutritional quality of bran, alongside the development of value-added products such as bran flour and fortified porridges or cookies suitable for school meals and maternal nutrition programs. Additionally, there is a strong case for supporting varietal trials aimed at identifying rice varieties with higher nutrient content, tailored to the diverse growing regions of Ahero, Budalangi, Bura, Vanga, and Mwea in Kenya.

Re-integrating rice bran into the Kenyan national food system is both timely and strategic, especially within the framework of nutrition-sensitive agriculture and the urgent need to address the double burden of malnutrition. With its demonstrated richness in zinc, particularly in varieties grown in Kwale, rice bran emerges as a promising, low-cost, and locally accessible nutritional intervention. It has the potential to support diarrhea prevention by strengthening gut barrier function, contribute to micronutrient fortification and reduce reliance on imported supplements, and aid in the prevention of chronic diseases through its dietary fiber and antioxidant properties.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter covers a summary of the research, conclusions and recommendations.

5.2 Summary

A total of eighteen (18) rice bran samples were analyzed for both heavy metals and essential elements and soil in Kirinyaga, Kwale and Kisumu Counties of Kenya. The rice bran was found to possess both essential elements and heavy metals. However, rice bran samples analyzed were found to possess arsenic concentration which was higher than the recommended level of 0.2 mg/kg by the WHO. The levels of Arsenic are higher in rice bran obtained from Kwale County. Rice bran from Kwale County is rich in Zinc compared to Kirinyaga County and Kisumu County. The levels of arsenic in the soil from all Counties were high and the level of arsenic bioaccumulation in rice bran was consequently high. Though iron was rich in the soil, rice bran did not significantly bioaccumulated iron.

5.3 Conclusions

This study determined the levels of essential elements and heavy metals in rice bran from different counties. There were significant levels of bioaccumulation of metal elements by cultivar and region. This study underscores the nutritional potential of rice bran and highlights geographic and varietal differences that can inform targeted interventions. Key differences in Zinc and Magnesium content provide valuable insight for stakeholders in nutritional sciences, and agriculture and rice processing industries. Policies that promote the utilization of rice bran for human nutrition—backed by nutrition-sensitive agricultural planning—can help Kenya meet its food security and public health goals, especially in vulnerable populations of under-fives.

5.4 Recommendations

This study recommends that irrigation water should be screened to ensure that rice do not bioaccumulate heavy metal contamination from water. It is also important to screen the level of heavy metals in fertilizers used in rice farms. The soil in which rice is grown should also be analyzed to determine levels of heavy metals.

It is also recommended that rice bran be integrated to human food because of its nutritious benefits. As it is being integrated to human food, care has to be taken to ensure that the levels of heavy metals should be below the recommended WHO standards. This will prevent heavy metal contamination.

This study also recommends that in cases of people with high Zinc deficiencies, rice bran from Supa and Pachanga can be used to fortify their food. This is because of high levels of Zinc in these bran varieties.

5.5 Suggestions for further research

i. Further studies need to be done to determine variations of metals in rice bran versus white rice.
ii. Further studies to be done to determine the variation of metals from different rice varieties other than the ones analyzed.
iii. Further research is recommended to explore the bioavailability and agronomic drivers in variation of essential elements in rice bran.
iv. Further research is suggested to be done on the metal composition of irrigation water against the level of metal elements bioaccumulated by rice bran.

REFERENCES

Ahero Irrigation Scheme – National Irrigation Authority. (n.d.). Retrieved November 4, 2025, from https://www.irrigationauthority.go.ke/projects/ahero-irrigation-scheme/

Ahmad, S. A., Khan, M. H., & Haque, M. (2018). Arsenic contamination in groundwater in Bangladesh: Implications and challenges for healthcare policy. *Risk Management and Healthcare Policy*, *11*, 251–261. https://doi.org/10.2147/RMHP.S153188

Akter, S., Begum, R., Dipti, S. S., Alim, M. A., Shuchy, S. I., Shozib, H. B., & Hasan, M. R. (2025). Effect of Degree of Milling (DOM) on Physicochemical and Nutritional Quality of Selected Rice Variety (BRRI dhan78). *International Journal of Food Science*, *2025*, 6034633. https://doi.org/10.1155/ijfo/6034633

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M.-Q. (2021). Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. *Toxics*, *9*(3), 42. https://doi.org/10.3390/toxics9030042

Arunrat, N., Kongsurakan, P., & Sereenonchai, S. (2024). Heavy metal contamination and potential health risks in upland rice-producing soils of rotational shifting cultivation in northern Thailand. *Environmental Sciences Europe*, *36*(1), 196. https://doi.org/10.1186/s12302-024-01023-3

Atera, E. A., Onyancha, F. N., & Majiwa, E. B. O. (2018). Production and marketing of rice in Kenya: Challenges and opportunities. *Journal of Development and Agricultural Economics*, *10*(3), 64–70. https://doi.org/10.5897/JDAE2017.0881

Avila, D. S., Puntel, R. L., & Aschner, M. (2013). Manganese in health and disease. *Metal Ions in Life Sciences*, *13*, 199–227. https://doi.org/10.1007/978-94-007-7500-8_7

B, M., & Ah, B. (2006). Selenoproteins and their impact on human health through diverse physiological pathways. *Physiology (Bethesda, Md.)*, *21*. https://doi.org/10.1152/physiol.00021.2006

Bakota, E. L., Dunn, R. O., & Liu, S. X. (2015). Heavy metals screening of rice bran oils and its relation to composition. *European Journal of Lipid Science and Technology*, *117*(9), 1452–1462. https://doi.org/10.1002/ejlt.201400443

Bharti, A., Jain, U., & Chauhan, N. (2024). Progressive analytical techniques utilized for the detection of contaminants attributed to food safety and security. *Talanta Open*, *10*, 100368. https://doi.org/10.1016/j.talo.2024.100368

Bhosale, S., & D.Vijayalakshmi. (2015). Processing and Nutritional Composition of Rice Bran. *Current Research in Nutrition and Food Science Journal*, *3*(1), 74–80. https://www.foodandnutritionjournal.org/volume3number1/processing-and-nutritional-composition-of-rice-bran/

Bilo, F., Lodolo, M., Borgese, L., Bosio, A., Benassi, L., Depero, L. E., & Bontempi, E. (2015). Evaluation of Heavy Metals Contamination from Environment to Food Matrix by TXRF: The Case of Rice and Rice Husk. *Hindawi Publishing Corporation Journal of Chemistry*. https://doi.org/10.1155/2015/274340

Bwire, D., Saito, H., Sidle, R. C., & Mugisha, M. (2025). Water management for rice production: A key component of food security in East Africa. *Discover Water*, *5*(1), 7. https://doi.org/10.1007/s43832-025-00196-z

Chang, C., Yin, R., Zhang, H., & Yao, L. (2019). Bioaccumulation and Health Risk Assessment of Heavy Metals in the Soil-Rice System in a Typical

Seleniferous Area in Central China. *Environmental Toxicology and Chemistry*, *38*(7), 1577–1584. https://doi.org/10.1002/etc.4443

Cozzolino, D., Dambergs, R. G., Janik, L., Cynkar, W. U., & Gishen, M. (2006). Analysis of Grapes and Wine by near Infrared Spectroscopy. *Journal of Near Infrared Spectroscopy*, *14*(5), 279–289. https://doi.org/10.1255/jnirs.679

Darko, A. M., Owusu Danquah, E., Dormatey, R., Keteku, A. K., Frimpong, F., Adjah, K. L., Osei-Wusu, M. O., Ayamba, B. E., Ofosu, K. A., Dankwa, K. O., & Danquah, F. O. (2025a). Chapter 1—Global rice production: Current status, challenges, and future scenarios. In S. Srivastava, K. Kumar, & O. P. Dhankher (Eds.), *Rice Cultivation Under Abiotic Stress* (pp. 3–21). Academic Press. https://doi.org/10.1016/B978-0-443-21793-7.00001-5

Darko, A. M., Owusu Danquah, E., Dormatey, R., Keteku, A. K., Frimpong, F., Adjah, K. L., Osei-Wusu, M. O., Ayamba, B. E., Ofosu, K. A., Dankwa, K. O., & Danquah, F. O. (2025b). Chapter 1—Global rice production: Current status, challenges, and future scenarios. In S. Srivastava, K. Kumar, & O. P. Dhankher (Eds.), *Rice Cultivation Under Abiotic Stress* (pp. 3–21). Academic Press. https://doi.org/10.1016/B978-0-443-21793-7.00001-5

de Oliveira, V. F., Busanello, C., Viana, V. E., Stafen, C. F., Pedrolo, A. M., Paniz, F. P., Pedron, T., Pereira, R. M., Rosa, S. A., de Magalhães Junior, A. M., Costa de Oliveira, A., Batista, B. L., & Pegoraro, C. (2021). Assessing mineral and toxic elements content in rice grains grown in southern Brazil. *Journal of Food Composition and Analysis*, *100*, 103914. https://doi.org/10.1016/j.jfca.2021.103914

Girden, E. R. (1992). *ANOVA: Repeated Measures*. SAGE.

Goufo, P., & Trindade, H. (2014). Rice antioxidants: Phenolic acids, flavonoids, anthocyanins, proanthocyanidins, tocopherols, tocotrienols, γ-oryzanol, and phytic acid. *Food Science & Nutrition*, *2*(2), 75–104. https://doi.org/10.1002/fsn3.86

Guillin, O. M., Vindry, C., Ohlmann, T., & Chavatte, L. (2019). Selenium, Selenoproteins and Viral Infection. *Nutrients*, *11*(9), 2101. https://doi.org/10.3390/nu11092101

Haque, M. A., Ferdous, N., Shozib, H. B., & Akter, S. (2021). Detection and quantification of Heavy metal and toxins in rice bran related products. *IJRDO - JOURNAL OF BIOLOGICAL SCIENCE*, *7*(1), Article 1. https://doi.org/10.53555/bs.v7i1.4038

Hasan, G. M. M. A., Das, A. K., & Satter, M. A. (2022). Accumulation of Heavy Metals in Rice (Oryza sativa. L) Grains Cultivated in Three Major Industrial Areas of Bangladesh. *Journal of Environmental and Public Health*, *2022*(1), 1836597. https://doi.org/10.1155/2022/1836597

Hauptman, M., Bruccoleri, R., & Woolf, A. D. (2017). An Update on Childhood Lead Poisoning. *Clinical Pediatric Emergency Medicine*, *18*(3), 181–192. https://doi.org/10.1016/j.cpem.2017.07.010

Heaphy, T. (2023, April 28). *United Nations 17 Sustainable Development Goals (SDGs) | Eurofins*. https://sustainabilityservices.eurofins.com/news-es/united-nations-17-sustainable-development-goals-sdgs/

Heavy Metal—An overview | ScienceDirect Topics. (n.d.). Retrieved November 4, 2025, from https://www.sciencedirect.com/topics/materials-science/heavy-metal

Heidari, S., Shayan Mostafaei, Razazian, N., Rajati, M., Saeedi, A., & Rajati, F. (2022). The effect of lead exposure on IQ test scores in children under 12 years: A systematic review and meta-analysis of case-control studies. *Systematic Reviews*, *11*(1), 106. https://doi.org/10.1186/s13643-022-01963-y

HJ 832-2017 English PDF. (2017). https://www.chinesestandard.net/PDF/English.amp.aspx/HJ832-2017?Redirect

Hu, X.-F., Jiang, Y., Shu, Y., Hu, X., Liu, L., & Luo, F. (2014). Effects of mining wastewater discharges on heavy metal pollution and soil enzyme activity of the paddy fields. *Journal of Geochemical Exploration*, *147*, 139–150. https://doi.org/10.1016/j.gexplo.2014.08.001

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, *7*(2), 60–72. https://doi.org/10.2478/intox-2014-0009

Jomova, K., Makova, M., Alomar, S. Y., Alwasel, S. H., Nepovimova, E., Kuca, K., Rhodes, C. J., & Valko, M. (2022). Essential metals in health and disease. *Chemico-Biological Interactions*, *367*, 110173. https://doi.org/10.1016/j.cbi.2022.110173

Kalpanadevi, C., Singh, V., & Subramanian, R. (2018). Influence of milling on the nutritional composition of bran from different rice varieties. *Journal of Food Science and Technology*, *55*(6), 2259. https://doi.org/10.1007/s13197-018-3143-9

KALRO. (2018). *Rice Response to Potassium Fertilization in Mwea, Kenya* (No. 52).

Kengo M, Kimani J, & Sang-Bok L. (2021). *Farmers' Demonstrate Rationality and Transitivity in Variety Choice: Empirical Evidence From two Rice Growing Niches in Coastal Kenya*. *6*(1), 46–55.

Kinyuru, J. N., Faculty of Agriculture, D. of F. S. and T., Borresen, E. C., Ryan, E. P., Department of Environmental and Radiological Health Sciences, C. S. U., & Department of Environmental and Radiological Health Sciences, C. S. U. (2015). Nutritional and Safety Evaluation of Heat-Stabilized Rice Bran for Supplementary Feeding of Malnourished Children in Kenya. *International Journal of Food Science, Nutrition and Dietetics*, 226. https://doi.org/10.19070/2326-3350-1500041

Kong, X., Liu, T., Yu, Z., Chen, Z., Lei, D., Wang, Z., Zhang, H., Li, Q., & Zhang, S. (2018). Heavy Metal Bioaccumulation in Rice from a High Geological Background Area in Guizhou Province, China. *International Journal of Environmental Research and Public Health*, *15*(10), 2281. https://doi.org/10.3390/ijerph15102281

Kuivenhoven, M., & Mason, K. (2025). Arsenic Toxicity. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK541125/

Lead poisoning. (n.d.). Retrieved November 5, 2025, from https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health

Linge, K., Julius, K. N., Fuchaka, W., Esther, K., & Douglas, S. (2020). Irrigation water quality analysis of Mitheu Stream in Machakos Municipality, Kenya. *African Journal of Environmental Science and Technology*, *14*(9), 241–249. https://doi.org/10.5897/AJEST2020.2849

Lower Kuja Irrigation Scheme – National Irrigation Authority. (n.d.). Retrieved November 8, 2025, from https://www.irrigationauthority.go.ke/projects/lower-kuja-irrigation-scheme/

Magoti, R., Kikuta, M., Chemining'wa, G., Kinama, J., John, K., Hiroaki, S., Patrick, G., & Makihara, D. (2019). Growth of Rice Varieties in Different Kenyan Soil Types Under Water-Deficit Conditions. *Journal of Agricultural Science*, *11*, 1–1. https://doi.org/10.5539/jas.v11n6p1

Manzoor, A., Pandey, V. K., Dar, A. H., Fayaz, U., Dash, K. K., Shams, R., Ahmad, S., Bashir, I., Fayaz, J., Singh, P., Khan, S. A., & Ganaie, T. A. (2023). Rice bran: Nutritional, phytochemical, and pharmacological profile and its contribution to human health promotion. *Food Chemistry Advances*, *2*, 100296. https://doi.org/10.1016/j.focha.2023.100296

Mao, C., Song, Y., Chen, L., Ji, J., Li, J., Yuan, X., Yang, Z., Ayoko, G. A., Frost, R. L., & Theiss, F. (2019). Human health risks of heavy metals in paddy rice based on transfer characteristics of heavy metals from soil to rice. *CATENA*, *175*, 339–348. https://doi.org/10.1016/j.catena.2018.12.029

Marshall, F., J, H., C, G., Chishala, B., Kapungwe, E., Volk, J., Agrawal, M., R, A., Sharma, R., & Singh, R. (2007). Contaminated Irrigation Water and Food Safety for the Urban and Peri-urban Poor: Appropriate Measures for Monitoring and Control from Field Research in India and Zambia. *Inspection Report*.

Martínez, S., Sánchez, R., Lefevre, J., & Todolí, J.-L. (2020). Multielemental analysis of vegetable oils and fats by means of ICP-OES following a dilution and shot methodology. *Journal of Analytical Atomic Spectrometry*, *35*(9), 1897–1909. https://doi.org/10.1039/D0JA00112K

Mercury. (n.d.). National Institute of Environmental Health Sciences. Retrieved November 5, 2025, from https://www.niehs.nih.gov/health/topics/agents/mercury

Miah, M., Ara, H., Jabin, S., Abedin, N., Azad, A., Hossain, A., & Ara, U. (2014). Nutritional Composition and Stabilization of Local Variety Rice Bran BRRI-28. *International Journal of Science and Technology*, *3*, 306–313.

Murtaza, G., Javed, W., Hussain, A., Wahid, A., Murtaza, B., & Owens, G. (2015). Metal uptake via phosphate fertilizer and city sewage in cereal and legume crops in Pakistan. *Environmental Science and Pollution Research International*, *22*(12), 9136–9147. https://doi.org/10.1007/s11356-015-4073-y

National-Rice-Development-Strategy-2019-2030.pdf. (n.d.). Retrieved November 4, 2025, from https://kilimo.go.ke/wp-content/uploads/2025/09/National-Rice-Development-Strategy-2019-2030.pdf

Odingo, S. K., Mapesa, J., Juma, R. J., Diba, H., Ouna, B. A., & Wanja, T. (2025a). Reintegrating rice bran into the diet: Community readiness and anthropometric assessments in combating malnutrition in rice growing regions in Kenya. *International Journal Of Community Medicine And Public Health*, *12*(1), 54–61. https://doi.org/10.18203/2394-6040.ijcmph20244000

Odingo, S. K., Mapesa, J., Juma, R. J., Diba, H., Ouna, B. A., & Wanja, T. (2025b). Reintegrating rice bran into the diet: Community readiness and anthropometric assessments in combating malnutrition in rice growing regions in Kenya. *International Journal Of Community Medicine And Public Health*, *12*(1), 54–61. https://doi.org/10.18203/2394-6040.ijcmph20244000

Office of Dietary Supplements—Magnesium. (2022). https://ods.od.nih.gov/factsheets/Magnesium-HealthProfessional/

Oluoko-Odingo, A. A. (2011). Vulnerability and Adaptation to Food Insecurity and Poverty in Kenya. *Annals of the Association of American Geographers*, *101*(1), 1–20. https://doi.org/10.1080/00045608.2010.532739

Ouna, B. A. (2025). Molecular Functions and Potential Utilization of Zinc Finger Proteins in Protozoan Parasites. *Extensive Reviews*, *5*(1), 17–29. https://doi.org/10.21467/exr.5.1.9879

Pateriya, A., & Kumar, R. (2020). Heavy Metal Toxicity in Rice and its Effects on Human Health. *Letters in Applied NanoBioScience*, *10*(1), 1833–1845. https://doi.org/10.33263/LIANBS101.18331845

Permyakov, E. A. (2021). Metal Binding Proteins. *Encyclopedia*, *1*(1), Article 1. https://doi.org/10.3390/encyclopedia1010024

Pirahanchi, Y., Jessu, R., & Aeddula, N. R. (2024). Physiology, Sodium Potassium Pump. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK537088/

Puri, S., Dhillon, B., & Sodhi, N. (2014). Effect of Degree of Milling (Dom) on Overall Quality of Rice -A Review. *International Journal of Advanced Biotechnology and Research*, *5*.

RÍsovÁ, V. (2019). The pathway of lead through the mother's body to the child. *Interdisciplinary Toxicology*, *12*(1), 1–6. https://doi.org/10.2478/intox-2019-0001

Rothenberg, S. E., Yin, R., Hurley, J. P., Krabbenhoft, D. P., Ismawati, Y., Hong, C., & Donohue, A. (2017). Stable Mercury Isotopes in Polished Rice (Oryza sativa L.) and Hair from Rice Consumers. *Environmental Science & Technology*, *51*(11), 6480–6488. https://doi.org/10.1021/acs.est.7b01039

Runge, J., Heringer, O. A., Ribeiro, J. S., & Biazati, L. B. (2019). Multi-element rice grains analysis by ICP OES and classification by processing types. *Food Chemistry*, *271*, 419–424. https://doi.org/10.1016/j.foodchem.2018.07.162

S, G., & Ak, S. (2017). Human health risk assessment due to dietary intake of heavy metals through rice in the mining areas of Singhbhum Copper Belt, India. *Environmental Science and Pollution Research International*, *24*(17). https://doi.org/10.1007/s11356-017-9039-9

Sadak, O. (2023). Chapter 15—Chemical sensing of heavy metals in water. In A. Barhoum & Z. Altintas (Eds.), *Advanced Sensor Technology* (pp. 565–591). Elsevier. https://doi.org/10.1016/B978-0-323-90222-9.00010-8

Saji, N., Francis, N., Schwarz, L. J., Blanchard, C. L., & Santhakumar, A. B. (2020). The Antioxidant and Anti-Inflammatory Properties of Rice Bran Phenolic Extracts. *Foods*, *9*(6), Article 6. https://doi.org/10.3390/foods9060829

Sapwarobol, S., Saphyakhajorn, W., & Astina, J. (2021). Biological Functions and Activities of Rice Bran as a Functional Ingredient: A Review. *Nutrition and Metabolic Insights*, *14*, 11786388211058559. https://doi.org/10.1177/11786388211058559

Satpathy, D., Reddy, M. V., & Dhal, S. P. (2014). Risk assessment of heavy metals contamination in paddy soil, plants, and grains (Oryza sativa L.) at the East Coast of India. *BioMed Research International*, *2014*, 545473. https://doi.org/10.1155/2014/545473

Scutarașu, E. C., & Trincă, L. C. (2023). Heavy Metals in Foods and Beverages: Global Situation, Health Risks and Reduction Methods. *Foods*, *12*(18), Article 18. https://doi.org/10.3390/foods12183340

Se, R., L, W.-M., & Je, C. (2014). Rice methylmercury exposure and mitigation: A comprehensive review. *Environmental Research*, *133*. https://doi.org/10.1016/j.envres.2014.03.001

Sharif, M. K., Butt, M. S., Anjum, F. M., & Khan, S. H. (2014). Rice bran: A novel functional ingredient. *Critical Reviews in Food Science and Nutrition*, *54*(6), 807–816. https://doi.org/10.1080/10408398.2011.608586

Sharma, A., Patni, B., Shankhdhar, D., & Shankhdhar, S. C. (2013). Zinc – An Indispensable Micronutrient. *Physiology and Molecular Biology of Plants : An International Journal of Functional Plant Biology*, *19*(1), 11–20. https://doi.org/10.1007/s12298-012-0139-1

Shi, Z., Carey, M., Meharg, C., Williams, P. N., Signes-Pastor, A. J., Triwardhani, E. A., Pandiangan, F. I., Campbell, K., Elliott, C., Marwa, E. M., Jiujin, X., Farias, J. G., Nicoloso, F. T., De Silva, P. M. C. S., Lu, Y., Norton, G., Adomako, E., Green, A. J., Moreno-Jiménez, E., … Meharg, A. A. (2020). Rice Grain Cadmium Concentrations in the Global Supply-Chain. *Exposure and Health*. https://doi.org/10.1007/s12403-020-00349-6

Spaggiari, M., Dall'Asta, C., Galaverna, G., & del Castillo Bilbao, M. D. (2021). Rice Bran By-Product: From Valorization Strategies to Nutritional Perspectives. *Foods*, *10*(1), Article 1. https://doi.org/10.3390/foods10010085

Srivastava, D., Tiwari, M., Dutta, P., Singh, P., Chawda, K., Kumari, M., & Chakrabarty, D. (2021). Chromium Stress in Plants: Toxicity, Tolerance and Phytoremediation. *Sustainability*, *13*(9), Article 9. https://doi.org/10.3390/su13094629

SUPA BC - The Rice Variety with Benefits. (2014, July 15). [Text]. IAEA. http://www.iaea.org/newscenter/news/supa-bc-rice-variety-benefits

Tang, L., Risalat, H., Cao, R., Hu, Q., Pan, X., Hu, Y., & Zhang, G. (2022). Food Security in China: A Brief View of Rice Production in Recent 20 Years. *Foods*, *11*(21), 3324. https://doi.org/10.3390/foods11213324

TatahMentan, M., Nyachoti, S., Scott, L., Phan, N., Okwori, F. O., Felemban, N., & Godebo, T. R. (2020). Toxic and Essential Elements in Rice and Other Grains from the United States and Other Countries. *International Journal of Environmental Research and Public Health*, *17*(21), 8128. https://doi.org/10.3390/ijerph17218128

Uma, A., Okello, D., & Opondo, F. (2025). Rice production potential and potential benefits from rice area expansion in Kenya: A literature review. *Discover Sustainability*, *6*(1), 1160. https://doi.org/10.1007/s43621-025-00947-x

Wani, A. L., Ara, A., & Usmani, J. A. (2015). Lead toxicity: A review. *Interdisciplinary Toxicology*, *8*(2), 55. https://doi.org/10.1515/intox-2015-0009

Weber, A. M., Baxter, B. A., McClung, A., Lamb, M. M., Becker-Dreps, S., Vilchez, S., Koita, O., Wieringa, F., & Ryan, E. P. (2021). Arsenic speciation in rice bran: Agronomic practices, postharvest fermentation, and human health risk assessment across the lifespan. *Environmental Pollution*, *290*, 117962. https://doi.org/10.1016/j.envpol.2021.117962

Wei, R., Chen, C., Kou, M., Liu, Z., Wang, Z., Cai, J., & Tan, W. (2023). Heavy metal concentrations in rice that meet safety standards can still pose a risk to human health. *Communications Earth & Environment*, *4*(1), 1–9. https://doi.org/10.1038/s43247-023-00723-7

Wilschefski, S. C., & Baxter, M. R. (2019). Inductively Coupled Plasma Mass Spectrometry: Introduction to Analytical Aspects. *The Clinical Biochemist Reviews*, *40*(3), 115. https://doi.org/10.33176/AACB-19-00024

Xuhui Z & Xiaolin Z. (2019). *Rice Bran and Rice Bran Oil* (1st ed.). Academic Press.

Yagi, T., Asakawa, A., Ueda, H., Ikeda, S., Miyawaki, S., & Inui, A. (2013). The Role of Zinc in the Treatment of Taste Disorders. *Recent Patents on Food, Nutrition & Agriculture*, *5*. https://doi.org/10.2174/2212798411305010007

Yao, B.-M., Chen, P., & Sun, G.-X. (2020). Distribution of elements and their correlation in bran, polished rice, and whole grain. *Food Science & Nutrition*, *8*(2), 982–992. https://doi.org/10.1002/fsn3.1379

Ye, Q., Park, J. E., Gugnani, K., Betharia, S., Pino-Figueroa, A., & Kim, J. (2017). Influence of iron metabolism on manganese transport and toxicity. *Metallomics : Integrated Biometal Science*, *9*(8), 1028–1046. https://doi.org/10.1039/c7mt00079k

Yilmaz Tuncel N. (2023). *Stabilization of Rice Bran: A Review*. *12*(9), 1924.

Zacchia, M., Abategiovanni, M. L., Stratigis, S., & Capasso, G. (2016). Potassium: From Physiology to Clinical Implications. *Kidney Diseases*, *2*(2), 72–79. https://doi.org/10.1159/000446268

Zambrana, L. E., Weber, A. M., Borresen, E. C., Zarei, I., Perez, J., Perez, C., Rodríguez, I., Becker-Dreps, S., Yuan, L., Vilchez, S., & Ryan, E. P. (2021). Daily Rice Bran Consumption for 6 Months Influences Serum Glucagon-Like Peptide 2 and Metabolite Profiles without Differences in Trace Elements and Heavy Metals in Weaning Nicaraguan Infants at 12 Months of Age. *Current Developments in Nutrition*, *5*(9), nzab101. https://doi.org/10.1093/cdn/nzab101

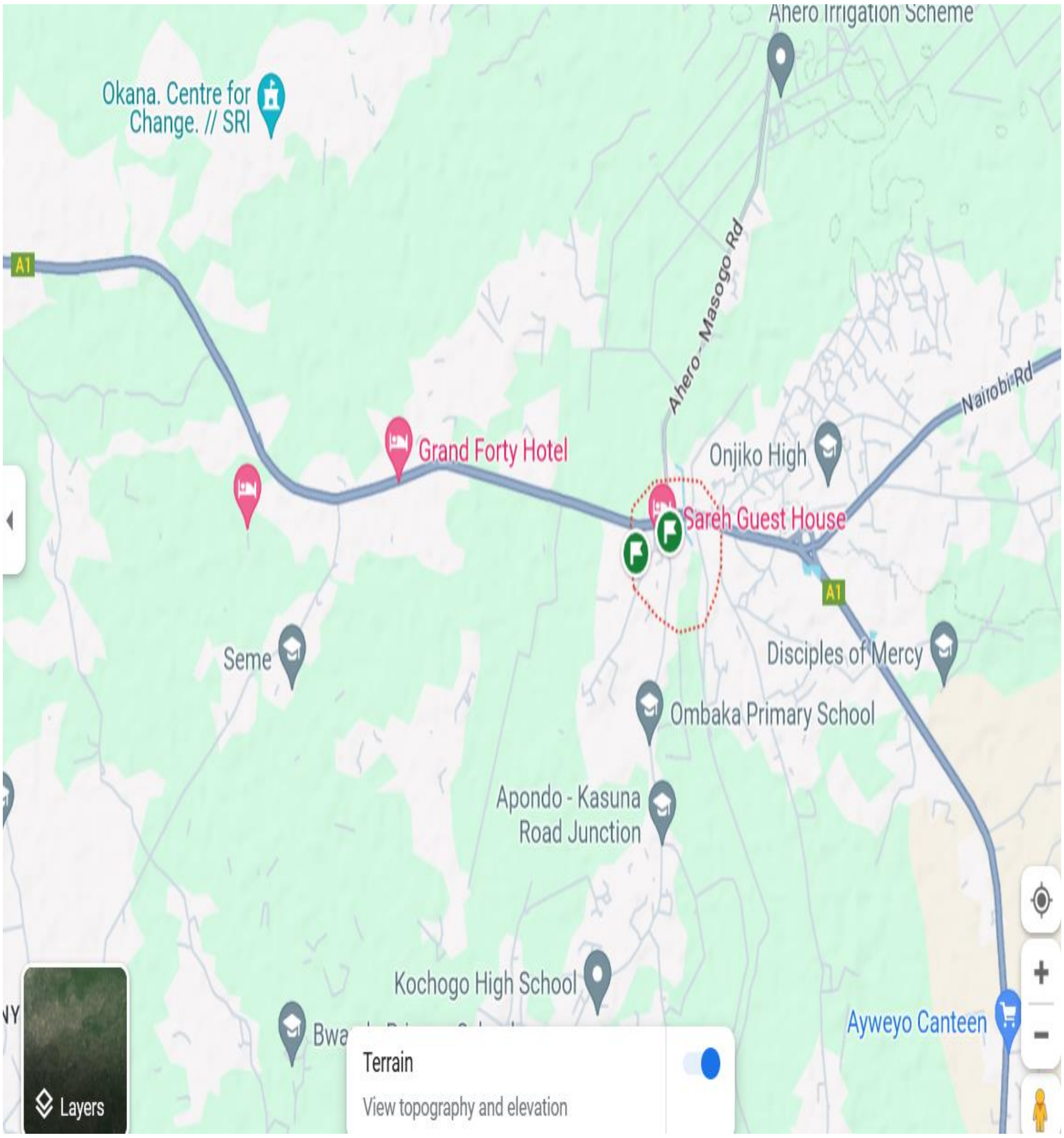
Zhang, L., Guo, Y., Liang, K., Hu, Z., Sun, X., Fang, Y., Mei, X., Yin, H., Liu, X., & Lu, B. (2020). Determination of Selenium in Common and Selenium-Rich Rice from Different Areas in China and Assessment of Their Dietary Intake. *International Journal of Environmental Research and Public Health*, *17*(12), 4596. https://doi.org/10.3390/ijerph17124596

Zuwei, W., & Zeng, X. (2015). Health Risks of Heavy Metals Uptake by Crops Grown in a Sewage Irrigation Area in China. *Polish Journal of Environmental Studies*, *24*(3), 1379–1386. https://doi.org/10.15244/pjoes/35282

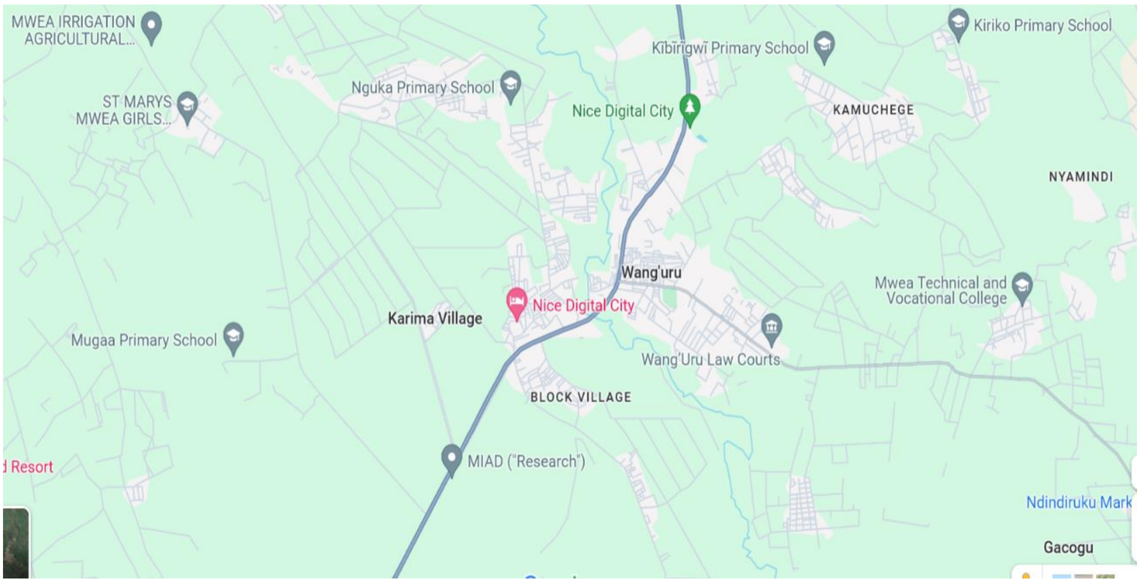
APPENDICES

APPENDIX I: Maps

Ahero Irrigation Schemes



Mwea Irrigation Schemes



Kwale Small- scale farms

APPENDIX II: Calibration Curves

Calibration Summary

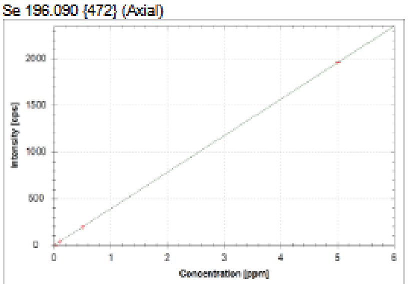
2/6/2024 8:38:43 AM

QTEGRA

LabBook: CA240008-CA240016 Zn, Fe and Se Analysis - Copy.imexp

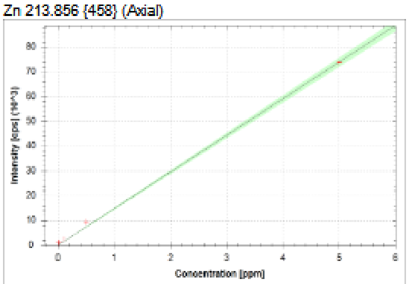
Calibration Graphs

Se 196.090 {472} (Axial)



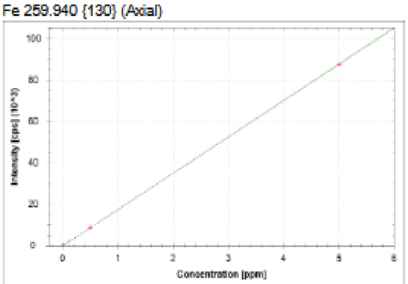
f(x) = 392.3521*x + -0.4886
R^2 = 1.0000
BEC = -0.001 ppm
LoD = 0.0050 ppm

Zn 213.856 {458} (Axial)



f(x) = 14791.0675*x + 16.9274
R^2 = 0.9983
BEC = 0.001 ppm
LoD = 0.0002 ppm

Fe 259.940 {130} (Axial)



f(x) = 17577.0327*x + 4.4630
R^2 = 1.0000
BEC = 0.000 ppm
LoD = 0.0006 ppm

APPENDIX III: Sample Raw Results

KEPHIS ANALYTICAL CHEMISTRY LABORATORY

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E-mail: director@kephis.org • Website: www.kephis.org

Client: Kiplagat Paul **Date:** 10th January, 2024

Address: Bomet

Contact: 0723245691

E-mail: gugomogor@gmail.com

REPORT OF ANALYSIS

The following is the partial analytical report for Rice Bran samples submitted to KEPHIS Analytical Chemistry Laboratory on 19th September, 2023 for analysis.

Note:

- This result refers only to the submitted sample.
- The results below were analysed using ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometer)
- This report should not be reproduced/copied/scanned except with written approval of the Head of Laboratory.
- mg/Kg =parts per million (ppm)
- LOQ= Limit of Quantification
- Pb=Lead
- Hg-Mercury
- Cd= Cadmium
- As=Arsenic
- Cr-Chromium
- Se= Selenium
- Zn= Zinc
- Fe= Iron
- Mn= Manganese
- Mg= Magnessium
- Cu= Copper
- K= Potassium

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Lab Code/Parameters Analysed	Client sample Identification	As Mg/kg	Zn Mg/kg	Cd Mg/Kg	Pb Mg/Kg	Se Mg/Kg	Hg Mg/Kg	Fe Mg/Kg	Mn Mg/Kg	Cr Mg/Kg	Mg Mg/Kg	K Mg/Kg	Cu Mg/Kg
CA230565	KRB13	-	46.38	-	<LOQ	0.54	<LOQ	200.26	346.23	-	4178.28	10214.69	10.33
CA230566	KRB14	-	55.22	-	<LOQ	0.35	<LOQ	316.56	237.91	-	4756.27	11667.97	9.39
CA230567	KRB15	-	56.36	-	<LOQ	0.35	<LOQ	246.11	161.45	-	4231.90	9091.32	7.46
CA230568	KRB16	-	48.67	-	<LOQ	0.31	<LOQ	174.42	169.70	-	4570.33	10518.76	9.64
CA230569	KRB17	-	40.73	-	<LOQ	0.40	<LOQ	207.91	220.30	-	4424.55	10259.66	7.81
CA230570	KRB18	-	47.28	-	<LOQ	1.49	<LOQ	472.55	372.79	-	3970.93	9749.86	8.58

Key

- Means those parameters yet to be analyzed.

Analyst	Technical Signatory	Authorized Signatory
Paul Njuguna	Timothy Osoro	Peter Kamuti
Laboratory Analyst	**Principal Laboratory Analyst**	**Laboratory Manager**

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APPENDIX IV: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 715441

Date of Issue: 20/August/2024

RESEARCH LICENSE

This is to Certify that Mr.. KIPLANGAT PAUL of University of Kabianga, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Kirinyaga, Kisumu, Kwale on the topic: DETERMINATION OF LEVEL OF SELECTED HEAVY METALS AND ESSENTIAL ELEMENTS IN RICEBRAN AND SOIL FROM KWALE, KIRINYAGA AND KISUMU COUNTIES, KENYA for the period ending : 20/August/2025.

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APPENDIX V: Publication