

**DETERMINATION OF THE NUTRITIONAL PROFILES OF SELECTED
MAIZE (*Zea mays*) VARIETIES GROWN IN KIRINYAGA COUNTY
KENYA**

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**A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Chemistry of Murang'a University of Technology**

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DECLARATION

Student Declaration

I hereby declare that this Thesis is my original work and, to the best of my knowledge, has not been presented with a degree award at this or any other university. I understand what plagiarism is and I am aware of the university's policy in this. I understand that any false claim regarding this work shall result in disciplinary action in accordance with the University Anti-Plagiarism Policy.

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Supervisors' Approval

The undersigned certify that they have read and hereby recommended for acceptance of Murang'a University of Technology a thesis entitled **“Determination of the Nutritional Profiles of Selected Maize (*Zea mays*) Varieties Grown in Kirinyaga County Kenya”**.

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DEDICATION

I dedicate this work to my parents Mugambi Kinyua Mbaka and Cecilia Muthoni, my siblings Dennis Ngari Mugambi and Esther Makena Mugambi, and all my friends for their support during the course of my study.

ACKNOWLEDGEMENT

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ABSTRACT

Maize (*Zea mays*) is a staple food in Kenya and plays a critical role in addressing food security and nutrition. Previous research has focused mainly on yield, and drought and disease tolerance there's however, limited comprehensive data available on the nutritional composition of different maize varieties which poses a potential for micro-nutrient deficiency. This study aimed to determine and compare the nutritional profiles of selected maize varieties grown across the five sub counties in Kirinyaga county. Twenty-five maize grain samples collected from demonstration farms to represent selected commercial varieties were analyzed. Fourier Transform Infrared (FTIR) and Atomic Absorption Spectroscopy (AAS) techniques to determine their nutritional profiles. FTIR provided valuable information on the macro-nutrient content. Absorbance intensities at wavenumbers 997 cm^{-1} -C-O stretch 1076 cm^{-1} -C-O-C-stretch 1149 cm^{-1} -C-O-C- asymmetric stretching attributable to carbohydrates, 2854 cm^{-1} -CH₂ symmetric stretching 2925 cm^{-1} asymmetric stretching 1743 cm^{-1} -C=O stretching 1709 cm^{-1} -C=O stretching attributed to fatty acids and fatty acid esters and, 1539 cm^{-1} amide ii -N-H bending/-C-N stretching 1646 cm^{-1} amide i C=O Stretching of peptide bonds linked to proteins were obtained to represent relative nutritional content in the samples. Principle component analysis and heatmaps was used to analyze the data collected from the spectra. FTIR-PCA which accounted for 95.53% of the variability showed clustering in terms of variety. Heatmaps revealed that KE-7 had consistently higher absorbance intensities across the measured wavenumbers. AAS was used to quantify essential micro-nutrients (Fe, Mg, Mn and Zn). Results showed that magnesium was the most abundant mineral with a mean concentration of 1254.14 mg/kg, zinc ranked second with a mean concentration of 43.27 mg/kg, iron had a mean concentration of 41.38 mg/kg while manganese had a mean concentration of 5.90 mg/kg. Significant regional differences were observed for the elements measured with Mwea east and west showing generally higher mineral concentrations. By employing FTIR, AAS and PCA this research provided a rapid, cost-effective, and accurate method for assessing the nutritional composition of maize varieties. The findings will contribute to enhancing our understanding of the nutrient content variation across different maize varieties in Kirinyaga, Kenya and guide agricultural practices, and dietary recommendations.

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ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
AEZ	Agro-ecological Zones
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
ATR	Attenuated Total Reflectance
CRISPR	Clustered regularly interspaced short palindromic repeats
DIAAS	Digestible indispensable amino acids score
FAD	Flavin adenine dinucleotide
FAO	Food and Agriculture Organization of the United Nations
FMN	Flavin mononucleotide
FTIR	Fourier Transform Infrared Spectroscopy
HSD	Honest significant difference
IQR	Interquartile range
KALRO	Kenya Agricultural and Livestock Research Organization
LDL	Low-density lipoproteins
NAD	Nicotinamide Adenine Dinucleotide
NADP	Nicotinamide Adenine Dinucleotide Phosphate
PCA	Principal Component Analysis
PCR	Principal Component Regression
PDCAAS	Protein digestibility-corrected amino acids score
PLS	Partial Least Squared
QPM	Quality protein maize
RS3	Resistant starch type 3
USDA	United States Department of Agriculture
WHO	World Health Organization

DEFINITION OF OPERATIONAL TERMS

Pulverize: To Reduce to a fine powder using mechanical grinding or milling in order to increase sample homogeneity and improve analytical accuracy

Background spectrum: An FTIR spectrum collected without the sample, representing atmospheric gases and instrument characteristics.

Spectrum: A graphical representation of the interaction between electromagnetic radiation and a sample, it shows the absorbance or transmittance as a function of the wavenumber.

Absorbance mode: An FTIR measurement mode in which the amount of infrared radiation absorbed by a sample is recorded and displayed as absorbance against the wavenumber.

Baseline correction: A data-processing procedure in which spectral distortions are removed to ensure that peak intensities accurately represent the sample's chemical composition.

Asymmetric stretching: A molecular vibration in which excited atoms within a functional group move simultaneously in opposite directions, resulting in unequal changes in bond lengths.

Symmetric stretching: A molecular vibration in which two or more bonds increase or decrease in length simultaneously and equally while maintaining molecular symmetry.

Atomize: To convert into free gaseous atoms to enable elemental analysis.

Deionized: A solvent from which dissolved ionic impurities have been removed.

Homogeneous: Having a uniform composition and properties throughout the sample.

Temperature ramp: A controlled, gradual increase or decrease in temperature at a specified rate.

Dissolution: The process by which a solid sample dissolves completely in a solvent.

Calibration curve: A graph constructed by plotting an instruments response against known concentrations of standards, it is used to determine the concentration of analytes in unknown samples.

Stock solution: A concentrated solution of accurately known concentration prepared for dilution into working standards.

Reagent blank: A solution containing all reagents used in sample preparation but no analyte.

Calibration standard: A solution containing accurately known concentrations of an analyte. It is used to plot calibration curves.

Dry ashing: A sample preparation technique in which organic samples are heated to remove organic matter leaving inorganic mineral ash for subsequent analysis.

CHAPTER ONE INTRODUCTION

1.1 Background Information of the Study

Maize (*Zea mays*), one of the most widely cultivated cereal crops worldwide, is a staple food in Kenya, providing sustenance to millions and contributing significantly to the country's economy. In 2024, approximately 2.4 million hectares were devoted to maize cultivation, and the crop's production value was estimated at about KSh 199 billion, underscoring its agricultural dominance and major contribution to national food security and the agricultural sector (Kenya National Bureau of Statistics, 2024). Beyond its economic importance, maize plays a critical role in human nutrition as a major source of energy and nutrients, supplying primarily carbohydrates alongside moderate amounts of protein and essential micronutrients such as iron, zinc, and magnesium that contribute to metabolic functions and overall health (Ifie et al., 2026). However, the nutritional value of maize varies significantly across different varieties due to genetic diversity, environmental factors, and cultivation practices (Qamar et al., 2016). This variability is of concern in Kenya, where maize is a dietary staple and malnutrition remains a persistent challenge (Were, 2021).

Research on maize in Kenya has historically focused heavily on improving agronomic traits such as yield potential, drought tolerance, and resistance to pests and diseases. Recent research confirms that breeders and farmers alike tend to prioritize attributes associated with productivity and stress resilience, while nutritional quality and compositional traits have received comparatively limited emphasis in many varietal development and adoption studies (Garcia-Medina et al., 2026). This imbalance highlights the need for a more holistic research and development approach that integrates nutritional composition into maize breeding and evaluation frameworks to better align productivity gains with dietary quality outcomes.

Globally, studies have demonstrated the value of nutritional profiling in improving dietary intake. Multi-environmental studies conducted across sub-Saharan Africa, Asia, and Latin America, revealed significant differences in the macro- and micronutrient content of maize varieties, linking these variations to genetic and environmental factors (Prasanna et al. 2020). Similarly, studies involving diverse

maize germplasm across multiple regions, highlighted the variation in kernel chemical composition, emphasizing the role of genetic diversity in determining nutrient level (Flint-Garcia et al., 2015). More recently, Kumar et al. (2019) explored the potential of biofortification to enhance the nutritional quality of maize, particularly in addressing micronutrient deficiencies in developing countries. These findings demonstrate the potential applicability of nutritional analysis in guiding breeding programs and agricultural practices to meet dietary needs.

Kirinyaga County is a maize-growing region with diverse varieties (hybrids, and locally adapted types). The final nutritional density of maize at the point of consumption is a product of Genotype $\times$ Environment ($G \times E$) interactions. While genetic potential determines the theoretical limit of a variety's nutrient content, the actual expression of these nutrients depends heavily on site-specific factors such as soil mineral availability, pH, and rainfall. For instance, maize varieties cultivated in high-altitude regions generally demonstrate higher concentrations of micronutrients compared to those grown in lowland areas (Ifie et al., 2026). Therefore, assessing maize varieties directly from the diverse agro-ecological zones where they are cultivated provides a more realistic representation of the nutritional value available to the local population than studies conducted in isolated, controlled environments.

1.2 Statement of the Problem

Maize is a staple crop in Kenya, contributing significantly to the country's food security and nutrition. Existing literature demonstrates that the nutritional composition of maize can vary significantly among varieties and with geographical origin. A critical gap exists in understanding how the nutritional profiles of common maize varieties are expressed across the diverse terrains of Kirinyaga County. Most nutritional data in Kenya is derived from breeding stations under optimal conditions, which may not reflect the actual nutrient density of maize harvested from smallholder farms with varying soil fertilities. Consequently, there is an urgent need to conduct a field-based analytical survey that maps the actual nutritional outcomes in different sub-counties to identify which varieties consistently maintain high quality across varying ecological conditions. This variation can have implications for human nutrition, livestock feed quality, and the development of improved maize breeding programs.

The use of Fourier Transform Infrared Spectroscopy (FTIR) and Atomic Absorption Spectroscopy (AAS), provide accurate and efficient means of nutritional analysis. Unlike proximate analysis, which is often time-consuming, destructive to the sample, and dependent on hazardous chemical reagents, FTIR offers a rapid, non-destructive, and reagent-free approach that can simultaneously identify multiple functional groups associated to different macronutrient. AAS provides great sensitivity and precision in quantifying micronutrients. However, despite these benefits, the concurrent application of FTIR and AAS in determining the nutritional content of maize within the Kenyan context remains largely unexplored.

1.3. Objectives of the Study

1.3.1 General Objective

To assess and compare the nutritional content of various maize varieties grown in Kirinyaga County, Kenya.

1.3.2 Specific Objectives

1. To determine the macronutrients composition (proteins, carbohydrates and lipids) of selected maize varieties, grown in Kirinyaga county.
2. To quantify the concentration of Fe, Zn, Mg, and Mn in selected maize samples.
3. To compare the nutritional profiles of the maize varieties grown in Kirinyaga using multivariate statistical analysis tools.

1.4 Research Questions

1. What is the macronutrient composition (proteins, carbohydrates, and lipids) of the selected maize varieties grown in Kirinyaga County?
2. What are the concentrations of iron (Fe), zinc (Zn), magnesium (Mg), and manganese (Mn) in the selected maize samples?
3. How do the nutritional profiles of the selected maize varieties grown in Kirinyaga County compare based on multivariate statistical analysis?

1.5 Significance of the Study

This study helped quantify the nutritional content of maize in Kirinyaga county. The study advanced the understanding of how nutritional quality varies with geographical origin in Kirinyaga county. The data collected under this study will provide maize breeders with potential varieties for advancement when breeding maize of higher nutritional quality. The research also highlights high performing varieties that farmers may adopt. This work will also help promote sustainable agriculture.

1.6 Scope of the Study

The study's findings and conclusions are contingent on the representativeness of the collected maize samples. The selection process and sample size does not fully encompass the entire range of maize varieties grown in Kirinyaga. Therefore, the generalization of results to the entire population of maize varieties should be treated with caution. The study quantifies micro nutrients and develops a nutritional profile of the different maize varieties; it does not account for the bioavailability of these nutrients. Factors such as anti-nutritional compounds (e.g., phytates, tannins), which are known to inhibit the absorption of minerals like zinc and iron, are not considered.

1.7 Limitation of the Study

All environmental variables such as soil chemistry, agronomic practices, altitude, moisture etc. potentially introducing variability in the nutritional profiles observed may not be accounted for. Despite these limitations, this research aimed at providing valuable insights into the nutritional content of maize varieties in Kirinyaga. By acknowledging these potential constraints, the study's results can be appropriately interpreted.

1.8 Contributions of the Thesis

The main contributions of this study were:

- I. FTIR analysis identified characteristic absorption bands associated with carbohydrates (997 cm^{-1} , 1076 cm^{-1} and 1149 cm^{-1}), lipids (1709 cm^{-1} , 1743 cm^{-1} , 2854 cm^{-1} and 2925 cm^{-1}) and proteins (1539 cm^{-1} and 1646 cm^{-1}), providing a rapid comparative assessment of macronutrient composition among the maize varieties. Principal Component Analysis of the FTIR data, demonstrated that

differences in macronutrient composition were largely associated with maize variety.

- II. Heatmap analysis identified KE-7 as the variety exhibiting consistently higher absorbance intensities across the analyzed functional groups.
- III. The study quantified the concentrations of essential micronutrients in maize grown in Kirinyaga County. Magnesium was identified as the most abundant mineral with a mean concentration of 1254.14 mg/kg, followed by zinc (43.27 mg/kg), iron (41.38 mg/kg), and manganese (5.90 mg/kg).
- IV. Inferential statistics showed that Kirinyaga East had significantly lower magnesium concentrations than Kirinyaga West, Mwea East, and Mwea West ($P < 0.05$). However, Kirinyaga West, Mwea East, and Mwea West did not differ significantly from one another ($P > 0.05$). Mwea East and Mwea West had significantly higher manganese concentrations than Kirinyaga Central ($P < 0.05$) Kirinyaga East had significantly higher zinc concentrations than Kirinyaga Central ($p = 0.033$) Mwea East had significantly higher iron concentrations than Kirinyaga Central ($p = 0.012$), while Kirinyaga East also had significantly higher iron concentrations than Kirinyaga Central ($p = 0.047$).

1.9 Organization of the Thesis

Chapter One begins with an introduction of the study it has the following sub sections, background information of the study, statement of the problem, objectives of the study, hypothesis of the study, justification of the study, significance of the study and the scope and the limitations of the study.

Chapter Two which is the literature review gives an overview of the maize plant, its nutritional content, studies carried out on the nutritional content in maize FTIR and AAS quantification techniques and their applications in the food industry.

Chapter Three which is materials and methods outlines the materials and all methods applied in achieving the studies objectives.

Chapter Four chapter four discusses the results and data obtained from the methods in chapter three. The results are arranged sequentially as per the objectives.

Chapter Five the chapter discusses the conclusions drawn from this study, it also gives policy and research recommendations for future studies.

CHAPTER TWO LITERATURE REVIEW

2.1 Introduction

Maize, scientifically known as *Zea mays*, is one of the most widely cultivated cereal crops and a major staple food globally. It belongs to the grass family Poaceae and is believed to have originated in Mesoamerica, where it was domesticated from wild relatives known as teosintes before spreading worldwide. The crop is characterized by a tall growth habit, broad leaves, and distinct cobs that bear rows of edible kernels consumed in various forms (Ifie et al., 2026; Moustafa, 2024)

In Kenya, maize is grown at altitudes ranging from 900 - 2200 m above sea level and requires a mean annual rainfall ranging from 600 to 1,200 mm distributed uniformly throughout the growing period. Despite being able to grow in various soil types maize flourishes in fertile well-drained soils whose pH ranges from 5.5 to 7.5. Waterlogging reduces crop yield and growth (Cairns et al., 2013)

2.2 Parts of a Maize Plant

Maize plants typically grow to a height of 2–4 meters, although some dwarf varieties are shorter (Shiferaw et al., 2011). The plant consists of a sturdy stem with long, broad leaves arranged alternately along the stem as shown in Figure 2.1. Maize has a fibrous root system, consisting of numerous thin, branching roots that spread out in the soil (Rossini et al., 2018).

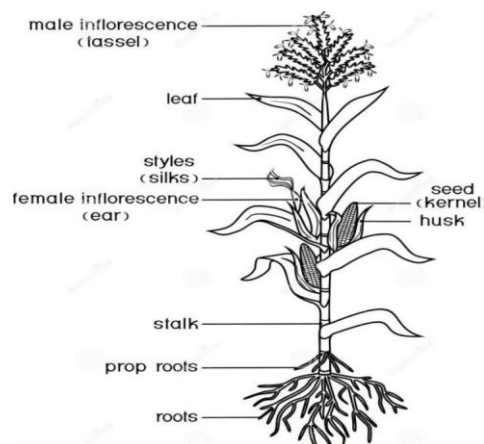


Figure 2.1: Parts of a maize plant (Albertsen et al., 2014)

These roots play a crucial role in absorbing water and nutrients from the soil to support plant growth. The main stem of the maize plant, known as the stalk, provides structural support. It is rigid and hollow, composed of long, cylindrical segments called inter-nodes. The leaves have parallel veins running lengthwise, providing support and facilitating the transport of water and nutrients throughout the plant at the top of the maize plant, a structure called the tassel emerges (Strable & Nelissen, 2021; Chen & Gallavotti, 2021). The tassel is the male reproductive organ, consisting of a central stalk with numerous branches. It produces pollen, which is necessary for pollination and fertilization of the maize ears. Maize ears are the reproductive structures of the plant. They are cylindrical or conical in shape and located at the leaf axils on the main stem (Rossini et al., 2018). The ears are covered by several layers of modified leaves called husks. Within the husks, rows of tightly packed kernels develop, each attached to a central cob. The number of rows and kernels per row varies among different maize varieties (Shiferaw et al., 2011)

2.3 The Kernel

Maize kernels, also referred to as maize seeds, are the edible part of the maize plant and are enclosed within the protective husks. Maize kernels have an oval or wedge-shaped appearance. They are typically plump and rounded, tapering to a point at one end (Taiz et al., 2023).

The size of maize kernels varies depending on the variety and growing conditions but is usually between 0.5 to 2 centimeters in length. Maize kernels come in a range of colors, including yellow, white, and multicolored varieties as shown in Figure 2.2.



Figure 2.2: Color phenotype of four maize kernels; white, yellow, red–purple and purple–black arranged from left to right.(Jiang et al.,2023)

The color is determined by the genetic makeup of the maize variety and can vary significantly. Yellow and white are the most common kernel colors, while

multicolored kernels may display a combination of different shades and patterns (Chen et al., 2024). The texture of maize kernels is firm and starchy.

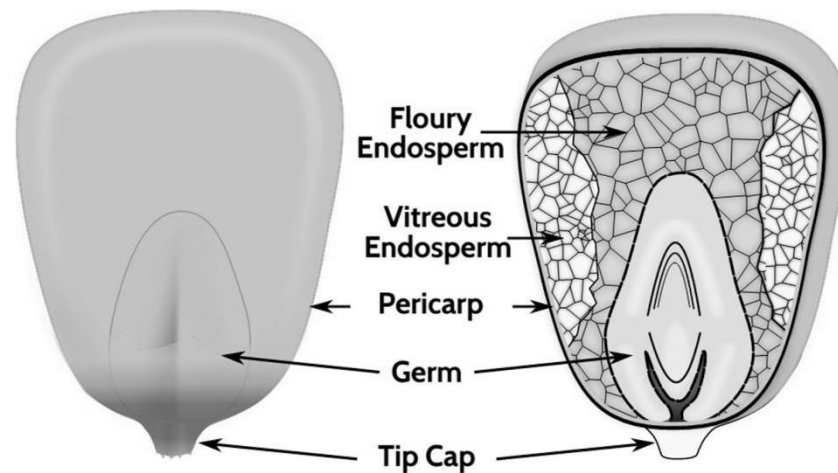


Figure 2.3: Parts of a maize kernel (Hernández et al., 2023)

The outer layer of the kernel, known as the pericarp or seed coat, is relatively tough and provides protection. Inside the pericarp is the endosperm, which constitutes the majority of the kernel's volume as shown in Figure 2.3.

The endosperm is composed primarily of starch but also contains proteins, oils, and vitamins, it is the largest part of the kernel and serves as the main source of energy and nutrients. (Alvarez et al., 2021).

The germ is the small embryo located at the base of the kernel and contains essential oils, proteins, and vitamins. (Burlini et al., 2020)

2.4 Nutritional Content of Maize

Maize kernels are a rich source of carbohydrates, providing energy to the human body. They also contain proteins, dietary fiber, vitamins, minerals (such as potassium and magnesium), and antioxidants (Kumar et al., 2019).

2.4.1 Carbohydrates

Carbohydrates are the main macronutrient in maize grain, typically comprising approximately 70–75% of the dry weight of the kernel, starch accounts for the majority of this fraction (Rahimi Jahangirlou et al., 2021; Zea et al., 2021). Starch is composed of two glucose polymers, amylose and amylopectin. Amylose is a linear polymer linked by α -(1 $\rightarrow$ 4) glycosidic bonds as shown in Figure 2.4.

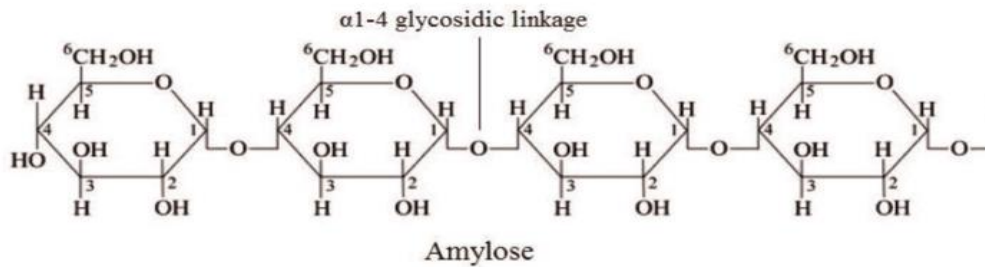


Figure 2.4: Structure of amylose (Bisht et al., 2022)

Amylopectin is highly branched with both α -(1 $\rightarrow$ 4) and α -(1 $\rightarrow$ 6) linkages, as shown in Figure 2.5, creating a larger, more complex molecular structure (BeMiller and Whistler, 2019; Martens et al., 2018).

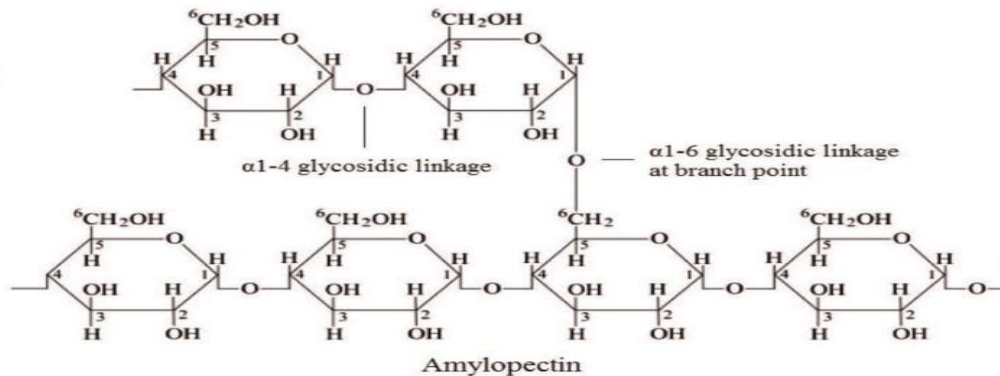


Figure 2.5: Structure of amylopectin (Bisht et al., 2022)

The relative proportions of amylose and amylopectin vary among maize genotypes, with dent and flint maize often showing about 25–30% amylose and 70–75% amylopectin, whereas specialized waxy maize contains almost exclusively amylopectin (Obadi et al., 2023; Singh et al., 2022).

Genetic studies demonstrate substantial variation in amylose and resistant starch content among maize inbred lines, with amylose ranging from 1.7% - 66.2% and resistant starch from 1.4% to 39.4% in sub tropically adapted lines (Shashidhar et al., 2023). Higher amylose content is positively correlated with resistant starch formation, which reduces enzymatic digestibility and contributes to lower postprandial glycemic response (Shashidhar et al., 2023). This variation highlights the potential for genetic selection and breeding to improve carbohydrate quality in maize for health-oriented applications (Zhong et al., 2022).

The digestibility of maize starch is influenced by both molecular structure and kernel physical traits. Endosperm hardness, protein–starch interactions, and granule packaging all significantly affect enzymatic accessibility. Hard endosperm varieties exhibit slower starch hydrolysis and lower estimated glycemic indices averaging 77.3 compared to soft endosperm types averaging 80.7, as the dense matrix of zein proteins in vitreous kernels acts as a physical barrier to enzyme penetration (Caballero-Rothar et al., 2022). These findings underscore the critical interplay between genotype, kernel structure, and nutritional outcomes in maize

Processing conditions, including drying, boiling, roasting, and extrusion cooking, further modify starch structure and digestibility. Elevated drying temperatures can promote resistant starch formation in high-amylose maize, decreasing enzymatic susceptibility and enhancing its functional properties as a slowly digestible carbohydrate (Wang et al., 2024). Extrusion cooking, a high-shear, high-temperature processing method, has been shown to differentially affect starch types: high-amylose maize retains significantly more resistant starch compared to waxy varieties after extrusion, which leads to distinct digestibility profiles (Huang et al., 2022).

Furthermore, starch undergoes gelatinization when heated in the presence of water, losing crystalline order and increasing susceptibility to enzymatic hydrolysis; however, subsequent cooling and storage can lead to retrogradation, forming resistant starch type 3 (RS3) (Shah et al., 2023). This specific type of starch resists small intestinal digestion and contributes to colonic fermentation, demonstrating how processing can be used to modulate the functional and nutritional properties of maize carbohydrates (Shah et al., 2016).

Non-starch polysaccharides, such as arabinoxylans, contribute to dietary fiber in maize. These structural carbohydrates, concentrated in the pericarp and cell walls, resist digestion in the small intestine and affect colonic fermentation and bowel motility. Milling and degemination reduce non-starch polysaccharides in refined maize flour, thereby altering carbohydrate composition and fiber content (Food and Agriculture Organization of the United Nations (FAO), 2019). Glucose, fructose, and sucrose are minor components of mature maize grain but are more prominent in sweet maize harvested at earlier developmental stages. (FAO, 2019).

2.4.2 Protein

Proteins constitute a nutritionally significant component of maize, particularly in regions where the crop functions as a principal staple and contributes substantially to daily protein intake despite its comparatively moderate protein concentration relative to legumes and animal-source foods (Tanumihardjo et al., 2017). On a dry weight basis, maize grain typically contains between 8% and 11% protein, although reported values vary considerably depending on genotype, soil fertility status, nitrogen availability, climatic conditions during grain filling, and post-harvest handling (Rahimi Jahangirlou et al., 2021; USDA, 2023). In sub-Saharan Africa, Latin America, and parts of Asia, where maize supplies a large proportion of daily caloric intake, even marginal changes in protein quantity or quality can exert pronounced effects on population-level nutritional outcomes (Bouis and Saltzman, 2017).

From a biochemical standpoint, maize kernel proteins are heterogeneously distributed across anatomical fractions of the grain, including the endosperm, germ, and aleurone layer. The endosperm, which constitutes the bulk of the kernel mass, is dominated by storage proteins, whereas the germ contains a higher proportion of enzymatic and metabolically active proteins that support seed viability and early seedling development. This anatomical partitioning has important implications for nutrition, as common milling practices preferentially remove the germ and outer layers, thereby altering both total protein content and amino acid composition of maize-based foods (USDA, 2023).

Maize proteins are conventionally classified into four major fractions based on differential solubility: albumins (water-soluble), globulins (salt-soluble), prolamins

(alcohol-soluble), and glutelins (alkali- or acid-soluble). Among these, prolamins collectively referred to as zeins are the predominant fraction, accounting for approximately 50–60% of total kernel protein in conventional maize varieties (Holding, 2014; Yang et al., 2018). Albumins and globulins, although quantitatively minor, are enriched in essential amino acids and contribute disproportionately to protein nutritional quality (Li et al., 2017).

Zeins are further subdivided into α -, β -, γ -, and δ -zeins, each encoded by complex multigene families and differing in molecular weight, sulfur amino acid content, and functional role within protein bodies (Li et al., 2017). α -zeins constitute the largest proportion and are particularly deficient in lysine and tryptophan, whereas γ - and β -zeins contain higher levels of cysteine and contribute to protein body structure through disulfide bond formation. The dominance of α -zeins in conventional maize is therefore a central determinant of its low protein quality.

The nutritional limitation of maize protein arises primarily from its imbalance in essential amino acids, especially lysine and tryptophan, which are required for protein synthesis, immune function, neurodevelopment, and nitrogen balance (Tanumihardjo et al., 2017). Diets heavily reliant on unmodified maize protein often fail to meet FAO/WHO amino acid requirements, resulting in low protein digestibility-corrected amino acid scores (PDCAAS) and digestible indispensable amino acid scores (DIAAS) (FAO, 1992). Historically, such dietary patterns have been associated with protein-energy malnutrition and deficiency-related disorders, particularly where maize is consumed without complementary protein sources such as legumes or animal products (Bouis and Saltzman, 2017).

The relationship between maize protein quality and human health has long been recognized, most notably through investigations into pellagra, a disease characterized by dermatitis, diarrhea, and dementia. While pellagra is primarily linked to niacin deficiency, inadequate tryptophan intake from maize-based diets exacerbates risk due to the role of tryptophan as a niacin precursor (FAO, 1992). This historical context underscores the interconnected nature of protein quality and micronutrient metabolism in maize-dependent populations.

Genetic improvement of maize protein quality has therefore been a long-standing objective in crop nutrition research. A major breakthrough occurred with the discovery of the opaque-2 (o2) mutation, a recessive allele that downregulates α -zein synthesis and increases the relative abundance of non-zein proteins with superior amino acid profiles (Holding, 2014; Jia et al., 2018). However, early opaque-2 maize lines exhibited undesirable agronomic traits, including soft, chalky endosperm, increased susceptibility to pests, and reduced yield stability (Li et al., 2017).

Subsequent breeding efforts led to the development of quality protein maize (QPM), which incorporates the opaque-2 mutation together with endosperm modifier genes that restore kernel hardness, vitreousness, and agronomic performance while retaining enhanced lysine and tryptophan levels (Prasanna et al., 2020). Modern QPM varieties typically contain 30–50% higher lysine and tryptophan concentrations than conventional maize and exhibit protein quality comparable to that of milk on a per-gram protein basis (Nuss and Tanumihardjo, 2010; Prasanna et al., 2020).

Extensive field evaluations across diverse agroecological zones have demonstrated that QPM can achieve yields comparable to conventional hybrids under both optimal and stress conditions, provided that appropriate breeding and management practices are employed (Prasanna et al., 2020). Feeding trials in children and livestock have consistently shown improved growth performance, nitrogen retention, and immune response when QPM replaces conventional maize as a primary protein source (Tanumihardjo et al., 2017).

At the molecular level, advances in genomics and transcriptomics have provided deeper insight into the regulatory networks governing maize protein accumulation. Storage protein synthesis is tightly coordinated with nitrogen uptake, assimilation, and remobilization pathways, as well as with carbon metabolism during endosperm development (Li et al., 2021). Genome-wide association studies have identified numerous quantitative trait loci associated with variation in total protein content, zein composition, and amino acid balance, highlighting the polygenic nature of protein traits in maize (Xu et al., 2022).

Proteomic analyses have further revealed extensive post-translational modification of maize proteins, including phosphorylation and redox-mediated disulfide bonding, which influence protein body formation, digestibility, and functional properties during processing (Holding, 2014). These findings open new avenues for precision breeding and biotechnological interventions aimed at optimizing both nutritional and processing-related protein attributes.

Protein digestibility represents an additional critical dimension of maize protein quality. Zeins are inherently resistant to proteolytic degradation due to their hydrophobic amino acid composition and dense packing within protein bodies, resulting in lower digestibility relative to non-zein fractions. This structural resistance limits the bioavailability of amino acids even when total protein intake appears adequate (Purewal et al., 2023).

Traditional and industrial processing methods can significantly modify protein digestibility and amino acid availability. Nixtamalization, which involves cooking maize in alkaline solutions, partially solubilizes zeins, disrupts protein bodies, and improves overall protein digestibility. Fermentation processes used in traditional foods similarly enhance protein quality by enzymatic hydrolysis and microbial synthesis of amino acids (Nkhata et al., 2018). Conversely, excessive thermal processing may induce protein cross-linking and Maillard reactions, reduce lysine availability and impair nutritional value (Li et al., 2021).

Environmental and agronomic factors further influence maize protein quantity and composition. Increased nitrogen fertilization generally elevates total grain protein concentration but disproportionately stimulates zein synthesis, thereby diluting essential amino acid content and reducing protein quality (Xu et al., 2022). This trade-off highlights the importance of breeding strategies that prioritize protein quality rather than protein quantity alone, particularly in low-input farming systems (Bouis and Welch, 2010).

From a global nutrition perspective, improving maize protein quality represents a cost-effective and sustainable intervention for addressing protein inadequacy in maize-dependent populations. Biofortification through QPM has been recognized as a

complementary strategy to dietary diversification and supplementation, particularly where access to animal-source proteins remains limited (Bouis and Welch, 2010). Integration of QPM into national agricultural and nutrition policies has shown promise in improving child growth outcomes and reducing the burden of malnutrition (Prasanna et al., 2020).

Future directions in maize protein research increasingly emphasize multi-trait improvement, combining enhanced protein quality with increased micronutrient density and climate resilience. Emerging genome-editing technologies, such as CRISPR/Cas-based approaches, offer potential for precise modification of storage protein genes while minimizing unintended agronomic effects (Xu et al., 2022). However, the successful deployment of such technologies will depend on regulatory frameworks, public acceptance, and equitable access for smallholder farmers.

2.4.3 Fats

The fat content of maize is influenced by genotypic variation, environmental growing conditions, and specific post-harvest processing methods. Recent analyses indicate that average fat concentrations typically range from 1.1% to 4.8% across diverse cultivars (Imam et al., 2025; Sharma et al., 2022). This lipid content remains relatively low compared to specialized oilseeds like soybeans and sunflower seeds, which can contain upwards of 20% to 50% fat, respectively (Purewal et al., 2023; Saad et al., 2021). The fatty acid profile in maize is primarily composed of triglycerides, which consist of fatty acids linked to a glycerol backbone. The fatty acid profile of maize fat can vary slightly depending on the variety. The predominant fatty acids found in maize include oleic acid, linoleic acid, and palmitic acid. Oleic acid is a monounsaturated fatty acid as shown in Figure 2.6. It is known for its potential health benefits, such as promoting heart health (Pravst, 2014)

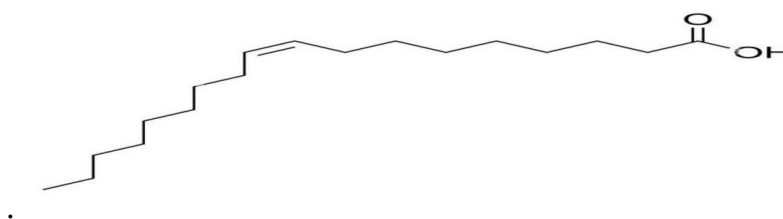


Figure 2.6: Structure of oleic acid (Bhardwaj et al., 2022)

Linoleic acid is a polyunsaturated omega-6 fatty acid (Figure 2.7) and is considered essential as the body cannot produce it. Linoleic acid plays a crucial role in maintaining healthy cell membranes and is important for proper growth and development (Whelan and Fritsche, 2013).

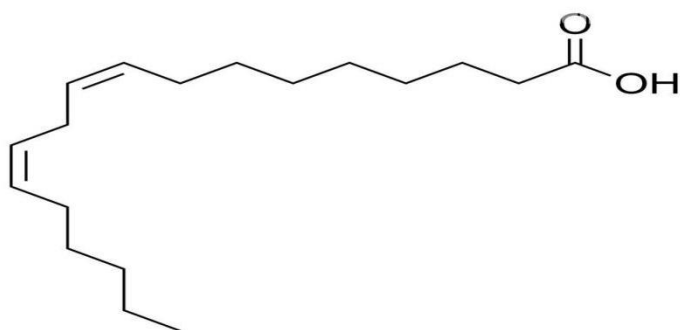


Figure 2.7: Structure of linoleic acid (Bhardwaj et al., 2022)

Palmitic acid is a saturated fatty acid (Figure 2.8) found in maize fat. High intake of saturated fats is generally advised to be limited due to their potential association with adverse health effects, such as elevated low-density lipoprotein (LDL) cholesterol, increased risk of cardiovascular diseases, and the promotion of metabolic inflammation (Agostoni et al., 2016). In particular, an over-accumulation of palmitic acid can lead to dyslipidemia and disrupted cholesterol homeostasis by impairing the body's ability to clear cholesterol from the bloodstream (Agostoni et al., 2016).

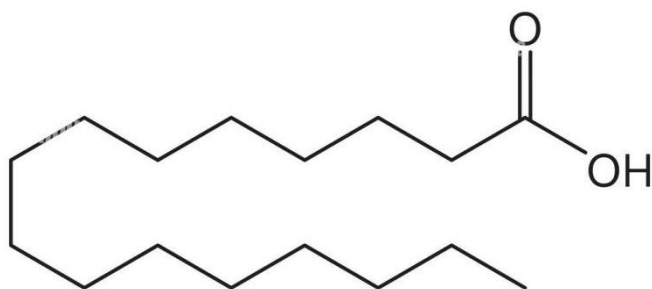


Figure 2.8: Structure of palmitic acid

2.4.4 Vitamins

Vitamins are important micronutrients required for normal physiological function, growth, metabolic regulation, and cognitive and immune competence (Tanumihardjo et al., 2017; USDA, 2020). Vitamins in maize are categorized as water-soluble vitamins which consists of members of the B complex group and ascorbic acid, and fat-soluble vitamins, provitamin A carotenoids and vitamin E (FAO, 1992; Azam et al., 2022; Bouis and Welch, 2010). Each of these compounds varies in concentration across maize varieties, and their availability to consumers depends on genetic makeup, environmental growing conditions, and post-harvest and processing methods to which maize is subjected (Menkir et al., 2020; De Moura et al., 2020; HarvestPlus, 2020).

The water-soluble vitamins in maize are thiamine (vitamin B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), and folate (B9) and trace amounts of vitamin C (ascorbic acid) (Nuss and Tanumihardjo, 2010; Azam et al., 2022). These compounds influence energy metabolism, nervous system function, DNA synthesis and repair, and amino acid metabolism (USDA, 2020). Thiamine functions as a coenzyme in the decarboxylation of α -keto acids and carbohydrate metabolism (Nuss and Tanumihardjo, 2010; USDA, 2020). Without adequate thiamine, energy production from dietary carbohydrates would be inefficient, and neurological dysfunctions may arise. In maize, thiamine concentrations are in tenths of a milligram per 100 grams of kernel, but the levels fluctuate widely among varieties and environmental conditions under which the maize was grown (Azam et al., 2022). Thiamine is heat sensitive, and its concentration decreases with some processing steps such as milling and thermal cooking, which are common in maize food systems (FAO, 1992).

Riboflavin (Figure 2.9) serves as a precursor for flavoproteins involved in redox reactions that are key in mitochondrial respiration. It is metabolized into the flavoenzymes flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD), which act as essential electron carriers in Complex I and Complex II of the mitochondrial electron transport chain, facilitating ATP production and maintaining cellular energy homeostasis.

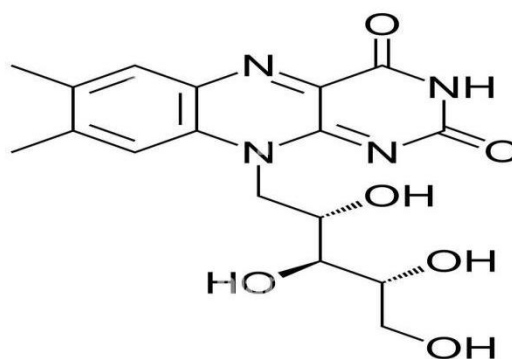


Figure 2.9: Chemical structure of riboflavin (Li MuXin et al., 2022)

Niacin (Figure 2.10) forms the core of NAD and NADP coenzymes that drive multiple metabolic reactions (Nuss and Tanumihardjo, 2010).

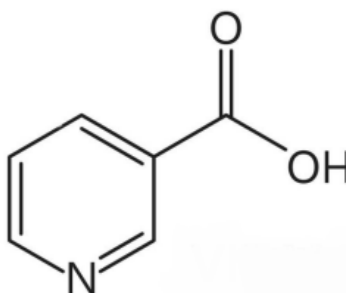


Figure 2.10: Chemical structure of niacin

Niacin in maize is found in a bound form that is not bioavailable to humans unless nixtamalization is done, the process involves cooking maize in an alkaline medium such as lime or wood ash that converts niacin into a form that can be absorbed and metabolized (FAO, 1992). This processing requirement has historical significance, as the absence of nixtamalization in regions outside of Mesoamerica contributed to outbreaks of pellagra, a niacin deficiency disease, in parts of Europe, North America, and Africa during the twentieth century (FAO, 1992).

Recent studies show that fermentation and nixtamalization can increase the bioavailability of riboflavin and niacin, nixtamalization releases bound niacin that is otherwise unavailable to humans (Santiago-Ramos et al., 2018). Conventional soaking, cooking, and dry milling reduce the quantities of bioavailable B vitamins due to

thermal degradation and leaching into water which reduces the overall nutritional contribution of refined maize products (Suri, and Tanumihardjo, 2016).

Besides primary B vitamins, maize also contains pantothenic acid and pyridoxine, which are involved in coenzyme synthesis and amino acid metabolism (USDA, 2020; Nuss and Tanumihardjo, 2010). Research evaluating inbred maize lines has revealed substantial genetic variation in B vitamin content, with ranges of vitamin B1 from approximately 0.1 to 2.7 mg/100 g, B2 from about 0.01 to 0.37 mg/100 g, and B6 from about 0.14 to over 1 mg/100 g (Azam et al., 2022). These findings show the need for genetic selection and biofortification to enhance B vitamin levels through targeted breeding to improve the nutritional quality of maize grain (Bouis and Welch, 2010).

Vitamin C (Figure 2.11) is present in maize in trace amounts. It is easily lost during thermal processing and storage (USDA, 2020). Its low concentration and ease of loss makes maize a poor source of vitamin C, especially since raw maize consumption is rare and cooking or milling predominate.

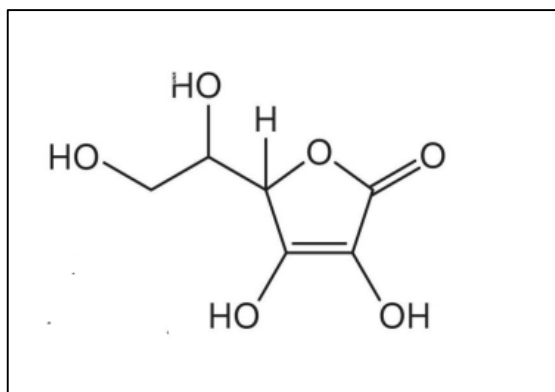


Figure 2.11: Chemical structure of ascorbic acid

Maize lacks vitamin B12 entirely, as this vitamin is generally obtained through animal-based foods therefore, populations that depend heavily on maize without adequate consumption of animal products or fortified foods are at risk for B12 deficiency unless appropriate supplementation or dietary diversification is achieved (Nuss and Tanumihardjo, 2010).

Fat-soluble vitamins in maize primarily consist of provitamin A carotenoids and vitamin E, both of which are sequestered within the lipid fractions of the kernel

(HarvestPlus, 2020) While commonly grown varieties often contain only negligible amounts, recent molecular breeding efforts have significantly enhanced these levels in biofortified lines (Zunjare et al., 2018). Provitamin A compounds such as β -carotene, α -carotene, and β -cryptoxanthin (Figure 13) are important due to their role as precursors to retinol, vitamin A, which is essential for vision, growth, immune function, and epithelial integrity (De Moura et al., 2020).

The concentration of provitamin A carotenoids in maize is dependent on kernel color and genetic background; white maize contains negligible amounts, whereas specially bred orange biofortified varieties possess significantly higher concentrations than conventional yellow types (Menkir et al., 2015). In conventional yellow maize, provitamin A levels typically range from 0.25 to 2.5 μg per gram of dry weight (Palacios-Rojas et al., 2020). Conversely, biofortified orange lines have been specifically engineered to meet target concentrations of 15 $\mu\text{g/g}$, a benchmark designed to provide approximately 50% of the estimated average requirement for women and children (Bouis & Saltzman, 2017; De Moura et al., 2020). These biofortified maize lines represent a major nutritional intervention in regions where vitamin A deficiency is prevalent, affecting an estimated 190 million preschool age children and millions of pregnant women. Vitamin A deficiency is a public health burden associated with impaired vision, increased infection risk, growth retardation, and elevated mortality (De Moura et al., 2020).

Vitamin E is found mainly in the maize germ in the form of tocopherols and tocotrienols and acts as a lipid-soluble antioxidant protecting cellular membranes from oxidative damage. Although present at lower concentrations than provitamin A carotenoids, vitamin E contributes to the dietary supply of antioxidants that support immune function and protect polyunsaturated fatty acids from peroxidation. The presence of vitamin E and other phytochemicals such as phenolic compounds and phytosterols further highlights maize as a complex source of micronutrients beyond its dominant carbohydrate fraction.

Maize nutritional quality is greatly affected by post-harvest and food processing procedures, which alter vitamin levels and their bioavailability (Awika, 2017; Azam et al., 2022). Maize undergoes a series of treatments prior to consumption such as

drying, milling, soaking, fermentation, boiling, baking, and nixtamalization. Each of these methods influences the retention, degradation, and accessibility of vitamins (Santiago-Ramos et al., 2018; Azam et al., 2022). Milling and degemination lead to significant losses of B vitamins and vitamin E, since these compounds are concentrated in the outer kernel fractions (USDA, 2023). Thermal processing such as boiling and roasting can further degrade heat-sensitive vitamins like thiamine and vitamin C, as well as reduce folate concentrations (Hassan et al., 2021; Tanumihardjo et al., 2017). However, certain traditional processing methods can enhance nutrient bioavailability; for example, fermentation increases the bioavailability of B vitamins, and nixtamalization facilitates the release of bound niacin, improves protein quality, and increases calcium content while also improving the sensory and functional properties of flour used for tortillas, tamales, and other products (Santiago-Ramos et al., 2018; Azam et al., 2022).

Processing affects provitamin A retention as well. Although carotenoids are relatively stable on exposure to oxygen, light, and elevated temperatures during storage and cooking can degrade these compounds, reducing the vitamin A potential of maize products (De Moura et al., 2020; Ortiz et al., 2021). Studies have shown that provitamin A levels may decline substantially during storage if not properly protected, with losses of up to 65% over a six-month period in the absence of specialized storage procedures (Taleon et al., 2017). However, when processed appropriately provitamin A retention can be high or even greater than the original kernel content in certain nixtamalization preparations, depending on genotype and processing method (De Moura et al., 2020).

Genetic diversity among maize varieties offers further opportunities and challenges for improving vitamin content. Traditional yellow and white maize lines vary widely in carotenoid content, and biofortified varieties have been developed through selective breeding to increase provitamin A concentrations. Similarly, substantial genetic variation exists for B vitamin content, which can be harnessed through breeding programs to create maize lines enriched in multiple vitamins (Zhu et al., 2018; Azam et al., 2022). Advances in conventional and molecular breeding, as well as emerging biotechnological approaches, aim to develop multinutrient biofortified maize that not only addresses vitamin A deficiency but also enhances other micronutrients and

essential amino acids (Bouis and Saltzman, 2017). Such approaches represent a cost-effective and sustainable strategy for improving nutrition in regions heavily reliant on maize.

The significance of maize vitamins for global nutrition cannot be overstated. Given maize's role as a staple that provides major contributions to daily calorie intake in many low-income countries, enhancing its micronutrient density through biofortification and optimizing processing methods to preserve and improve vitamin bioavailability are critical strategies in combating micronutrient deficiencies (De Moura et al., 2020). As maize continues to feed billions of people worldwide, a comprehensive understanding of its vitamin profile, the factors affecting nutrient concentration and stability, and the ways in which processing and genetic selection can improve nutritional outcomes is essential for informing agricultural, nutritional, and health policy. In this regard, maize not only represents a fundamental food source but also a key focus of global efforts to achieve improved nutritional health and food security for future generations (Bouis and Saltzman, 2017; Tanumihardjo et al., 2017).

2.5 Minerals

Maize encompasses a variety of essential minerals such as: magnesium, with an average content of about 37 mg per 100 grams (USDA, 2023). Magnesium is essential for many enzymatic reactions in the body and plays a vital role in energy production, nerve function, muscle contraction, and bone health (Al Alawi et al., 2018). Phosphorus content in maize is approximately 35 mg per 100 grams (Sheng et al., 2018). Phosphorus is an important mineral that is involved in bone and teeth formation, energy metabolism, and cell membrane structure. Potassium is present in maize with an average content of about 280 mg per 100 grams. Potassium is an electrolyte mineral that plays a key role in maintaining fluid balance, nerve function, muscle contraction, and blood pressure regulation

Although maize is not a significant source of calcium, it still contains a small amount of this mineral. The calcium content in maize is relatively low compared to other calcium-rich foods, with an average of about 7 mg per 100 grams (Tanumihardjo et al., 2017). Maize contains iron, an essential mineral involved in oxygen transport, energy production, and proper immune function. The iron content in maize varies

depending on factors such as variety and growing conditions, but it typically ranges from 1 to 3 mg per 100 grams. Maize is a source of zinc, an essential mineral that is involved in numerous enzymatic reactions, immune function, and cell growth and development. The zinc content in maize ranges from 1.2 to 1.9 mg per 100 grams (Sheng et al., 2018).

Trace minerals found in maize include; copper, which when consumed is necessary for the production of red blood cells, collagen synthesis, and the proper functioning of the immune system (Bost et al., 2016). The copper content in maize is relatively low, typically around 0.1 mg per 100 grams (USDA, 2023). Manganese serves in the body as a cofactor for several enzymes involved in metabolism, bone formation, and antioxidant defense. The manganese content in maize is approximately 0.2 mg per 100 grams (Sheng et al., 2018). Maize also contains trace amounts of selenium, when consumed, selenium exhibits antioxidant properties. It is involved in various physiological processes, including thyroid hormone metabolism and immune function (Kieliszek, 2019). The selenium content in maize is relatively low, usually below 1 µg per 100 grams (Sheng et al., 2018).

2.6 Studies on Nutritional Concentration of Maize

In 2024, Mohammed et al. conducted a study in the Somali region of Ethiopia on adapted maize varieties to compare their nutritional benchmarks with earlier Ethiopian data. They found that the protein content ranged from 12.82% to 15.24%. This was in agreement with the findings reported by Hailu in 2018 (9.69% - 15.30%). Specifically, the variety Melkasa-6Q achieved a protein content of 15.24%, nearly matching the 15.30% reported by Hailu for BHQMY 545. Mohammed et al. further reported that the ash content in these varieties reached as high as 5.88%, which was significantly higher than the 1.3% maximum reported by Ullah in 2010. Their mineral analysis showed calcium levels reaching up to 512 ppm, which surpassed the maximum level of 481 ppm reported by Hailu in 2018, suggesting that modern adapted varieties in semi-arid environments may possess a superior ability to accumulate minerals compared to those studied in earlier years.

Despite being effective for quantifying proteins, carbohydrates, and fats, the traditional wet-chemistry procedures used by Hailu and Delelegn (2020) and Ullah et

al. (2021) were slow, laborious, and chemical-intensive. The use of FTIR provides a cheaper, faster and less laborious method for the comparative and quantitative study of the nutritional content of maize.

2.7 Measurement Using FTIR

FTIR spectroscopy is a highly versatile analytical technique utilized for both qualitative and quantitative analysis across various scientific domains, such as chemistry, pharmaceuticals, environmental science, and the food industry. The technique is specifically used to identify functional groups and characterize molecular "fingerprints" by detecting the vibrations of chemical bonds (such as C–H, O–H, and C=O) when exposed to infrared radiation (Ozaki et al., 2021).

In the pharmaceutical and environmental sectors, it is used for drug purity assessment, stability testing, and the identification of microplastics in soil or water. Within the food industry, FTIR is used to determine macronutrient composition (proteins, fats, and carbohydrates), monitor the oxidation of lipids, and detect food adulteration (Valand et al., 2020). Crucially for grain science, FTIR can quantify starch ordered structures, specifically the ratio of crystalline to amorphous regions, which determines the digestibility of the starch (Warren et al., 2016).

2.7.1 Principles of FTIR Spectroscopy

FTIR spectroscopy operates by passing infrared radiation through a sample and recording the absorbed wavelengths. Each molecular bond within the sample absorbs specific frequencies of infrared light, resulting in a unique spectral fingerprint. Quantitative analysis is achieved by correlating the intensity of absorption bands to the concentration of analytes, using the Beer-Lambert Law. Advanced computational techniques, such as multivariate calibration, further refine the quantification process by accounting for complex sample matrices and overlapping spectral features (Yadav et al., 2020).

2.7.2 Food Industry Applications

FTIR has been extensively applied in the food industry to analyze the nutritional composition of cereals. For instance, FTIR has been utilized to assess changes in the physicochemical and nutritional characteristics of cereal grains during germination,

providing insights into molecular interactions and nutrient profiles. (Kaur et al., 2021). Additionally, FTIR has been employed to determine fructooligosaccharides (FOS) levels in cereals, facilitating the quantification of these prebiotic compounds. (Protonotariou et al., 2013).

FTIR has been applied in the food industry to ensure product quality and safety. Rohman and Che Man (2010) applied Fourier Transform Infrared spectroscopy to detect and quantify adulteration of extra virgin olive oil with soybean and palm oils through analysis of characteristic infrared absorption patterns. The study employed FTIR spectra combined with chemometric analysis to achieve precise quantification of adulterants, ensuring the authenticity of olive oil products.

FTIR spectroscopy is a versatile and powerful tool for quantitative analysis, with applications spanning various scientific fields. Its non-destructive nature, coupled with advancements in data processing techniques, has solidified its role in both laboratory and field settings. Continued research and technological innovations are expected to further enhance its quantification capabilities, making it an indispensable tool in analytical science.

2.7.3 Advances in FTIR Quantification Techniques

Recent advancements in Fourier Transform Infrared (FTIR) spectroscopy, particularly in instrumentation, data processing, and chemometric integration, have significantly enhanced its quantitative analytical capabilities. Traditionally regarded as a primarily qualitative technique, FTIR has evolved into a robust quantitative tool through improvements in spectral resolution, detector sensitivity, and advanced multivariate data analysis approaches (Iqtadar et al., 2025).

A major development contributing to this transition is the integration of FTIR spectroscopy with chemometric methods such as Principal Component Analysis (PCA), Partial Least Squares regression (PLS), and Principal Component Regression (PCR). These multivariate techniques enable the extraction of quantitative information from complex and highly overlapping infrared spectra, which is especially important when analyzing heterogeneous matrices such as food products, biological materials, environmental samples, and pharmaceutical formulations

Principal Component Analysis (PCA) plays a critical role in preprocessing and exploratory data analysis of FTIR spectra. By reducing data dimensionality while retaining the majority of spectral variance, PCA facilitates the identification of dominant spectral features, systematic trends, and potential outliers. Additionally, PCA assists in noise reduction and baseline variation correction, thereby improving the quality of spectral inputs used for subsequent quantitative modeling (Grzelec, 2024). This step is particularly important in FTIR datasets where instrumental noise, scattering effects, and sample heterogeneity can obscure chemically relevant information.

Similarly, FTIR–PCA has been used to evaluate butter authenticity and geographical origin. (Karoui et al., 2013) In the study PCA score plots clearly separated butter samples based on compositional differences, with the first two principal components explaining a substantial proportion of the total variance. The loading plots indicated that spectral regions corresponding to fatty acid functional groups contributed most to sample discrimination. The authors concluded that PCA can effectively distinguish butter origin and serve as a preliminary screening tool prior to quantitative chemometric modeling (Karoui et al., 2013).

PCA has also been used in detecting food adulteration. In an investigation of garlic powder adulterated with starch and other fillers, PCA separated pure and adulterated samples into distinct clusters. The discriminatory spectral regions were associated with carbohydrate absorption bands, indicating the presence of adulterants. The researchers concluded that PCA enables rapid identification of adulteration and improves the robustness of subsequent supervised classification models (Galvin-King et al., 2021). More recent research has applied FTIR–PCA to coffee authentication. PCA analysis showed clear grouping of pure coffee samples and those adulterated with barley and chickpea powders. PCA provided essential exploratory visualization and highlighted spectral features responsible for discrimination. (Khodabakhshian et al., 2026).

Overall, these studies demonstrate that PCA applied to FTIR spectra in food systems enables visualization of sample clustering, identification of key discriminatory spectral regions, detection of adulteration, and authentication of product origin. The

findings indicate that PCA improves exploratory analysis and supports the development of robust chemometric models for food quality and authenticity assessment. Following PCA, regression-based chemometric techniques such as PLS and PCR are widely employed for quantitative model development. PLS regression, in particular, has gained prominence due to its ability to simultaneously model spectral variance and concentration information, even when predictor variables exhibit multicollinearity. Numerous recent studies have demonstrated that FTIR–PLS models can achieve high coefficients of determination ($R^2 > 0.95$) and low prediction errors, confirming their suitability for accurate quantitative analysis in complex matrices (Fernando et al., 2023; Amit et al., 2020). PCR, while conceptually similar, has also been shown to be effective in applications where overlapping absorption bands present significant analytical challenges.

In parallel with advances in data analysis, significant progress has been made in FTIR instrumentation, particularly through the development of portable and handheld FTIR devices. These systems incorporate miniaturized interferometers, robust detectors, and optimized sampling accessories such as attenuated total reflectance (ATR) crystals, enabling reliable spectral acquisition outside traditional laboratory environments. Portable FTIR instruments have been successfully validated for on-site quantitative analysis in environmental monitoring, industrial quality control, forensic investigations, and food authentication studies (Iqtadar et al., 2025).

The coupling of portable FTIR systems with embedded chemometric models has further expanded their practical utility. Pre-calibrated PCA-PLS models allow for rapid, real-time quantification of target analytes without the need for extensive sample preparation or laboratory-based analysis. This capability is particularly advantageous in field-based applications where timely decision-making is critical, such as contamination assessment, process monitoring, and regulatory compliance testing (Iqtadar et al., 2025).

2.8 Quantification Using AAS

Atomic Absorption Spectroscopy (AAS) is an analytical technique used primarily in chemistry to measure the concentration of specific metal elements in a sample. AAS is based on the principle that atoms in a free gaseous state can selectively absorb

electromagnetic radiation at specific, unique wavelengths. When light from a lamp passes through an atomized sample the ground-state atoms absorb energy corresponding to the electronic transition between the ground and excited states. This decrease in light intensity is directly proportional to the number of atoms present in the light path, allowing for precise quantification of mineral concentrations (Wang et al., 2025).

An AAS instrument primarily consists of: A light source often, a hollow cathode lamp which emits light at wavelengths specific to the element being analyzed. An atomizer which can be a flame or an electrothermal atomizer. The sample is introduced into the atomizer where it's turned into atomic vapor.

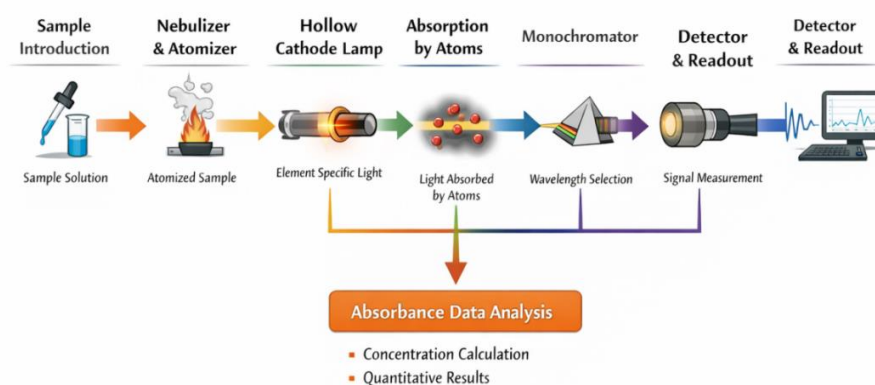


Figure 2.12: Flowchart on the working of an AAS

A monochromator selects the specific wavelength of light to be measured. A detector which measures the intensity of the light that passes through the sample. Less light means more absorption, hence more of the element in the sample. AAS is a fundamental technique in analytical chemistry for elemental analysis, valued for its precision, sensitivity, and the ability to measure elements in complex matrices.

2.9 Food industry applications

Atomic Absorption Spectroscopy (AAS) has been applied in maize nutritional studies for quantification of mineral elements. Queiroz et al. (2011) determined iron and zinc levels in tropical maize inbred lines, demonstrating variability among genotypes and the usefulness of AAS in mineral screening. Shobhana et al. (2013) similarly applied AAS to evaluate iron and zinc concentrations in maize germplasm, supporting its application in biofortification programs. Pereira et al. (2020) evaluated the mineral

profile of maize flour and quantified calcium, magnesium, iron, manganese, and zinc. Zano et al. (2000) AAS combined with wet digestion for accurate determination of zinc and manganese in maize samples.

2.10 Chapter Summary

This chapter discusses maize in depth providing insights into its morphology, nutritional content and work that has been done to quantify these nutrients globally and in the regional context. The section places this study into context. The chapter also extensively discusses FTIR and AAS as analytical tools in food nutrition. Modern statistical approaches to FTIR interpretation have also been highlighted

CHAPTER THREE MATERIALS AND METHODS

3.1 Introduction

This chapter outlines the materials and methods that were used in analyzing the nutritional content of maize samples collected in Kirinyaga county. FTIR was used to determine the biochemical profile of the collected maize samples while AAS was employed for the elemental analysis of the samples. The elements iron, magnesium, zinc and manganese were analyzed.

3.2 Materials

The following reagents were used in the analytical process and were purchased from Sigma-Adrich

- $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ (99.2%)
- $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ (99%)
- $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$ (99.3%)
- ZnCl_2 (98%)
- Nitric(v)acid (65%)

Other equipment used include:

- Crucibles
- 50 mL volumetric flasks
- Oven
- Muffle furnace
- Tongs
- Weighing balance
- Whatman filter papers
- Filter funnels
- Glass stirring rods

3.3 Study Area

Kirinyaga County is found in the central region of Kenya (Figure 3.1). It is located on the southern slopes of Mount Kenya. The county lies between latitudes $0^\circ 1' \text{ S}$ and $0^\circ 40' \text{ S}$ and longitudes 37° E and 38° E , covering approximately 1,478.1 square

kilometers (County Government of Kirinyaga, 2023). Its headquarters, Kerugoya, is located approximately 120 kilometers northeast of Nairobi. The county shares its borders with several counties: Nyeri County to the west, Embu County to the east, and Murang'a and Machakos Counties to the southwest and south respectively.

The County has a steep altitudinal gradient that significantly influences its climate and vegetation. The terrain rises dramatically from the low-lying Mwea plains at approximately 1,158 meters above sea level to the summit of Mount. Kenya, which exceeds 5,000 meters (Jaetzold et al., 2006). This topographical transition results in a bimodal rainfall pattern. The highlands receive up to 2,146 mm of annual rainfall, while the southern plains average about 1,100 mm (County Government of Kirinyaga, 2023). The county is partitioned into distinct agro-ecological zones (AEZs). The higher altitudes are characterized by deep, well-drained red volcanic nitisols. As the elevation drops into the midlands, the vegetation shifts toward more modified agricultural landscapes. Finally, the lower midland zones are defined by vertisols, commonly known as "black cotton soils," which are highly prized for their moisture retention in irrigated agriculture (Kenya Agricultural and Livestock Research Organization [KALRO], 2020).

These ecological conditions dictate the specific economic activities that sustain the county's residents. In this high-altitude region, farmers primarily plant late-maturing maize varieties, which are better adapted to the prolonged growing seasons (KALRO, 2020). Transitioning into the upper midlands which grow medium-maturity maize hybrids. The lowlands in the southern region represent a distinct economic hub dominated by the Mwea Irrigation Scheme, which produces over 80% of the rice consumed in Kenya (Jaetzold et al., 2006). Due to the shorter rainy seasons in these plains, maize cultivation focuses on early-maturing and drought-tolerant varieties.

Administratively, Kirinyaga County is divided into five sub-counties that align largely with its political constituencies: Kirinyaga East (Gichugu), Kirinyaga West (Ndia), Kirinyaga Central, Mwea East, and Mwea West.

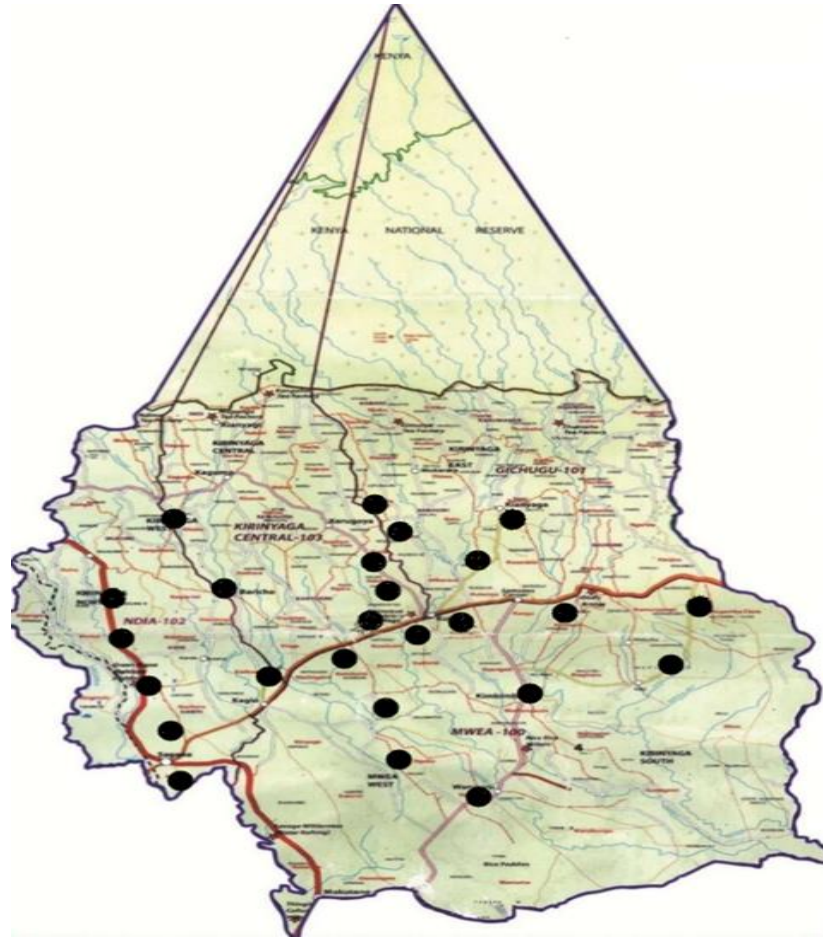


Figure 3.1: Map of Kirinyaga county showing sample collection points

(Adapted from ResearchGate with some modification)

According to a KPHC report in 2019, its population was 610411 with a population density of 413 people per square kilometer and an annual growth rate of 1.5%.

3.4 Sample Collection

The maize samples for this study were collected from twenty-five demo farms in Kirinyaga County, Kenya as shown in Figure 16. The farms were located in different sub counties in Kirinyaga county as shown in Table 3.1.

Table 3.1: Geolocation of sample collection points

At each selected farm, random sampling was conducted within the maize fields. Two maize plants were chosen to represent the maize variety being grown. Care was taken

SUB-COUNTY COLLECTION	OF	GEO LOCATION	VARIETY
Kirinyaga central		-0.5710680, 37.2980777	AMI-5
		-0.5728557, 37.3117610	DE-7
		-0.5575333, 37.3065766	MAK
		-0.544612, 37.310283	• DUM-3
		-0.5585850, 37.3074792	• DE-9
		-0.556788,37.306249	• DE-7
Kirinyaga east		-0.5889997, 37.2824874	• DE-9
		-0.5480940, 37.3100652	• PI-3
		-0.6290425, 37.3612065	• DE-7
		-0.5654960, 37.3796722	• PI-8
Mwea west		-0.676434, 37.442823	• DUM -3
		-0.6054180, 37.2947991	• SUN
		-0.701478,37.426277	• PI-3
		-0.6711776, 37.3610858	• TS-6
Mwea east		-0.656123, 37.288862	• PA-5
		-0.6610828, 37.2876067	• DUM-3
		-0.6735800, 37.3621181	• PI-3
		-0.567809,37.241425	• KE-7
		-0.6055819, 37.2003709	● MAK
Kirinyaga west		-0.6105776, 37.2531658	• PI-6
		-0.567809,37.241425	• PA-5
		-0.6500295, 37.2094076	• DE-1
		-0.520041, 37.255637	• MAK
		-0.5505941, 37.1858849	• DE-3
		-0.5720802, 37.1899827	• PI-2

to ensure selected plants appeared healthy and free from any visible diseases or pests. For each selected plant, the maize cob was harvested. Special care was taken to avoid any contamination or mixing of samples. The harvested cobs were labeled properly with unique identifiers to ensure traceability. The samples were placed in clean and well labeled sample bags.

Each sample was stored separately to maintain the integrity of individual samples. Proper documentation was maintained for each collected sample, including information such as farm location, maize variety, and date of collection. The collected maize samples were sun-dried to obtain an optimum moisture content for storage. After collection and drying the maize samples were transported to the laboratory in 500 g zip-lock bags. The samples were stored in a cool, dry place to minimize any changes in their characteristics until further analysis.

3.5 Pre-treatment of the Samples

3.5.1 Cleaning and Sorting

Upon arrival at the laboratory, the maize samples underwent a cleaning and sorting process. Any visible dirt, debris, or foreign materials were removed from the samples to eliminate potential sources of contamination. Damaged or discolored kernels were also removed, ensuring that only healthy and representative kernels were analysed.

3.5.2 Milling

To ensure sample homogeneity and facilitate subsequent analysis, the dried maize kernels were pulverized into a fine powder using a KM-1500 high-speed rotary mill (MRC Ltd., Holon, Israel), achieving a uniform particle size across all samples. The powdered samples were stored in airtight zip-lock bags to maintain their integrity until they were analyzed.

3.5.3 Sample Replication

For quality control purposes and to account for any potential variation within the maize samples, replication of the pre-treated samples was carried out. This involved dividing the powdered samples into triplicates that were used for analyses. The replicated samples underwent the same analytical procedures, enabling validation of the results and ensuring the accuracy of the findings.

3.6 Analysis of Macronutrients

The ground maize samples were sieved using a 0.5 mm sieve. About 100 mg of the powdered solid sample was used for each analysis. The ATR crystal surface was cleaned with isopropanol to remove any contaminants. A background spectrum was collected with no sample applied to the crystal. The powdered sample was placed directly onto the ATR crystal ensuring uniform contact between the sample and the crystal. Spectra were collected using a Shimadzu Ir spirit FTIR instrument in absorbance mode in the mid-infrared range (4000-500 cm^{-1}) with a resolution of 1.43 cm^{-1} . The background spectrum was subtracted from the spectrum obtained from each sample. After the spectra had been obtained and baseline corrected, the peak heights at specific wavenumbers were measured as an indicator of the quantity of macro nutrients present. These wave numbers were: 997 cm^{-1} -C-O stretch 1076 cm^{-1} -C-O-C- stretch 1149 cm^{-1} -C-O-C- asymmetric stretching attributable to carbohydrates, 2854 cm^{-1} -CH₂ symmetric stretching 2925 cm^{-1} asymmetric stretching 1743 cm^{-1} -C=O stretching 1709 cm^{-1} -C=O stretching attributed to fatty acids and fatty acid esters and, 1539 cm^{-1} amide ii -N-H bending/-C-N stretching 1646 cm^{-1} amide I C=O Stretching of peptide bonds linked to proteins.

3.7 Analysis of Micronutrients

Micronutrient analysis was conducted using an AA-7000 Atomic Absorption Spectrophotometer manufactured by Shimadzu Corporation. The instrument generated atomized vapor for each prepared sample and measured the absorption of element-specific wavelengths of light corresponding to the target micronutrients. The analytical wavelengths used were 213.9 nm for zinc, 285.2 nm for magnesium, 248.3 nm for iron, and 279.5 nm for manganese (Shimadzu Corporation, 2012, Section 4).

3.7.1 Measurement Procedure

3.7.1.1 Diluent Preparation

A 2.5 L volumetric flask was used to prepare a 1.0 M nitric acid solution. 158 mL of 65% nitric acid was carefully measured and transferred into the volumetric flask containing a portion of deionized water. The solution was then diluted with deionized water up to the 2.5 L mark on the flask. The flask was stoppered and inverted several times to ensure complete mixing, yielding a homogeneous 1.0 M nitric acid solution (Harris, 2020).

3.7.1.2 Crucible Preparation

The crucibles used were washed with soap and tap water, they were then soaked in 1.5 M nitric (V) acid for 12 hrs. The crucibles were then washed with deionized water and dried in an oven for 30 minutes at 105 °C.

3.7.1.3 Sample Incineration

10 g of the ground maize sample was weighed and placed in a clean crucible. The samples were then transferred into an oven and dried at 120 °C for 90 minutes. The crucibles were transferred to a muffle furnace and temperature ramped from 250 °C to 500 °C with a temperature increase of 50 °C every 30 minutes. The temperature was then maintained at 500 °C for three hours. If the ash color was black after leaving the furnace, the process was repeated until the ash was white or slightly colored (Nielsen, 2017).

3.7.1.4 Sample Dilution

The volumetric flask, funnel and stirrers were washed with the diluent prepared. About 30 mL of the diluent was poured into the crucible and stirred until no further dissolution occurred. The contents of the crucible were filtered into a 50 mL volumetric flask using Whatman filter papers (No. 1). The crucible was washed with the diluent and filtered again, ensuring that all the contents of the crucible were

emptied. The solution in the volumetric flask was topped up to the mark with the diluent.

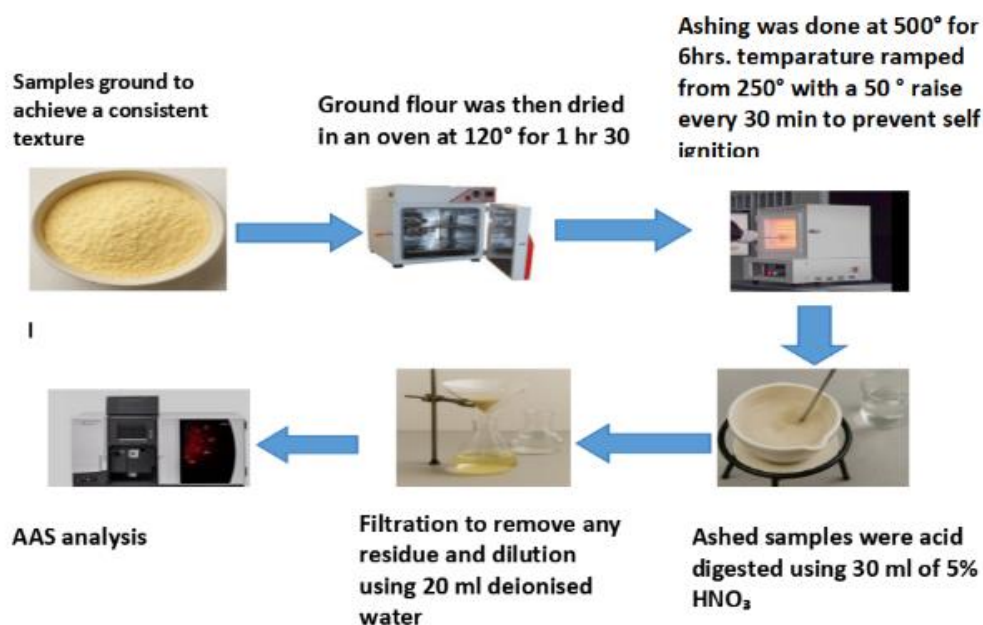


Figure 3.2: A flowchart of the AAS analysis procedure

The prepared maize samples, along with the calibration standards and blank solutions, were introduced into the AAS instrument. The instrument sequentially analyzed each sample and standard, measuring the absorbance at the specific wavelengths (Zn 213.9 nm, Mg 285.2 nm, Fe 248.3 nm, and Mn 279.5 nm) associated with the target micro-nutrients. The absorbance values were then compared to the calibration curves to determine the concentrations of the micro-nutrients in the maize samples.

3.7.2 Preparation of Standards

3.7.2.1 Iron

The stock solution for iron was prepared by dissolving 4.9785 g of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ in 50 mL of 1 M HNO_3 . The solution was then transferred into a 1000 mL volumetric flask and then filled to the mark with 1 M HNO_3 to make up the standard. (1000 mg/L Fe). The standards was then prepared as follows: 0 mg/L prepared by using 50 mL of 1 M HNO_3 as blank; 2 mg/L prepared by using 0.1 mL stock then adding 49.9 mL 1 M HNO_3 ; 4 mg/L prepared by using 0.2 mL stock then adding 49.8 mL 1 M HNO_3 ; 6 mg/L prepared by using 0.3 mL stock then adding 49.7 mL 1 M HNO_3 ; 8 mg/L prepared by using 0.4 mL stock then adding 49.6 mL 1 M HNO_3 ; and 10 mg/L prepared by using 0.5 mL stock then adding 49.5 mL 1 M HNO_3 (Harris, 2020).

3.7.2.2 Magnesium

The stock solution for magnesium was prepared by dissolving 8.366 g of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ in 50 mL of 1 M HNO_3 . The solution was transferred into a 1000 mL volumetric flask and diluted to the mark with 1 M HNO_3 to obtain a standard solution containing 1000 mg/L of Mg. From this stock solution, working standards were prepared by serial dilution as follows: a 0 mg/L standard was prepared using 50 mL of 1 M HNO_3 as the blank; 2 mg/L, 4 mg/L, 6 mg/L, 8 mg/L and 10 mg/L standards were prepared by pipetting 0.1 mL, 0.2 mL, 0.3 mL, 0.4 mL and 0.5 mL of the stock solution, respectively, and each was diluted to 50 mL with 1 M HNO_3 (Harris, 2020).

3.7.2.3 Manganese

The stock solution for manganese was prepared by dissolving 3.603 g of $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$ in mL of 1 M HNO_3 . The solution was then transferred into a 1000 mL volumetric flask and diluted to the mark with 1 M HNO_3 to give a standard solution containing 1000 mg/L of Mn. Working standards were prepared by serial dilution to obtain concentrations of 0 mg/L, 2 mg/L, 4 mg/L, 6 mg/L, 8 mg/L and 10 mg/L, corresponding to 0 mL, 0.1 mL, 0.2 mL, 0.3 mL, 0.4 mL and 0.5 mL of the stock solution, respectively, each made up to 50 mL with 1 M HNO_3 (Harris, 2020).

3.7.2.4 Zinc

The stock solution for zinc was prepared by weighing 4.876 g of ZnCl_2 and dissolving it in 50 mL of 1 M HNO_3 , the solution was then transferred to a 1000 mL volumetric flask and filled to the mark with 1 M HNO_3 to make the standard. (1000 mg/L Zn) The standards were then prepared as follows: 0 mg/L prepared by using 50 mL of 1 M HNO_3 as blank, 2 mg/L prepared by using 0.1 mL stock then adding 49.9 mL 1 M HNO_3 , 4 mg/L prepared by using 0.2 mL stock then adding 49.8 mL 1 M HNO_3 , 6 mg/L prepared by using 0.3 mL stock then adding 49.7 mL 1 M HNO_3 , 8 mg/L prepared by using 0.4 mL stock then adding 49.6 mL 1 M HNO_3 , and 10 mg/L prepared by using 0.5 mL stock then adding 49.5 mL 1 M HNO_3 (Harris, 2020).

3.8 Quality Control and Method Validation

Quality control measures were implemented during the Atomic Absorption Spectroscopy (AAS) and Fourier Transform Infrared Spectroscopy (FTIR) analyses to ensure the reliability and consistency of the results. Reagent blanks were analyzed

alongside the samples during AAS analysis to monitor possible contamination and background interference. Standard solutions of known concentrations were used to generate calibration curves for manganese (Mn), magnesium (Mg), zinc (Zn), and iron (Fe). All samples for both FTIR and AAS analyses were analyzed in triplicates, and the mean values were calculated and used for data analysis. This was done to improve the precision and reproducibility of the analytical results. Method validation for the AAS analysis was carried out by assessing the linearity of the calibration curves and the reproducibility of the measurements. Calibration standards ranging from 2 ppm to 10 ppm were used for each element analyzed. The calibration curves showed strong linear relationships with correlation coefficients of 0.9910 for Mn, 0.9976 for Fe, 0.9950 for Mg, and 0.9994 for Zn(appendix), indicating good instrument performance and analytical reliability.

3.9 Statistical Data Analysis

The obtained micro and macro-nutrient data was subjected to statistical analysis to determine any significant variations and similarities among the maize varieties. The measured absorbance intensities were subjected to PCA to identify similarities and differences among the samples a heatmap was then employed to visualize the identified similarities among the varieties. Descriptive statistics, PCA and heat maps were employed to compare the micro-nutrient profiles and identify any significant differences. The software employed was R (R version 4.3.1).

3.10 Chapter summary

This chapter comprehensively discusses the materials and methods followed to achieve the studies objectives. The chapter provides the procedures followed for sample collection and preprocessing for both FTIR and AAS analysis. Comprehensive procedures for dry ashing along with standard preparation procedures for calibration standards are discussed in depth.

CHAPTER FOUR RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the macronutrient composition and micronutrient content of the maize flour samples that were determined using FTIR and AAS respectively. The data collected using FTIR was analyzed using PCA and heatmaps. Results from AAS were presented in tables then further analyzed using PCA, ANOVA, WELCH'S ANOVA, Kruskal-Wallis, Dunn's test, Tukey's HSD and Games-Howells test.

4.2 Macronutrient Composition of Maize

Maize flour samples were characterized using Fourier Transform Infrared (FTIR) in absorbance mode. Each sample was analyzed in triplicate, yielding a total of 75 spectra for the study. The replicate spectra were averaged using R version 4.3.1 and subsequently plotted on a common scale (Figure 4.1).

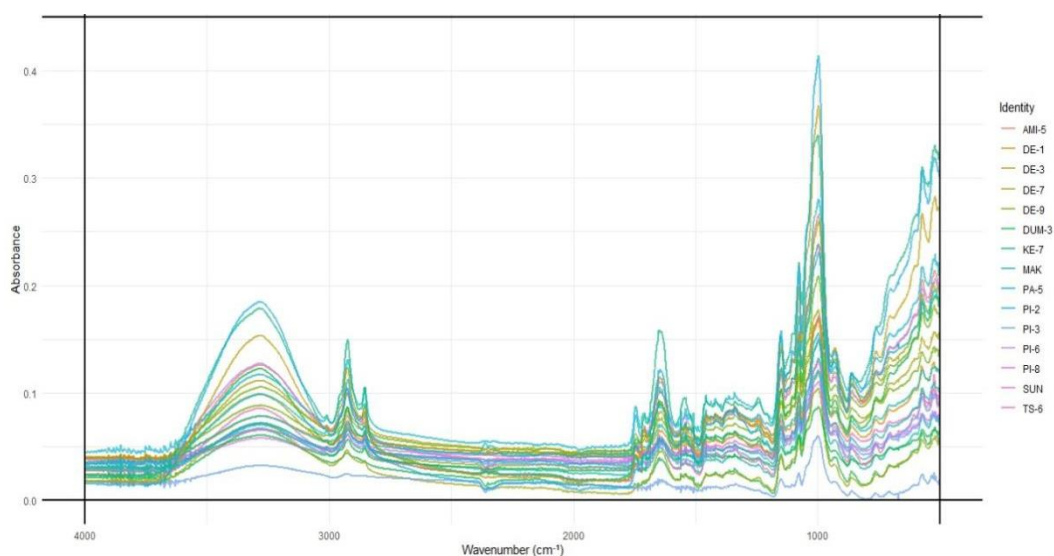


Figure 4.1: Extracted FTIR spectra

The averaged spectra were baseline corrected to eliminate background variation. Following baseline correction, peak heights at specific wavenumbers associated with major macronutrients were extracted. These were 997 cm^{-1} -C-O stretch 1076 cm^{-1} -C-O-C- stretch 1149 cm^{-1} -C-O-C- asymmetric stretching attributable to carbohydrates, 2854 cm^{-1} -CH₂ symmetric stretching 2925 cm^{-1} asymmetric stretching 1743 cm^{-1} -C=O stretching 1709 cm^{-1} -C=O stretching attributed to fatty

acids and fatty acid esters and, 1539 cm^{-1} amide ii -N-H bending/-C-N stretching 1646 cm^{-1} amide I C=O Stretching of peptide bonds linked to proteins. These results of these measurements are shown in table 4.1. Values are in arbitrary units.

4.1: Absorbance intensities for maize samples collected in Kirinyaga county

VARIETY	997	1076	1646	2854	2925	1149	1519	1539	1709	1746
DE-9	0.1714	0.0925	0.0528	0.0349	0.0480	0.0662	0.0294	0.0340	0.0220	0.0163
MAK	0.1104	0.0518	0.0280	0.0291	0.0395	0.0372	0.0123	0.0141	0.0081	0.0113
DE-9	0.1320	0.0773	0.0388	0.0317	0.0448	0.0551	0.0197	0.0254	0.0191	0.0130
DE-7	0.1524	0.0941	0.0558	0.0317	0.0448	0.0668	0.0285	0.0334	0.0194	0.0150
DUM-3	0.1134	0.0547	0.0333	0.0293	0.0375	0.0363	0.0160	0.0187	0.0094	0.0083
DUM-3	0.2208	0.1238	0.0753	0.0470	0.0688	0.0855	0.0305	0.0421	0.0106	0.0233
AMI-5	0.2395	0.1308	0.0745	0.0512	0.0730	0.0929	0.0360	0.0420	0.0380	0.0191
DE-7	0.0982	0.0548	0.0404	0.0298	0.0408	0.0350	0.0139	0.0186	0.0125	0.0060
SUN	0.0949	0.0475	0.0227	0.0241	0.0314	0.0352	0.0135	0.0140	0.0107	0.0167
PI-3	0.0597	0.0254	0.0192	0.0224	0.0243	0.0198	0.0128	0.0141	0.0124	0.0117
PI-3	0.0886	0.0452	0.0280	0.0378	0.0279	0.0342	0.0140	0.0178	0.0110	0.0187
DUM-3	0.0599	0.0334	0.0301	0.0214	0.0299	0.0230	0.0162	0.0207	0.0150	0.0084
PI-6	0.2054	0.1227	0.0786	0.0483	0.0714	0.0846	0.0363	0.0463	0.0369	0.0165
PA-5	0.2372	0.1278	0.0619	0.0620	0.0878	0.0969	0.0368	0.0420	0.0380	0.0444
PI-8	0.0761	0.0406	0.0212	0.0199	0.0268	0.0279	0.0138	0.0162	0.0092	0.0145
DE-7	0.2225	0.1166	0.0544	0.0439	0.0617	0.0845	0.0307	0.0348	0.0230	0.0244
TS-6	0.1547	0.0794	0.0414	0.0441	0.0624	0.0575	0.0161	0.0201	0.0199	0.0171
PI-3	0.1261	0.0587	0.0291	0.0315	0.0409	0.0417	0.0128	0.0152	0.0105	0.0147
PA-5	0.1981	0.1156	0.0576	0.0580	0.0800	0.0908	0.0346	0.0396	0.0335	0.0468
KE-7	0.3239	0.2055	0.1425	0.0896	0.1336	0.1371	0.0632	0.0793	0.0636	0.0410
MAK	0.1210	0.0604	0.0295	0.0294	0.0389	0.0418	0.0155	0.0177	0.0116	0.0137
DE-1	0.1305	0.0603	0.0284	0.0236	0.0308	0.0419	0.0154	0.0187	0.0101	0.0097
MAK	0.1207	0.0659	0.0363	0.0271	0.0369	0.0460	0.0212	0.0259	0.0152	0.0150
DE-3	0.3533	0.1840	0.1001	0.0726	0.1086	0.1302	0.0433	0.0532	0.0532	0.0275
PI-2	0.4051	0.2093	0.1131	0.0594	0.0953	0.1496	0.0432	0.0539	0.0345	0.0196

Although the spectral profiles across these regions exhibited only subtle visual differences that made structural discrimination difficult, noticeable variations in peak intensities were observed. These differences suggest quantitative rather than qualitative variation among the maize samples. Examination of individual wavenumbers of interest further demonstrated distinct absorbance patterns. For example, KE-7 displayed the greatest absorbance intensity at 1646 cm^{-1} , whereas PI-2 exhibited the highest intensity at around 997 cm^{-1} .

Principal component analysis (PCA) was then applied to allow for the extraction of more conclusive data from the extracted absorbance intensity peaks. This was done using the multivariate data analysis software (R version 4.3.1 (2023-06-16 ucrt). PC1 and PC2 were responsible for 95.53% of the variability in the dataset with PC1 was responsible for 89.75% of the variability. The scatter plot was separated into four close but distinct clusters. Cluster 1 was composed of PI-3, PI-8, and SUN (Figure 4.2), which showed that they had similarity in their biochemical profiles and comparable nutritional composition.

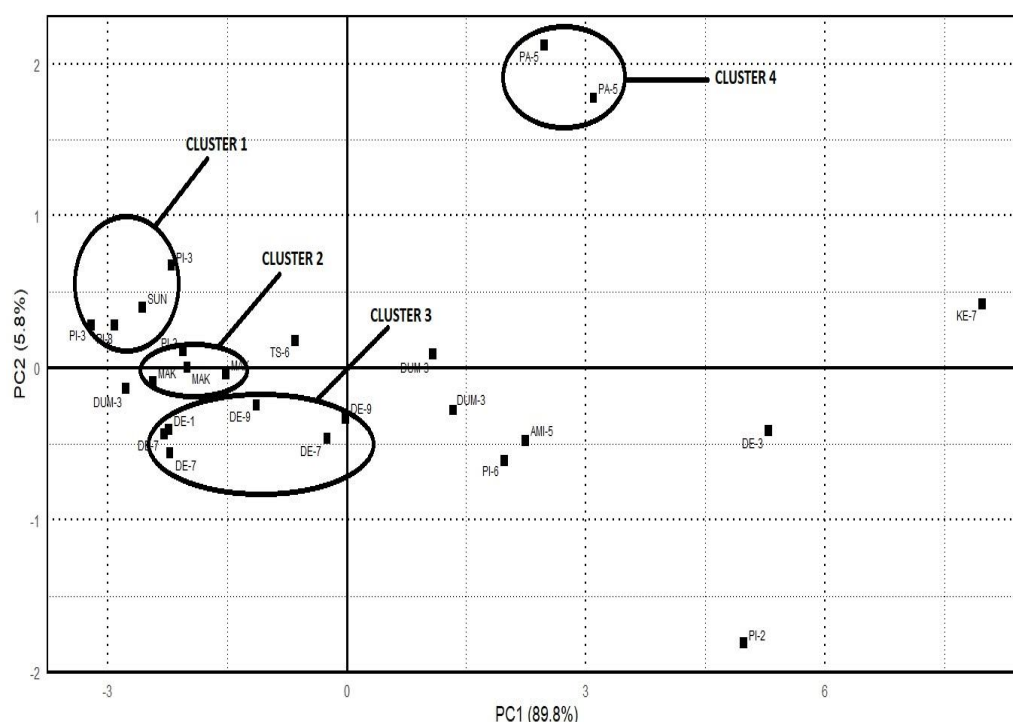


Figure 4.2: PCA plot for extracted FTIR absorbance intensities

A second cluster, Cluster 2, was located very close to cluster 1, comprised majorly of the MAK variety. This variety was developed by the Kenya Agricultural and Livestock Research Organization (KARLO). The variety was bred to enhance food security in arid and semi-arid areas with a focus on drought resilience, early maturity, and improved yield in limited water supply. This can be thought of as indicating that the MAK variety had its own unique biochemical profile.

Cluster 3, which was the largest of the clusters, contained DE-7, DE-9 and, DE-1. This cluster comprised of three of the four DE varieties which implies that the three

varieties had similar profiles. This may arise from a similar genotypic make up since all the samples had been bred by the same parent company. The fourth DE variety (DE-3) did not cluster in any of the clusters implying some uniqueness of its nutritional makeup. All DE varieties have however, been separated by PC 1 with little separation by PC 2, A fourth cluster, cluster 4, was observed that had PA-5 only. This cluster was separated from all the others, which implied that PA-5 has a unique nutritional profile compared to the other varieties in this study. KE-7 and PI-2 separated from the rest of the samples indicating unique profiles. PI-6 and AMI-5 separated from the other clusters and showed similar nutritional properties. Both genetic and agronomic factors contribute to variation in the amount and quality of maize constituents, influencing nutrient composition and grain quality (Prasanna et al., 2020).

To visualize the spectroscopic differences of the maize varieties already highlighted in general terms by PCA, a heat map(green-yellow-red) of the spectral data set was generated and presented as Figure 4.3.

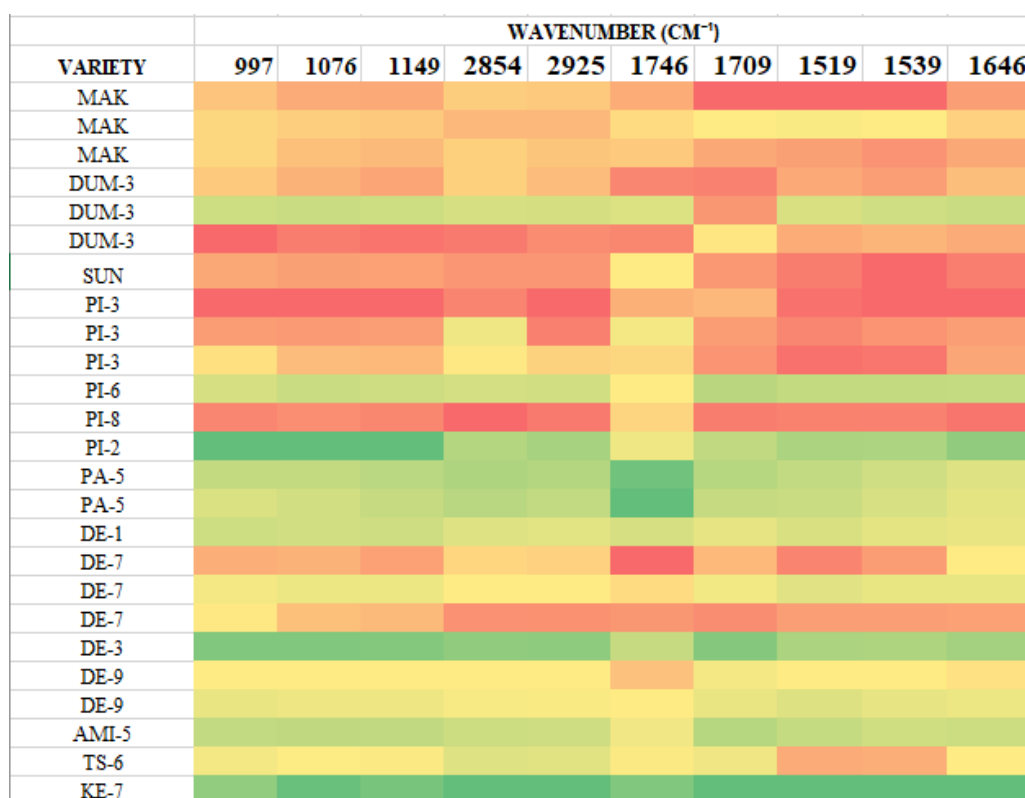


Figure 4.3: Heatmap of absorbance intensities at wavenumbers corresponding to different macronutrients

From visual inspection it could be seen that both DUM-3 and MAK varieties had low (red) absorbance intensities across all the measured wavenumbers. This indicated similarities in their nutritional profiles. The DE varieties (DE-3, DE-7, DE-1 and DE-9) showed moderate (yellow) to high(green) absorbance intensities across the measured wavenumbers which indicated similar chemical profiles. DE-3 had the highest absorbance intensities of all the DE varieties, which set it apart from the rest of the DE varieties.

PI-3 and PI-8 showed similar and low absorbance intensities across the measured wavenumbers; however, the absorbance intensities for wave numbers associated with lipids in PI-3 higher. PI-2 and PI-6 showed well-balanced profiles, with their absorbance intensities ranging from moderate to high when compared to the other varieties in the study. PI-2 had the highest absorbance intensities across wavenumbers associated with carbohydrates when compared to other varieties in the study. PA-5 showed a balanced profile with moderately high absorbance intensities across wavenumbers associated with starch, proteins, and lipids. It was also noted that the variety indicated a very high absorbance intensity at 1746, which was particularly unique for all the samples in the study which was responsible for its separation from the rest of samples in the PCA plot (Figure 4.2).

AMI-5 and TS-6 have moderate absorbance intensities across the measured wavenumbers; however, it was noted that TS-5 lower absorbance intensities across the wave numbers associated with proteins in comparison. SUN was noted to have a very similar profile to PI-3, which could indicate a similarity in their nutritional makeup. KE-7 had notably high absorbance intensities across all the measured wave numbers when compared to the rest of the samples in the study. This implied it had a unique profile which separated it from the rest of the varieties in the study.

4.3 Micro-Nutrient Quantification

The digested maize samples were analyzed for their micro-nutrient composition. The micronutrient composition of the maize samples was analyzed using AAS in triplicate. The mean values were then presented in Table 4.2. The data obtained from AAS were in mg/L and were converted to mg/Kg using the mathematical equation;

$$\text{Concentration of sample } \left(\frac{\text{mg}}{\text{Kg}} \right) = \frac{\text{concentration of solution } \left(\frac{\text{mg}}{\text{L}} \right) \times \text{Final volume of digest (L)} \times \text{dilution factor (DF)}}{\text{Mass of digest (Kg)}}$$

Table 4.2: Micronutrient concentrations for analyzed maize samples

Sub county	Maize Variety	Iron	Zinc	Manganese	Magnesium
Kirinyag a central	DE-9	34.33 ± 0.49	42.69 ± 3.56	0.63 ± 0.03	1283.38 ± 96.95
Kirinyag a central	MAK	21.79 ± 0.50	29.65 ± 2.59	3.40 ± 0.20	1205.35 ± 85.25
Kirinyag a east	DE-9	38.83 ± 2.12	28.44 ± 0.33	4.14 ± 0.19	1175.97 ± 112.78
Kirinyag a central	DE-7	21.83 ± 1.15	23.40 ± 0.46	5.55 ± 0.07	1203.87 ± 62.68
Mwea east	DUM-3	36.04 ± 3.08	19.65 ± 0.31	5.27 ± 0.08	1217.67 ± 115.90
Kirinyag a central	DUM-3	20.47 ± 0.97	37.47 ± 1.41	5.15 ± 0.25	1266.17 ± 41.03
Kirinyag a central	AMI-5	30.05 ± 1.55	38.65 ± 2.13	3.65 ± 0.10	1245.71 ± 39.41
Kirinyag a central	DE-7	35.14 ± 2.13	39.84 ± 1.95	5.17 ± 0.21	1228.15 ± 20.14
Mwea west	SUN	71.99 ± 2.16	83.95 ± 6.03	11.05 ± 0.17	1354.39 ± 123.37
Mwea east	PI-3	46.89 ± 3.99	58.58 ± 5.44	9.67 ± 0.52	1329.54 ± 46.37
Mwea west	PI-3	38.57 ± 1.51	41.93 ± 0.44	5.58 ± 0.10	1255.84 ± 60.37
Mwea west	DUM-3	94.43 ± 2.66	34.73 ± 1.01	10.35 ± 0.23	1201.53 ± 78.04
Kirinyag a west	PI-6	34.88 ± 1.45	45.74 ± 1.72	6.62 ± 0.56	1288.26 ± 46.69
Kirinyag a west	PA-5	42.81 ± 3.25	44.90 ± 2.27	7.64 ± 0.45	1300.07 ± 90.80
Kirinyag a east	PI-8	47.96 ± 0.96	36.95 ± 1.17	4.91 ± 0.18	1135.69 ± 85.29
Kirinyag a east	DE-7	40.41 ± 3.46	31.19 ± 1.19	4.37 ± 0.33	1145.24 ± 12.04
Mwea west	TS-6	26.42 ± 2.31	49.09 ± 3.20	5.27 ± 0.27	1270.00 ± 120.76
Kirinyag a east	PI-3	37.56 ± 2.80	24.25 ± 1.83	4.35 ± 0.22	1197.28 ± 38.66
Mwea east	PA-5	46.92 ± 0.74	60.47 ± 0.69	8.21 ± 0.09	1308.94 ± 92.49
Mwea east	KE-7	65.87 ± 2.32	71.33 ± 6.77	6.17 ± 0.56	1332.65 ± 112.32

Mwea east	MAK	46.47 ± 0.52	61.61 ± 5.80	6.82 ± 0.66	1314.67 ± 100.00
Kirinyaga west	DE-1	43.81 ± 4.11	45.90 ± 2.68	6.54 ± 0.62	1302.07 ± 119.84
Kirinyaga west	MAK	35.95 ± 1.85	34.36 ± 2.78	6.40 ± 0.52	1279.55 ± 65.82
Kirinyaga west	DE-3	39.28 ± 2.46	42.07 ± 1.38	5.81 ± 0.11	1270.56 ± 125.25
Kirinyaga west	PI-2	34.75 ± 0.51	54.02 ± 5.03	6.00 ± 0.52	1239.06 ± 119.04
Mean		41.38	43.27	5.90	1254.14
Highest value		34.33 ± 0.49	42.69 ± 3.56	0.63 ± 0.03	1283.38 ± 96.95
Lowest value		21.79 ± 0.50	29.65 ± 2.59	3.40 ± 0.20	1205.35 ± 85.25

*Values are means ± SD (n=3)

From the table, magnesium recorded the highest concentration among the analyzed micronutrients, ranging from 1135.69 to 1354.39 ppm, with an average of 1254.14 ppm across maize varieties grown in Kirinyaga County. These concentrations are comparatively higher than those reported in several studies conducted in other regions of Africa and worldwide.

For example, Ullah et al. (2010), in a comparative study on maize cultivars in Pakistan, reported magnesium concentrations ranging from 985.2 to 1125.3 ppm, values that are approximately 18.8% lower than those obtained in the current study. Similarly, Guo et al. (2020), working with twenty-four Chinese maize cultivars under varying nitrogen fertilization levels, observed magnesium contents between 0.97 and 1.11 g·kg⁻¹ (equivalent to 970–1110 ppm), which were also lower than the Kirinyaga mean.

In Europe, Dumbravă et al. (2009) analyzed different maize hybrids and reported magnesium concentrations ranging from 970 to 3006 ppm, a much wider span attributed to both genetic differences and the type of sample analyzed (grain and flour extracts). In Africa, Majamanda et al. (2022) found lower magnesium levels averaging 819 ppm in orange maize varieties grown in Dedza, Malawi.

Furthermore, Gashu et al. (2021) reported in a geospatial assessment of cereal nutrient composition across sub-Saharan Africa that maize grain magnesium concentrations typically range from 700 to 1500 ppm, depending on soil fertility and agroecological zone. When compared across these studies, the magnesium concentrations obtained

from Kirinyaga maize (1135–1354 ppm) fall toward the upper limit of the ranges reported internationally.

Zinc was the second most abundant micronutrient detected in the maize samples analyzed from Kirinyaga County. The concentrations ranged from 19.65 to 83.95 ppm, with an average of 43.27 ppm across the different varieties. These values show considerable variation among the samples, reflecting possible variation in soil zinc availability.

When compared to published studies, the mean zinc concentrations observed in the study is within or higher than the range reported in several other regions. For instance, Hailu et al. (2017) investigated zinc levels in Ethiopian maize and reported concentrations ranging from 23.1 ppm to 29.3 ppm, which are substantially lower than the Kirinyaga mean of 43.27 ppm. Similarly, Ullah et al. (2010), in a comparative study of maize cultivars, found zinc concentrations ranging between 37.05 ppm and 52.4 ppm, the mean recorded in Kirinyaga falls within the range reported in this particular study.

Additional comparative data from outside Africa further supports these findings. Guo et al. (2020), analyzing Chinese maize cultivars under different nitrogen regimes, reported zinc concentrations between 21 ppm and 38 ppm (converted from their data in $\text{mg}\cdot\text{kg}^{-1}$). In Europe, Dumbravă et al. (2009) documented zinc contents ranging between 22 ppm and 58 ppm in maize hybrids from Romania. Moreover, Gashu et al. (2021), in a geospatial analysis of cereal nutrient composition across sub-Saharan Africa, noted maize grain zinc concentrations typically within 20–40 ppm, depending on soil and environmental conditions.

Manganese concentrations in maize samples from Kirinyaga County ranged from 0.63 ppm to 11.05 ppm, with an average of 5.90 ppm across all regions and varieties analyzed. Although manganese occurred in lower quantities compared to macronutrients such as magnesium, its concentration varied notably among samples, reflecting both genetic and environmental influences. Varieties such as DE-7 (Kirinyaga Central) and MAK (Mwea East) exhibited the highest Mn levels (> 10

ppm), while DE-9 from Kirinyaga Central recorded the lowest concentration (0.63 ppm).

The mean manganese content (5.90 ppm) obtained in this study is broadly comparable to international values reported for maize grain. For instance, Ullah et al. (2010) found manganese concentrations between 4.95 ppm and 8.24 ppm in maize grown in Pakistan, while Guo et al. (2020) observed values ranging from 3.2 ppm to 6.5 ppm among Chinese maize cultivars. Similarly, Dumbravă et al. (2009) reported a range of 2.4 ppm to 5.6 ppm in Romanian hybrids, whereas Majamanda et al. (2022) recorded 1.25 ppm to 2.33 ppm in orange maize varieties from Malawi. A continental-scale study by Gashu et al. (2021) also reported that maize grains across sub-Saharan Africa generally contain between 1.0 ppm and 5.0 ppm of manganese.

Based on these comparisons, the manganese levels observed in Kirinyaga maize are within and slightly above the global range, particularly for certain varieties exceeding 10 ppm. These elevated concentrations suggest that local agroecological factors such as soil type, pH, and organic matter may enhance Mn bioavailability, or that specific genotypes possess superior Mn uptake efficiency. Conversely, the lower Mn concentrations recorded in some varieties may be linked to soil redox conditions or varietal differences in metal transport and accumulation (Tao et al., 2023; Long et al., 2020)

The iron (Fe) concentrations in maize samples from Kirinyaga County ranged from 20.47 ppm to 94.43 ppm, with an average of 41.38 ppm across the sampled regions and varieties. Iron was one of the major micronutrients detected, exhibiting considerable variation among varieties and sites. The highest Fe level was observed in the MAK variety from Mwea East (94.43 ppm), while the lowest occurred in DUM-3 from Kirinyaga Central (20.47 ppm). Such variability may be attributed to genotypic differences, soil Fe availability, and environmental conditions influencing metal uptake and translocation (Bouis and Saltzman, 2017)

When compared with literature, the mean Fe concentration obtained in Kirinyaga maize (41.38 ppm) is within or slightly above the range reported in other studies. Ullah et al. (2010) reported Fe levels between 33.15 and 46.50 ppm in maize cultivars grown

in Pakistan, which closely aligns with the current findings. Similarly, Guo et al. (2020) observed Fe concentrations ranging from 28.6 to 53.2 ppm in Chinese maize cultivars, showing a comparable magnitude. In contrast, Hailu et al. (2015) found relatively lower iron levels in Ethiopian maize varieties, ranging from 22.4 to 34.1 ppm, while Dumbravă et al. (2009) reported slightly higher Fe values of 45.8 to 64.5 ppm in Romanian hybrids.

Regionally, Gashu et al. (2021), in a geospatial nutrient mapping study across sub-Saharan Africa, reported Fe concentrations in maize generally ranging between 20 and 60 ppm, with substantial site-specific variation driven by soil properties and genotype–environment interactions. The Fe concentrations in Kirinyaga maize therefore fall toward the upper portion of this continental range, indicating favorable soil Fe bioavailability or efficient Fe uptake by local varieties such as MAK and PI-3.

To further help analyze the data and explain similarities and differences between the samples PCA was done and the scatter plot presented in Figure 4.4.

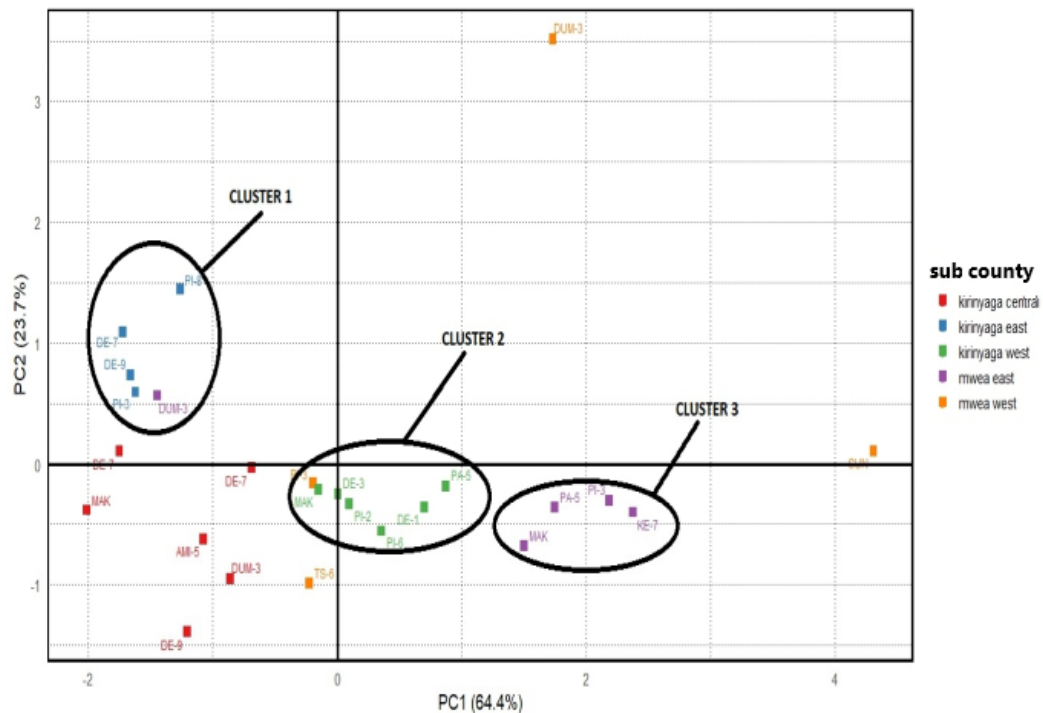


Figure 4.4: PCA plot for the concentration of micronutrients

From the PCA results, the first two principal components (PC1 and PC2) accounted for 90.7% of the total variability, with PC1 contributing 68.1% and PC2 22.6%. This

indicates that most of the variation in micronutrient composition among the maize varieties can be effectively summarized along these two axes.

The scatter plot revealed three distinct clusters. Cluster 1 was primarily occupied by samples from Kirinyaga East, suggesting that these varieties shared similar micronutrient accumulation patterns possibly due to analogous soil micronutrient availability. Cluster 2 consisted of samples from Kirinyaga West suggesting that this variety shared compositional similarity in certain minerals. Cluster 3 was composed of Mwea East samples this indicates that this samples had a similar micro nutrient profile. Samples from Kirinyaga central formed a large cluster below cluster one however this cluster was not as close knit as the other three clusters this indicated that there were more intraregional differences in Kirinyaga central than the other regions

The observed overlap among samples from Mwea West with those from other sub counties suggests non-uniformity in soil micronutrient distribution and its potential influence on mineral uptake. Variability in soil pH, moisture regime, and organic matter between the lowland (Mwea) and upland (Kirinyaga Central/East/West) zones may also contribute to these compositional differences.

Prior to running analysis of variance (ANOVA) to validate the observed PCA clustering, Shapiro wilk test and Levene's test were performed to test for normality and homogeneity of variance in the dataset respectively. Table 4.3 presents the results of the Shapiro wilk test for the different metals per region.

Table 4.3: Shapiro wilk's test results

Mineral	W-statistic	p-value
IRON	0.8360	0.0010
ZINC	0.9500	0.2511
MANGANESE	0.9474	0.2192
MAGNESIUM	0.9745	0.7581

The test provides two outputs: the W statistic and the p-value. The W statistic indicates how closely the sample distribution approximates a normal distribution, with values closer to 1 suggesting stronger agreement with normality. The p-value determines whether deviations from normality are statistically significant.

For Iron, the Shapiro–Wilk test showed a statistically significant departure from normality ($W = 0.8360$, $p = 0.0010$), indicating that iron concentration data were not normally distributed. For Zinc ($W = 0.9500$, $p = 0.2511$), Manganese ($W = 0.9474$, $p = 0.2192$), and Magnesium ($W = 0.9745$, $p = 0.7581$), the p-values were greater than 0.05, indicating no statistically significant departure from normality. These results suggest that the distributions of zinc, manganese, and magnesium were approximately normal.

Table 4.4: Levene’s test results

Mineral	Df(group,res)	F-value	Pr(>f)	Verdict
Iron	4,20	10.188	0.0001	Unequal
Zinc	4,20	6.077	0.0022	Unequal
Manganese	4,20	2.550	0.0710	Equal
Magnesium	4,20	0.544	0.7054	Equal

Levene’s test produces two key outputs: the F-statistic, and the p-value. The F-statistic measures the extent to which group variances differ from each other, with larger values indicating greater inequality of variances. The p-value indicates whether these differences are statistically significant. A p-value > 0.05 , as observed for Mn: 0.0710 and Mg: 0.7054 in Table 5, suggests that the assumption of homogeneity of variances is met, meaning the group variances are not significantly different. In contrast, a p-value < 0.05 , as seen for Fe: 0.0001 and Zn: 0.0022, indicates that the variances are significantly different across groups, thus violating the assumption of equal variances.

ANOVA was then performed on the two nutrients that showed normality and homogeneity of variance (Mn and, Mg) to test for significant difference between different sub counties. Table 4.5 presents the results of ANOVA for the different metals per region.

Table 4.5: ANOVA between sub counties

Mineral	F-value	P-value	Significant
MANGANESE	5.170	0.0050	Yes
MAGNESIUM	7.988	0.0005	Yes

ANOVA measured the intra-group and inter-group variability between the five sub counties in Kirinyaga.

The f-value measures the ratio of these variances. From Table 4.5 magnesium had the largest f-value indicating it had the most difference among the five sub counties. The associated p-values of $p < 0.05$ in Mg and Mn indicated that there was significant difference in the quantities of these metals between the different sub counties. The mean concentrations per region for Mg and Mn were then calculated prior to running post hoc tests. The resultant means for the regions are presented in Table 4.6.

Table 4.6: Mean concentration of magnesium and manganese across Kirinyaga county, Kenya.

Sub County	Magnesium (mg/kg) Mean $\pm$ SD	Manganese (mg/kg) Mean $\pm$ SD
Kirinyaga Central	1238.77 $\pm$ 32.36	3.93 $\pm$ 1.84
Kirinyaga East	1163.54 $\pm$ 28.31	4.44 $\pm$ 0.33
Kirinyaga West	1279.93 $\pm$ 23.34	6.50 $\pm$ 0.64
Mwea East	1300.69 $\pm$ 47.46	7.23 $\pm$ 1.73
Mwea West	1270.44 $\pm$ 63.27	8.06 $\pm$ 3.06

Mean magnesium levels ranged from 1163.54 $\pm$ 28.31 mg/kg in Kirinyaga East to 1300.69 $\pm$ 47.46 mg/kg in Mwea East. Relatively high magnesium concentrations were also observed in Mwea West 1270.44 $\pm$ 63.27 mg/kg and Kirinyaga West 1279.93 $\pm$ 23.34 mg/kg, while Kirinyaga Central 1238.77 $\pm$ 32.36 mg/kg showed intermediate values.

Mean manganese concentrations also showed clear regional gradient, with the lowest levels recorded in Kirinyaga Central 3.93 $\pm$ 1.84 mg/kg and Kirinyaga East 4.44 $\pm$ 0.33 mg/kg. Higher manganese concentrations were observed in Kirinyaga West 6.50 $\pm$ 0.64 mg/kg and Mwea East 7.23 $\pm$ 1.73 mg/kg, with the highest mean manganese level occurring in Mwea West 8.06 $\pm$ 3.06 mg/kg.

Follow-up comparison using Tukey's HSD provided deeper insight into the specific regional contrasts responsible for these effects. Table 4.7 presents results for Tukey's HSD.

Table 4.7: Turkey's HSD results for Manganese.

Comparison	Diff	Lwr	Upr	P adj
Mwea East – Kirinyaga Central	3.301	0.18	6.43	0.0353
Mwea West – Kirinyaga Central	4.138	0.81	7.47	0.0106
Kirinyaga West – Kirinyaga Central	2.578	-0.4	5.56	0.1106
Kirinyaga East – Kirinyaga Central	0.518	-2.81	3.85	0.9897
Kirinyaga West – Kirinyaga East	2.06	-1.27	5.39	0.3743
Mwea East – Kirinyaga East	2.784	-0.68	6.25	0.1546
Mwea West – Kirinyaga East	3.62	-0.03	7.27	0.0525
Mwea East – Kirinyaga West	0.723	-2.4	3.85	0.9558
Mwea west – Kirinyaga west	1.56	-1.77	4.89	0.6339
Mwea west – Mwea east	0.837	-2.63	4.3	0.9486

*Diff = Mean difference between groups, Lwr = Lower bound of 95% confidence interval, Upr = Upper bound of 95% confidence interval, P adj = Tukey-adjusted p-value

Manganese showed some regional patterns. Both Mwea East and Mwea West exhibited significantly higher manganese concentrations compared to Kirinyaga Central ($P < 0.05$). No significant differences were observed among the remaining pairs ($P > 0.05$). These results indicate that the Mwea regions are consistently richer in Manganese, suggesting that soil characteristics, irrigation water composition, or environmental factors in Mwea may enhance manganese availability to maize plants.

The strongest regional effect was observed for magnesium as shown in Table 4.8. Tukey's post-hoc test showed that Kirinyaga East had significantly lower magnesium levels than Kirinyaga West, Mwea East, and Mwea West, ($P < 0.05$). while the three latter regions did not differ significantly among themselves ($P > 0.05$). This pattern indicates that Kirinyaga East is uniquely deficient in magnesium compared to the rest

of the county. Such a localized deficiency may be linked to soil type, past land-use patterns, or nutrient depletion from intensive cultivation.

Table 4.8: Turkey's HSD results for magnesium.

Comparison	Diff	Lwr	Upr	P adj
Kirinyaga West – Kirinyaga East	116.383	39.87	192.9	0.0016
Mwea East – Kirinyaga East	137.149	57.63	216.66	0.0004
Mwea West – Kirinyaga East	106.893	23.08	190.71	0.0085
Kirinyaga East – Kirinyaga Central	-75.226	-151.74	1.29	0.0554
Kirinyaga West – Kirinyaga Central	41.157	-27.28	109.59	0.401
Mwea East – Kirinyaga Central	61.923	-9.85	133.7	0.1121
Mwea West – Kirinyaga Central	31.667	-44.85	108.18	0.7298
Mwea East – Kirinyaga West	20.766	-51.01	92.54	0.906
Mwea West – Kirinyaga West	-9.49	-86.0	67.02	0.9956
Mwea West – Mwea East	-30.256	-109.77	49.26	0.7845

*Diff = Mean difference between groups, Lwr = Lower bound of 95% confidence interval, Upr = Upper bound of 95% confidence interval adj = Tukey-adjusted p-value

Since the assumption of homogeneity of variances was violated for zinc ($p < .05$), Welch ANOVA was conducted since it assumes unequal variance. Table 4.9 shows the Welch's ANOVA results for zinc

Table 4.9: Welch's ANOVA result for zinc

Mineral	F-statistic	df1	df2	p-value
Zinc	4.23	4	8.93	0.034

Welch's ANOVA measured the intra-group and inter-group variability of zinc concentrations across the five sub-counties in Kirinyaga. The F-value represents the ratio of these variances, the obtained F-value of 4.23 indicates that there were observable differences in zinc concentrations among the five sub-counties. The degrees of freedom ($df2 = 8.93$) reflect the Welch–Satterthwaite adjustment, which accounts for unequal variances among groups. The associated p-value of 0.034 ($p <$

0.05) indicates that there was a statistically significant difference in zinc concentrations between the sub-counties.

Follow up comparison using Games–Howell post hoc test was used to determine which specific sub-counties differed significantly in zinc concentrations following the significant Welch ANOVA result. This test compares all possible pairs of sub-counties while accounting for unequal variances and unequal sample sizes Table 4.10 shows this result.

Table 4.10: Games-Howell test results for zinc

Group 1	Group 2	Estimate	Conf. High	Conf. Low	p-value
Kirinyaga central	Kirinyaga east	-5.07	8.78	-18.9	0.714
Kirinyaga central	Kirinyaga west	9.22	22.3	-3.83	0.213
Kirinyaga central	Mwea east	19.0	57.2	-19.1	0.374
Kirinyaga central	Mwea west	17.1	71.8	-37.5	0.609
Kirinyaga east	Kirinyaga west	14.3	27.4	1.18	0.033
Kirinyaga east	Mwea east	24.1	62.6	-14.3	0.216
Kirinyaga east	Mwea west	22.2	77.4	-33.0	0.425
Kirinyaga west	Mwea east	9.83	48.3	-28.6	0.822
Kirinyaga west	Mwea west	7.93	63.2	-47.4	0.943
Mwea east	Mwea west	-1.90	50.3	-54.1	1.000

*Conf. High-highest confidence interval, Conf. Low- lowest confidence interval

The results showed that most pairwise comparisons were not statistically significant ($p > 0.05$), indicating that zinc concentrations were relatively similar across most sub-counties. However, a significant difference was observed between Kirinyaga East and Kirinyaga Central ($p = 0.033$), where zinc levels in Kirinyaga East were significantly higher than those in Kirinyaga Central. All other comparisons did not show statistically significant differences.

Since Fe did not show normality in the dataset Kruskal-Wallis test which is a non - parametric statistical test used to determine whether there are statistically significant differences between independent groups was ran. Table 4.11 shows these results

Table 4.11: Kruskal-Wallis test results for iron.

TEST	X ² (H- statistic)	DEGREE OF FREEDOM (df)	p- value
Kruskal Wallis	13.022	4	0.011

Kruskal-Wallis produces two results the H-statistic which represents how far apart group rankings are and a p-value which indicates the probability of obtaining the observed test statistic assuming that no true difference exists among the groups. A p-value < 0.05 indicates that observed differences are statistically significant. The observed p- value of 0.011 therefore indicates that the group differences are statistically significant.

Following a significant Kruskal-Wallis test, post-hoc pairwise comparisons were performed using Dunn's test with Benjamini–Hochberg false discovery rate adjustment. Table 4.12 shows these results

Table 4.12: Dunn's test results for iron

Comparison	Z	P. unadj	P.adj
Kirinyaga Central - Mwea East	-3.24613595	0.00116983	0.0116983
Kirinyaga Central - Kirinyaga East	-2.45576245	0.01405861	0.04686202
Kirinyaga Central - Mwea West	-2.56100942	0.01043685	0.05218426
Kirinyaga Central - Kirinyaga West	-1.92193812	0.05461354	0.13653386
Kirinyaga West - Mwea East	-1.41363985	0.15746767	0.31493535
Kirinyaga East - Kirinyaga West	0.73672874	0.46128733	0.6589819
Kirinyaga West - Mwea West	-0.8419757	0.39980156	0.66633593
Mwea East - Mwea West	0.46586011	0.64131564	0.71257293
Kirinyaga East - Mwea East	-0.56713405	0.57062311	0.71327889
Kirinyaga East - Mwea West	-0.09607689	0.9234595	0.9234595

Dunn's test gives two results; the Z statistic reflects the difference in mean ranks between the two regions a negative Z value shows the second region has higher ranks while a Positive Z value shows the first region has higher ranks. The test revealed significant differences between Kirinyaga Central and Mwea East (p = 0.012), and

between Kirinyaga Central and Kirinyaga East ($p = 0.047$). Regional iron concentrations were summarized using medians and interquartile ranges (IQR) due to non-normal distributions. The results are shown in Table 4.13.

Table 4.13: Medians and interquartile ranges for iron across Kirinyaga county.

Region	Median	IQR
Mwea West	55.3	42.1
Mwea East	46.9	0.453
Kirinyaga East	39.6	3.79
Kirinyaga West	37.6	6.79
Kirinyaga Central	25.9	11.5

From Table 4.13 Median iron concentrations were higher in Mwea East and Kirinyaga East compared to Kirinyaga Central.

4.4 Chapter Summary

The micronutrient content of the collected maize samples was successfully quantified using AAS. PCA run on the data collected from AAS revealed clustering in terms of sub county of origin. Statistical analysis for the data collected from AAS showed that there was significant difference in the levels of all the elements analyzed within the county. PCA run on the measured absorbance intensities revealed clustering in terms of variety.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

FTIR spectroscopy was successfully applied to identify the macronutrient composition of the maize varieties through characteristic absorption bands corresponding to carbohydrates, proteins, and lipids. Major peaks were recorded around 997 cm^{-1} -C-O stretch 1076 cm^{-1} -C-O-C- stretch 1149 cm^{-1} -C-O-C- asymmetric stretching attributable to carbohydrates, 2854 cm^{-1} -CH₂ symmetric stretching 2925 cm^{-1} asymmetric stretching 1743 cm^{-1} -C=O stretching 1709 cm^{-1} -C=O stretching attributed to fatty acids and fatty acid esters and, 1539 cm^{-1} amide ii -N-H bending/-C-N stretching 1646 cm^{-1} amide I C=O Stretching of peptide bonds linked to proteins. The observed variations in spectral intensities among varieties indicated differences in macronutrient content amongst the varieties.

Principal Component Analysis (PCA) of the FTIR data accounted for 95.53% of total variance, confirming distinct biochemical groupings among varieties. (DE-9, DE-7, and DE-1) formed a single cluster, reflecting compositional similarity likely due to genetic similarity. Conversely, KE-7, PI-6, and PA-5 formed distinct clusters, implying unique biochemical signatures. KE-7 exhibited the highest spectral intensities across major bands, suggesting a balanced and rich macronutrient profile. On the other hand, DUM-3 and MAK varieties recorded relatively low absorbance intensities, reflecting lower carbohydrate and protein contents. These results indicate that macronutrient composition is predominantly influenced by genetic makeup, with environmental factors playing a secondary role.

Atomic Absorption Spectroscopy provided precise quantification of Fe, Zn, Mn, and Mg across the maize samples collected. The results revealed substantial variation both between and within varieties, indicating the influence of both genotype and soil nutrient availability. Magnesium recorded the highest concentrations, ranging from 1135.69 to $1354.39\text{ mg}\cdot\text{kg}^{-1}$ with a mean of $1254.14\text{ mg}\cdot\text{kg}^{-1}$, suggesting that Kirinyaga soils are rich in Mg and that the maize varieties under study have high Mg uptake efficiency. Zinc concentrations ranged between 19.65 and $83.95\text{ mg}\cdot\text{kg}^{-1}$, averaging $43.27\text{ mg}\cdot\text{kg}^{-1}$, with DE-7 and KE-7 exhibiting the highest Zn levels. Iron

levels ranged from 20.47 to 94.43 mg·kg⁻¹, with a mean of 41.38 mg·kg⁻¹. The highest Fe concentration was observed in the MAK variety from Mwea East, implying that both genotype and local soil conditions favor Fe accumulation. Manganese (Mn) concentrations were lowest, ranging from 0.63 to 11.05 mg·kg⁻¹, with a mean of 5.90 mg·kg⁻¹. PCA of micronutrient data explained 90.7% of total variation (PC1 = 68.1%, PC2 = 22.6%), revealing clear clustering patterns based on region. These results demonstrate that genetic variation and environmental conditions jointly influence mineral accumulation.

Comparison of macronutrient and micronutrient profiles across sub-counties revealed distinct nutritional patterns. Samples from Mwea East and Mwea West generally exhibited higher nutrient concentrations compared to those from Kirinyaga East and Kirinyaga West. When both FTIR and AAS findings were integrated, KE-7 emerged as the most nutritionally superior variety in this study, exhibiting high absorbance intensities across FTIR spectra and elevated Zn and Mg contents in AAS results. DE-3 also demonstrated balanced macronutrient and micronutrient composition, making it suitable for nutritional enhancement initiatives. In contrast, DUM and PI-3 recorded lower nutrient levels, indicating they are better suited for yield-based or drought-tolerant breeding objectives rather than nutrition-focused programs. The clear clustering of varieties according to genotype for macro nutrients rather than region further supports the conclusion that genetic factors are the major determinants of maize nutritional quality (Govender et al., 2020; Hailu et al., 2017).

5.2 Recommendations

The findings of this study demonstrated significant variation in both macronutrient and micronutrient composition across maize varieties cultivated in Kirinyaga County. The results emphasize the importance of genotype in determining nutritional quality, supported by minor but notable environmental effects. Therefore, from the insights offered by this research, the following recommendations are made:

5.2.1. Policy Recommendations

- I. Significant variability in nutrient density was observed among the sampled varieties. This suggests that the Kenya Agricultural and Livestock Research

Organization (KALRO) and other plant breeding institutions should incorporate nutrient profiling using FTIR and AAS into standard varietal development.

- II. Since drought-tolerant varieties (e.g., MAK and DUM-3) showed relatively lower nutrient content in this study, future programs should focus on balancing resilience and nutritional quality through breeding and agronomic optimization.
- III. The successful application of FTIR and AAS in this study highlights their potential for use in food quality monitoring. National laboratories and agro-industries should adopt these technologies for routine analysis to ensure consistent nutrient standards in maize-based food products regardless of the variety or region of origin.

5.2.2 Recommendations for Future Studies

- I. Since nutrient composition varied by sub-county, a county-wide or national nutrient mapping program should be initiated. This would identify areas with micronutrient-deficient soils and inform site-specific soil and crop management practices.
- II. While this study quantified nutrient concentrations, it did not assess their bioavailability. Future studies should analyze anti-nutritional factors such as phytates, oxalates, and tannins, which influence mineral absorption, to provide a more realistic picture of nutritional quality.
- III. The observed micronutrient variability could partly be attributed to differences in soil fertility and agronomic management. Future research should integrate soil and plant analyses to elucidate nutrient uptake dynamics and optimize fertilizer regimes.
- IV. The current study analyzed samples collected during a single season. Longitudinal studies across multiple growing seasons should be undertaken to capture seasonal variations and provide a more comprehensive understanding of nutrient stability.
- V. The study established that genotype plays a significant role in macronutrient composition. Further research should utilize genomic and transcriptomic analyses to identify specific genes responsible for nutrient accumulation and metabolism in maize

VI. While some varieties (e.g., KE-7 and DE-3) exhibited higher nutrient levels in this survey, these results should be validated through controlled, multi-locational trials to isolate genetic potential from environmental influences.

REFERENCES

- Agostoni, C., Moreno, L., and Shamir, R. (2016). Palmitic acid and health: Introduction. *Critical reviews in Food Science and Nutrition*, 56(12), 1941-1942.
- Ahmed, N., Rahman, M., and Islam, M. (2025). Meat authenticity predictive classification by implementing Fourier transform infrared spectroscopy combined with chemometrics. *Journal of Food Composition and Analysis*, 145, 107862. <https://doi.org/10.1016/j.jfca.2025.107862>
- Al Alawi, A. M., Majoni, S. W., & Falhammar, H. (2018). Magnesium and human health: Perspectives and research directions. *International Journal of Endocrinology*, 2018, Article 9041694. <https://doi.org/10.1155/2018/9041694>
- Álvarez-Iglesias, L., Malvar, R. A., Garzón, R., Rosell, C. M., & Revilla, P. (2021). Nutritional value of whole maize kernels from diverse endosperm types and effects on rheological quality. *Agronomy*, 11(12), 2509. <https://doi.org/10.3390/agronomy11122509>
- Amit, A., Jamwal, G., Kumari, N., Dhaulaniya, A., Balan, R., and Singh, S. (2020). Application of FTIR spectroscopy coupled with chemometrics for quantitative analysis of fats and oils. *Molecules*, 25(22), 5485. <https://doi.org/10.3390/molecules25225485>
- Awika, J. M. (2017). Sorghum: Its unique nutritional and health-promoting attributes. In J. R. N. Taylor & J. M. Awika (Eds.), *Gluten-free ancient grains: Cereals, pseudocereals, and legumes* (pp. 21–54). Woodhead Publishing. <https://doi.org/10.1016/B978-0-08-100866-9.00003-0>
- Azam, F. M. S., Tong, L., Liang, Q., Wang, W., Zhang, C., & Jiang, L. (2022). Variation of vitamin B contents in maize inbred lines: Potential genetic resources for biofortification. *Frontiers in Nutrition*, 9, 1029119. <https://doi.org/10.3389/fnut.2022.1029119>
- BeMiller, J. N., and Whistler, R. L. (2009). *Starch: Chemistry and technology* (3rd ed.). Academic Press.
- Berardo, N., Mazzinelli, G., Valoti, P., Laganà, P., & Redaelli, R. (2009). Characterization of maize germplasm for the chemical composition of the grain. *Journal of Agricultural and Food Chemistry*, 57(6), 2378–2384. <https://doi.org/10.1021/jf803688t>
- Bhowmik, D., Chiranjib, K. P., & Kumar, S. (2010). A potential medicinal importance of zinc in human health and chronic disease. *International Journal of Pharmaceutics and Biomedical Sciences*, 1(1), 5–11.

- Borrás, L., Curá, J. A., and Otegui, M. E. (2002). Maize kernel composition and post-flowering source-sink ratio. *Crop Science*, **42**(3), 781-790.
- Bost, M., Houdart, S., Oberli, M., Kalonji, E., Huneau, J. F., & Margaritis, I. (2016). Dietary copper and human health: Current evidence and unresolved issues. *Journal of Trace Elements in Medicine and Biology*, **35**, 107–115. <https://doi.org/10.1016/j.jtemb.2016.02.006>
- Bouis, H. E., & Welch, R. M. (2010). Biofortification—A sustainable agricultural strategy for reducing micronutrient malnutrition in the global South. *Crop Science*, **50**(Supplement_1), S20–S32. <https://doi.org/10.2135/cropsci2009.09.0531>
- Burlini, I., Grandini, A., Tacchini, M., Maresca, I., Guerrini, A., & Sacchetti, G. (2020). Different strategies to obtain corn (*Zea mays* L.) germ extracts with enhanced antioxidant properties. *Natural Product Communications*, **15**(1), 1934578X20903562. <https://doi.org/10.1177/1934578X20903562>
- Caballero-Rothar, N. N., Borrás, L., & Gerde, J. A. (2022). Physical and chemical kernel traits affect starch digestibility and glycemic index of cooked maize flours. *Food Chemistry*, **369**, Article 130953. <https://doi.org/10.1016/j.foodchem.2021.130953>
- Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., and Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security*, **5**, 345-360.
- Chen, W., Cui, F., Zhu, H., Zhang, X., Lu, S., Lu, C., Chang, H., Fan, L., Lin, H., Fang, J., An, Y., Li, X., & Qi, Y. (2024). Genome-wide association study of kernel color traits and mining of elite alleles from maize. *BMC Plant Biology*, **24**, 25. <https://doi.org/10.1186/s12870-023-04662-5>
- Chen, Z., & Gallavotti, A. (2021). Improving architectural traits of maize inflorescences. *Molecular Breeding*, **41**(3), 21. <https://doi.org/10.1007/s11032-021-01212-5>
- De Moura, F. A., Azevedo, L. C., Campelo, P. H., & others. (2020). Effect of process and variety on physico-chemical and rheological properties of two corn flour varieties (Atp and Kassai). *Journal of Agriculture and Food Research*, **2**, 100075. <https://doi.org/10.1016/j.jafr.2020.100075>
- De Moura, F. F., Miloff, A., & Boy, E. (2015). Retention of provitamin A carotenoids in staple crops targeted for biofortification in Africa: Cassava, maize and sweet potato. *Critical Reviews in Food Science and Nutrition*, **55**(9), 1246–1269. <https://doi.org/10.1080/10408398.2012.724477>

- Demeke, K. H. (2018). Nutritional quality evaluation of seven maize varieties grown in Ethiopia. *Biochemistry and Molecular Biology*, 3(2), 45–48. <https://doi.org/10.11648/j.bmb.20180302.11>
- Dumbravă, D., Moldovan, C., Moldovan, Z., & Mureșan, E. (2009). Determination by atomic absorption spectrometry of mineral content from maize hybrids obtained in Turda area. *Annals of the University of Oradea, Fascicle: Environmental Protection*, 14, 46–51.
- Fernando, W. M. A. D. B., Karunaratne, D. N., and Amaratunga, G. A. J. (2023). Quantitative determination of food constituents using FTIR spectroscopy coupled with partial least squares regression. *Food Chemistry*, 404, 134512. <https://doi.org/10.1016/j.foodchem.2022.134512>
- Flint-Garcia, S. A., et al. (2015). Compositional assessments of key maize populations: B73 hybrids of the Nested Association Mapping founder lines and diverse landrace inbred lines. *Journal of Agricultural and Food Chemistry*, 63(21), 5282–5295. <https://doi.org/10.1021/acs.jafc.5b00208>
- Franca, A. S., & Oliveira, L. S. (2011). Potential uses of Fourier transform infrared spectroscopy (FTIR) in food processing and engineering. In B. C. Siegler (Ed.), *Food engineering* (pp. 211–257). Nova Science Publishers.
- Galvin-King, P., Haughey, S. A., & Elliott, C. T. (2021). Garlic adulteration detection using NIR and FTIR spectroscopy and chemometrics. *Journal of Food Composition and Analysis*, 96, 103757. <https://doi.org/10.1016/j.jfca.2020.103757>
- Garcia-Medina, M., Kilwinger, F., Almekinders, C. J. M., & Donovan, J. (2026). Maize variety traits for different needs: Using the means-end chains method to identify preferences and perceived benefits among smallholder farmers in Kenya. *Food Security*, 18(2), 581–598. <https://doi.org/10.1007/s12571-025-01637-2>
- Garcia-Medina, M., Kilwinger, F., Almekinders, C., & Donovan, J. (2026). Maize variety traits for different needs: Using the means-end chains method to identify preferences and perceived benefits among smallholder farmers in Kenya. *Food Security*, 18(2), 581–598. <https://doi.org/10.1007/s12571-025-01637-2>
- Gashu, D., Nalivata, P. C., Amede, T., Ander, E. L., Bailey, E. H., Botoman, L., Chagumaira, C., Gameda, S., Haefele, S. M., Hailu, K., Joy, E. J. M., Kalimbira, A. A., Kumssa, D. B., Lark, R. M., Ligowe, I. S., McGrath, S. P., Milne, A. E., Mossa, A. W., Munthali, M., Towett, E. K., Walsh, M. G., Wilson, L., Young, S. D., & Broadley, M. R. (2021). The nutritional quality of

- cereals varies geospatially in Ethiopia and Malawi. *Nature*, 594(7861), 71–76.
<https://doi.org/10.1038/s41586-021-03559-3>
- Grzelec, K. (2024). Application of chemometric techniques in FTIR spectral preprocessing and analysis. *Journal of Molecular Structure*, 1302, 137432.
<https://doi.org/10.1016/j.molstruc.2024.137432>
- Guo, S., Chen, Y., Chen, X., Chen, Y., Yang, L., Wang, L., Qin, Y., Li, M., Chen, F., Mi, G., Gu, R., & Yuan, L. (2020). Grain mineral accumulation changes in Chinese maize cultivars released in different decades and the responses to nitrogen fertilizer. *Frontiers in Plant Science*, 10, 1662.
<https://doi.org/10.3389/fpls.2019.01662>
- HarvestPlus. (2020). Vitamin A maize. <https://www.harvestplus.org/crop/vitamin-a-maize/>
- HarvestPlus. (2021). Crop biofortification: The pathway to scaling up. https://www.harvestplus.org/wp-content/uploads/2021/12/Crop-Biofortification_The-Pathway-to-Scaling-Up.pdf
- Hernández, G. L., Hernández Aguilar, C., Domínguez Pacheco, A., Martínez Sibaja, A., Cruz Orea, A., et al. (2023). Thermal properties of maize seed components. *Cogent Food & Agriculture*, 9(1), 2231681.
<https://doi.org/10.1080/23311932.2023.2231681>
- Holding, D. R. (2014). Recent advances in the study of prolamin storage protein organization and function. *Frontiers in Plant Science*, 5, 276.
<https://doi.org/10.3389/fpls.2014.00276>
- Huang, X., Liu, H., Ma, Y., Mai, S., & Li, C. (2022). Effects of extrusion on starch molecular degradation, order–disorder structural transition and digestibility—A review. *Foods*, 11(16), 2538. <https://doi.org/10.3390/foods11162538>
- Ifie, S. E., Dangana, R. S., Swase, D., Okon, M. B., Makena, W., Agunloye, M. O., Ugwu, C. N., Ifie, J. E., Odoma, S., Babangida, A. I., & Aja, P. M. (2026). Nutritional composition of *Zea mays* L.: A comprehensive review of macronutrients, micronutrients, and bioactive compounds. *Open Research Africa*, 8, 15. <https://doi.org/10.12688/openresafrika.16056.2>
- Imam, M. N., Ibrahim, O., & Abdulrahman, Y. S. (2025). Comparative proximate composition of some maize (*Zea mays* L.) varieties grown in Northern Nigeria. *Greener Journal of Agricultural Sciences*, 15(1), 1–7.
<https://doi.org/10.15580/gjas.2025.1.010125002>
- Iqtadar, R., Ahmed, N., Asghar, S., & Azam, M. (2025). Advances and applications of FTIR spectroscopy: Precision, accuracy, and validation challenges. *Journal of Pharma and Biomedics*, 3(1), 91–103.
<https://doi.org/10.39401/jpbm.003.01.0037>

- Jia, M., Wu, H., Clay, K. L., Jung, R., Larkins, B. A., & Gibbon, B. C. (2018). High-resolution mapping of modifiers for quality protein maize reveals a zinc finger protein that influences the expression of a zein-like protein. *Theoretical and Applied Genetics*, 131(1), 1–13. <https://doi.org/10.1007/s00122-017-2983-5>
- Jiang, Y., Yang, L., Xie, H., Qin, L., Wang, L., Xie, X., Zhou, H., Tan, X., Zhou, J., & Cheng, W. (2023). Metabolomics and transcriptomics strategies to reveal the mechanism of diversity of maize kernel color and quality. *BMC Genomics*, 24, 194. <https://doi.org/10.1186/s12864-023-09272-x>
- Karoui, R., Kemps, B., Bals, B., Béliard, E., & De Baerdemaeker, J. (2013). Prediction of the geographical origin of butters by partial least square discriminant analysis (PLS-DA) applied to infrared spectroscopy (FTIR) data. *Journal of Food Composition and Analysis*, 30(2), 122–128. <https://doi.org/10.1016/j.jfca.2013.02.004>
- Kaur, H., & Gill, B. S. (2021). Changes in physicochemical, nutritional characteristics and ATR–FTIR molecular interactions of cereal grains during germination. *Journal of Food Science and Technology*, 58(6), 2313–2324. <https://doi.org/10.1007/s13197-020-04742-6>
- Khan, A. H., Minhas, N. M., Asad, M. J., Iqbal, A., Ilyas, M., & Mahmood, R. T. (2014). Estimation of protein, carbohydrate, starch and oil contents of indigenous maize (*Zea mays L.*) germplasm. *European Academic Research*, 2(4), 5230–5240.
- Khodabakhshian, R., Tarandakzad, Y., & Khojastehpour, M. (2026). Detection of ground coffee adulteration using FTIR coupled with pattern recognition techniques. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 348, 127077. <https://doi.org/10.1016/j.saa.2025.127077>
- Kumar, P., Choudhary, M., Hossain, F., Singh, N. K., Choudhary, P., Gupta, M., Singh, V., Chikappa, G. K., Kumar, R., Kumar, B., Jat, S. L., & Rakshit, S. (2019). Nutritional quality improvement in maize (*Zea mays*): Progress and challenges. *The Indian Journal of Agricultural Sciences*, 89(6), 895–911. <https://doi.org/10.56093/ijas.v89i6.90756>
- Larkins, B. A., Pedersen, K., Marks, M. D., & Wilson, D. R. (1984). The zein proteins of maize endosperm. *Trends in Biochemical Sciences*, 9(7), 306–308. [https://doi.org/10.1016/0968-0004\(84\)90297-4](https://doi.org/10.1016/0968-0004(84)90297-4)
- Li, K., Wang, H., Hu, X., Ma, F., Wu, Y., Wang, Q., Liu, Z., & Huang, C. (2017). Genetic and quantitative trait locus analysis of cell wall components and forage digestibility in the Zheng58 × HD568 maize RIL population at anthesis stage. *Frontiers in Plant Science*, 8, 1472. <https://doi.org/10.3389/fpls.2017.01472>
- Li, L., & Yang, X. (2018). The essential element manganese, oxidative stress, and

- metabolic diseases: Links and interactions. *Oxidative Medicine and Cellular Longevity*, 2018, 7580707. <https://doi.org/10.1155/2018/7580707>
- Long, L., Kristensen, R. K., Guo, J., Chen, F., Pedas, P. R., Zhang, G., Schjoerring, J. K., & Yuan, L. (2021). Assessing the variation in traits for manganese deficiency tolerance among maize genotypes. *Environmental and Experimental Botany*, 183, 104344. <https://doi.org/10.1016/j.envexpbot.2020.104344>
- Madurapperumage, A., Johnson, N., Thavarajah, P., Tang, L., & Thavarajah, D. (2022). Fourier-transform infrared spectroscopy (FTIR) as a high-throughput phenotyping tool for quantifying protein quality in pulse crops. *The Plant Phenome Journal*, 5, e20047. <https://doi.org/10.1002/ppj2.20047>
- Majamanda, J., Manani, T., & Phiri, S. (2022). Nutrient composition and consumer acceptability of orange maize varieties grown in Malawi. *African Journal of Food, Agriculture, Nutrition and Development*, 22(2), 19676–19691. <https://doi.org/10.18697/ajfand.110.21870>
- Martens, B. M. J., Gerrits, W. J. J., Bruininx, E. M. A. M., & Schols, H. A. (2018). Amylopectin structure and crystallinity explains variation in digestion kinetics of starches across botanic sources in an in vitro pig model. *Journal of Animal Science and Biotechnology*, 9, 91. <https://doi.org/10.1186/s40104-018-0303-8>
- Menkir, A., Palacios-Rojas, N., Alamu, O., Dias Paes, M. C., Dhliwayo, T., Maziya-Dixon, B., Mengesha, W., Ndhlela, T., Oliveira Guimarães, P. E., Pixley, K., & Rocheford, T. (2018). Vitamin A-biofortified maize: Exploiting native genetic variation for nutrient enrichment (Science Brief: Biofortification No. 2). Crop Trust <https://doi.org/10.22004/ag.econ.283983>
- Mohammed, A., Ahmed, M., & Seid, A. (2024). Nutritional and mineral characterization of adapted maize (*Zea mays L.*) varieties in the Somali region of Ethiopia. *Scientific African*, 23, e02058. <https://doi.org/10.1016/j.sciaf.2024.e02058>
- Moustafa, K. (2024). Maize's origin to be revisited. *Plant Signaling & Behavior*, 19(1), 2332017. <https://doi.org/10.1080/15592324.2024.2332017>
- Muzhingi, T., Langyintuo, A. S., Malaba, L. C., & Bänziger, M. (2016). Consumer acceptability of yellow maize products in Zimbabwe. *Food and Nutrition Bulletin*, 27(4), 352–361. <https://doi.org/10.1177/156482650602700407>
- Muzhingi, T., Palacios-Rojas, N., Miranda, A., Cabrera, M. L., Yeum, K.-J., & Tang, G. (2017). Genetic variation of carotenoids, vitamin E and phenolic compounds in provitamin A biofortified maize. *Journal of the Science of Food and Agriculture*, 97(3), 793–801. <https://doi.org/10.1002/jsfa.7798>
- Nkhata, S. G., Ayua, E., Kamau, E. H., & Shingiro, J. B. (2018). Fermentation and germination improve nutritional value of cereals and legumes through

- activation of endogenous enzymes. *Food Science & Nutrition*, 6(8), 2446–2458. <https://doi.org/10.1002/fsn3.846>
- Nuss, E. T., & Tanumihardjo, S. A. (2011). Quality protein maize for Africa: Closing the protein inadequacy gap in vulnerable populations. *Advances in Nutrition*, 2(3), 217–224. <https://doi.org/10.3945/an.110.000182>
- Obadi, M., Qi, Y., & Xu, B. (2023). High-amylose maize starch: Structure, properties, modifications and industrial applications. *Carbohydrate Polymers*, 299, 120185. <https://doi.org/10.1016/j.carbpol.2022.120185>
- Orhun, G. E. (2013). Maize for life. *International Journal of Food Science and Nutrition*
- Ortiz, D., Lawson, T., Jarrett, R., Ring, A., & others. (2021). Biofortified orange corn increases xanthophyll density and yolk pigmentation in egg yolks from laying hens. *Poultry Science*, 100(7), 101117. <https://doi.org/10.1016/j.psj.2021.101117>
- Ozaki, Y. (2021). Infrared spectroscopy—Mid-infrared, near-infrared, and far-infrared/terahertz spectroscopy. *Analytical Sciences*, 37(9), 1193–1212. <https://doi.org/10.2116/analsci.20R008>
- Palacios-Rojas, N., McCulley, L., Kaeppler, M., Titcomb, T. J., Gunaratna, N. S., Lopez-Ridaura, S., & Tanumihardjo, S. A. (2020). Mining maize diversity and improving its nutritional aspects within agro-food systems. *Comprehensive Reviews in Food Science and Food Safety*, 19(4), 1809–1834. <https://doi.org/10.1111/1541-4337.12552>
- Prasanna, B. M., Palacios-Rojas, N., Hossain, F., & Muthusamy, V. (2020). Quality protein maize: Genetics, breeding, and nutritional impact. *Plant Breeding Reviews*, 43, 145–204. <https://doi.org/10.1002/9781119616801.ch4>
- Pravst, I. (2014). Oleic acid and its potential health effects. In L. Whelan (Ed.), *Oleic acid: Production, uses and potential health effects* (pp. 35–54). Nova Science Publishers.
- Protonotariou, S. V., Pappas, C., Tarantilis, P. A., Polissiou, M., Yanniotis, S., Evageliou, V., & Mandala, I. (2013). Determination of fructooligosaccharides (FOS) with FT-IR in cereals. Their impact as substitute sweeteners in starch-based desserts. *Journal of Cereal Science*, 58(3), 415–421
- Purewal, S. S., Kaur, P., Bangar, S. P., Sandhu, K. S., Singh, S. K., & Kaur, M. (Eds.). (2023). *Maize: Nutritional composition, processing, and industrial uses*. Taylor & Francis. <https://doi.org/10.1201/9781003245230>
- Qamar, S., Aslam, M. A., & Javed, M. A. (2016). Determination of proximate chemical composition and detection of inorganic nutrients in maize (*Zea mays* L.). *Materials Today: Proceedings*, 3(2), 715–718.

<https://doi.org/10.1016/j.matpr.2016.01.118>

- Queiroz, V. A. V., Guimarães, P. E. O., Queiroz, L. R., Guedes, E. O., Vasconcelos, V. D. B., Guimarães, L. J., Ribeiro, P. E. A., & Schaffert, R. E. (2011). Iron and zinc availability in maize lines. *Ciência e Tecnologia de Alimentos*, 31(3), 577–583. <https://doi.org/10.1590/S0101-20612011000300005>
- Queiroz, V. A. V., Guimarães, P. E. O., Queiroz, L. R., Guedes, E. O., Vasconcelos, V. B., Guimarães, L. J. M., & Schaffert, R. E. (2011). Iron and zinc availability in maize lines. *Food Science and Technology*, 31(3), 577–583. <https://doi.org/10.1590/S0101-20612011000300005>
- Rahimi Jahangirlou, M., Akbari, G. A., Alahdadi, I., Soufizadeh, S., & Parsons, D. (2021). Grain quality of maize cultivars as a function of planting dates, irrigation and nitrogen stress: A case study from semiarid conditions of Iran. *Agriculture*, 11(1), 11. <https://doi.org/10.3390/agriculture11010011>
- Rohman, A., & Che Man, Y. B. (2010). Fourier transform infrared (FTIR) spectroscopy for analysis of extra virgin olive oil adulterated with palm oil. *Food Research International*, 43(3), 886–892. <https://doi.org/10.1016/j.foodres.2009.12.006>
- Rohman, A., Ghazali, M. A. B., Windarsih, A., Irnawati, Riyanto, S., Yusof, F. M., & Mustafa, S. (2020). Comprehensive review on application of FTIR spectroscopy coupled with chemometrics for authentication analysis of fats and oils in the food products. *Molecules*, 25(22), 5485. <https://doi.org/10.3390/molecules25225485>
- Rossini, M. A., Otegui, M. E., Martínez, E. L., & Maddonni, G. A. (2018). Contribution of the early-established plant hierarchies to maize crop responses to N fertilization. *Field Crops Research*, 216, 141–149. <https://doi.org/10.1016/j.fcr.2017.11.020>
- Saad, S. S., Elmabsout, A. A., Alshukri, A., El-Mani, S., Al Mesmary, E., Alkuwafi, I., Almabrouk, O., & Buhagar, S. A. M. (2021). Approximate composition analysis and nutritive values of different varieties of edible seeds. *Asian Journal of Medical Sciences*, 12(6), 101–108. <https://doi.org/10.3126/ajms.v12i6.33792>
- Salinas-Moreno, Y., Salas-Sánchez, G., Rubio-Hernández, D., & Ramos-Lobato, N. (2005). Characterization of anthocyanin extracts from maize kernels. *Journal of Chromatographic Science*, 43(9), 483–487. <https://doi.org/10.1093/chromsci/43.9.483>
- Santiago-Ramos, D., Figueroa-Cárdenas, J. D. D., Mariscal-Moreno, R. M., Escalante-Aburto, A., Ponce-García, N., & Véles-Medina, J. J. (2018). Physical and chemical changes undergone by pericarp and endosperm during

- corn nixtamalization—A review. *Journal of Cereal Science*, 81, 108–117. <https://doi.org/10.1016/j.jcs.2018.04.003>
- Shah, T. R., Prasad, K., & Kumar, P. (2016). Maize—A potential source of human nutrition and health: A review. *Cogent Food & Agriculture*, 2(1), Article 1166995. <https://doi.org/10.1080/23311932.2016.1166995>
- Sharma, Y., Wadhawan, N., Lakhawat, S., Jain, S. K., & Babel, R. (2022). Analysis of nutritional composition of popular maize varieties. *The Pharma Innovation Journal*, 11(10S), 238–241. <https://www.thepharmajournal.com/archives/2022/vol11issue10S/PartD/S-11-9-318-387.pdf>
- Shashidhar, B. R., Muthusamy, V., Zunjare, R. U., Chhabra, R., Talukder, Z. A., & Hossain, F. (2023). Composition of kernel-amylose and -resistant starch among subtropically adapted maize. *Journal of Food Composition and Analysis*, 119, Article 105236. <https://doi.org/10.1016/j.jfca.2023.105236>
- Sheng, S., Li, T., & Liu, R. H. (2018). Corn phytochemicals and their health benefits. *Food Science and Human Wellness*, 7(3), 185–195. <https://doi.org/10.1016/j.fshw.2018.09.003>
- Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security*, 3(3), 307–327. <https://doi.org/10.1007/s12571-011-0140-5>
- Shobhana, V. G., Senthil, N., Kalpana, K., Abirami, B., Sangeetha, J., Saranya, B., Jana Jeevan, R., Tamilkumar, P., Nagarajan, P., Velu, V., Arumugachamy, S., John Joel, A., Vellaikumar, S., & Raveendran, M. (2013). Comparative studies on the iron and zinc contents estimation using atomic absorption spectrophotometer and grain staining techniques (Prussian blue and DTZ) in maize germplasms. *Journal of Plant Nutrition*, 36(2), 329–342. <https://doi.org/10.1080/01904167.2012.744419>
- Singh, N., Kaur, A., & Shevkani, K. (2014). Maize: Grain structure, composition, milling, and starch characteristics. In D. P. Chaudhary, S. Kumar, & S. Langyan (Eds.), *Maize: Nutrition dynamics and novel uses* (pp. 65–76). Springer India. https://doi.org/10.1007/978-81-322-1623-0_5
- Singh, V., Singh, N., and Kaur, L. (2022). Structure, functional properties and applications of waxy maize starch: A review. *Food Hydrocolloids*, 124, 107349. <https://doi.org/10.1016/j.foodhyd.2021.107349>
- Stats Kenya. (2024, March 17). Maize production in Kenya by county – Agriculture statistics. <https://statskenya.co.ke/public/at-stats-kenya/about/maize-production-in-kenya-by-county-agriculture-statistics/130/>

- Strable, J., & Nelissen, H. (2021). The dynamics of maize leaf development: Patterned to grow while growing a pattern. *Current Opinion in Plant Biology*, 63, 102038. <https://doi.org/10.1016/j.pbi.2021.102038>
- Sui, S., Tong, L., & Liu, R. H. (2018). Corn phytochemicals and their health benefits. *Food Science and Human Wellness*, 7(3), 185–195. <https://doi.org/10.1016/j.fshw.2018.09.003>
- Suri, D. J., & Tanumihardjo, S. A. (2016). Effects of different processing methods on the micronutrient and phytochemical contents of maize: From A to Z. *Comprehensive Reviews in Food Science and Food Safety*, 15(5), 912–926. <https://doi.org/10.1111/1541-4337.12216>
- Taiz, L., Zeiger, E., Møller, I. M., Murphy, A., & Klein, A. S. (2023). *Plant physiology and development* (7th ed.). Oxford University Press.
- Taleon, V., Mugode, L., Cabrera-Soto, L., & Palacios-Rojas, N. (2017). Carotenoid retention in biofortified maize using different post-harvest storage and packaging methods. *Food Chemistry*, 232, 60–66. <https://doi.org/10.1016/j.foodchem.2017.03.158>
- Tanumihardjo, S. A., Ball, A. M., Kaliwile, C., & Pixley, K. V. (2017). The research and implementation continuum of biofortified sweet potato and maize in Africa. *Annals of the New York Academy of Sciences*, 1390(1), 88–103. <https://doi.org/10.1111/nyas.13315>
- Ullah, I., Ali, M., & Farooqi, A. (2010). Chemical and nutritional properties of some maize (*Zea mays L.*) varieties grown in NWFP, Pakistan. *Pakistan Journal of Nutrition*, 9(11), 1113–1117. <https://doi.org/10.3923/pjn.2010.1113.1117>
- United States Department of Agriculture. (2020). Food Data Central: Corn, yellow, raw. U.S. Department of Agriculture. <https://fdc.nal.usda.gov/fdc-app.html#/food-details/168521/nutrients>
- unjare, R. U., Hossain, F., Muthusamy, V., Baveja, A., Chauhan, H. S., Bhat, J. S., Thirunavukkarasu, N., Saha, S., & Gupta, H. S. (2018). Development of biofortified maize hybrids through marker-assisted stacking of β -carotene hydroxylase, lycopene- ϵ -cyclase and opaque2 genes. *Frontiers in Plant Science*, 9, 178. <https://doi.org/10.3389/fpls.2018.00178>
- Valand, R., Tanna, S., Lawson, G., & Bengtström, L. (2020). A review of Fourier Transform Infrared (FTIR) spectroscopy used in food adulteration and authenticity investigations. *Food Additives & Contaminants: Part A*, 37(1), 19–38. <https://doi.org/10.1080/19440049.2019.1675909>
- Wang, J., Chen, L., & Liu, X. (2024). Effects of drying temperatures on the structural, physicochemical, and digestive properties of high-amylose maize

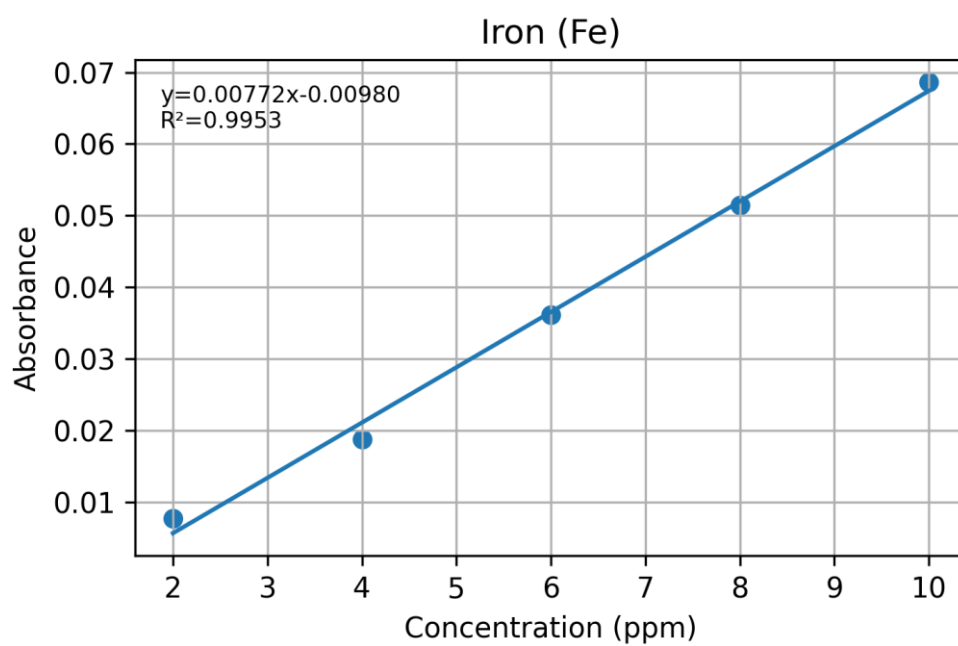
- starch. *International Journal of Biological Macromolecules*, 254, Article 127824. <https://doi.org/10.1016/j.ijbiomac.2023.127824>
- Wang, L., and Johnson, D. (2021). High-throughput quantification of protein and sulfur-containing amino acids in pulses using FTIR. *Crop Science*, 61(4), 2054–2063. <https://doi.org/10.1002/ppj2.20047>
- Warren, F. J., Gidley, M. J., & Flanagan, B. M. (2016). Infrared spectroscopy as a tool to characterise starch ordered structure—A joint FTIR-ATR, NMR, XRD and DSC study. *Carbohydrate Polymers*, 139, 35–42. <https://doi.org/10.1016/j.carbpol.2015.11.066>
- Were, M. A. (2021). A critical analysis of food security and policy in Eastern Africa: The case study of the maize sub-sector in Kenya [Doctoral dissertation, University of Nairobi]. University of Nairobi Institutional Repository.
- Whelan, J., & Fritsche, K. (2013). Linoleic acid. *Advances in Nutrition*, 4(3), 311–312. <https://doi.org/10.3945/an.113.003772>
- Xu, Y., Li, P., Zou, C., Lu, Y., Xie, C., Zhang, X., & Prasanna, B. M. (2022). Enhancing genetic gain for maize protein quality through genomics-assisted breeding. *Theoretical and Applied Genetics*, 135(2), 355–370. <https://doi.org/10.1007/s00122-021-03949-5>
- Yadav, N., Sharma, S., & Shrivastava, S. (2020). Applications of FTIR spectroscopy in various scientific domains: A review. *Materials Today: Proceedings*, 34, 531–538. <https://doi.org/10.1016/j.matpr.2020.03.111>
- Yang, G., Wang, Q., Liu, C., Wang, X., Fan, S., & Huang, W. (2018). Rapid and visual detection of the main chemical compositions in maize seeds based on Raman hyperspectral imaging. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 200, 186–194. <https://doi.org/10.1016/j.saa.2018.04.026>
- Zea, M. A., Pérez, J. C., & López, R. (2021). Nutritional composition of maize kernels and variation among genotypes. *Cereal Chemistry*, 98(4), 645–654. <https://doi.org/10.1002/cche.10456>
- Zhong, Y., Bertoft, E., Mazumder, K., & Blennow, A. (2022). Different genetic strategies to generate high amylose starch mutants by engineering the starch biosynthetic pathways. *Carbohydrate Polymers*, 287, Article 119327. <https://doi.org/10.1016/j.carbpol.2022.119327>
- Zhu, C., Farré, G., Zanga, D., Lloveras, J., Michelena, A., Ferrio, J. P., Voltas, J., Slafer, G. A., Savin, R., Albajes, R., Capell, T., & Christou, P. (2018). High-carotenoid maize: Development of plant biotechnology prototypes for human and animal health and nutrition. *Phytochemistry Reviews*, 17, 195–209. <https://doi.org/10.1007/s11101-017-9506-4>

Zunjare, R. U., Hossain, F., Muthusamy, V., Baveja, A., Chauhan, H. S., Bhat, J. S., Thirunavukkarasu, N., Saha, S., & Gupta, H. S. (2018). Development of biofortified maize hybrids through marker-assisted stacking of β -carotene hydroxylase, lycopene- ϵ -cyclase and opaque2 genes. *Frontiers in Plant Science*, 9, 178. <https://doi.org/10.3389/fpls.2018.00178>

APPENDICES

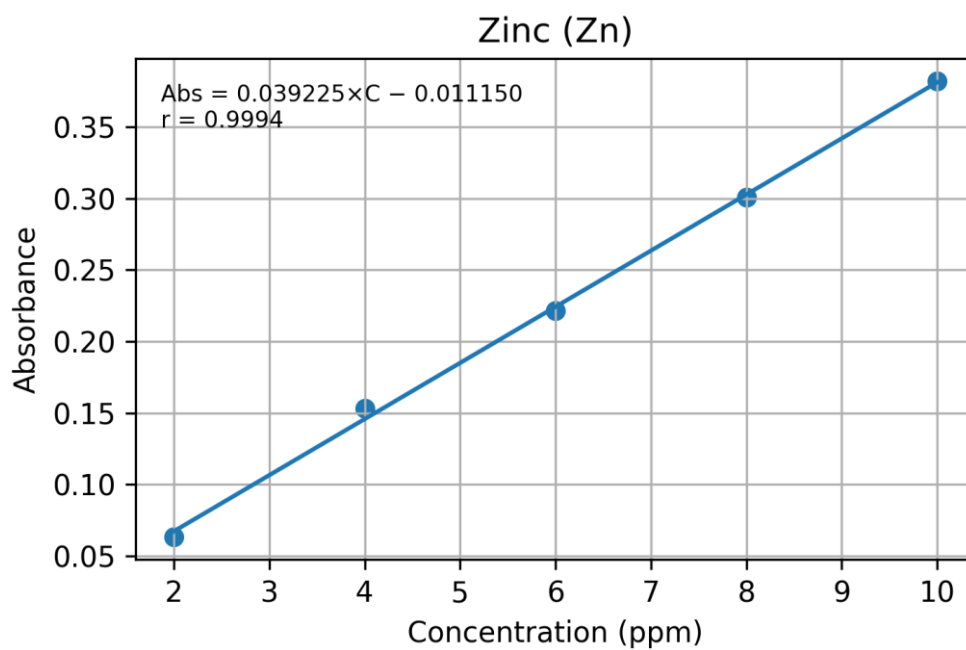
Appendix 1: Calibration Curves and Tables

Iron (Fe)



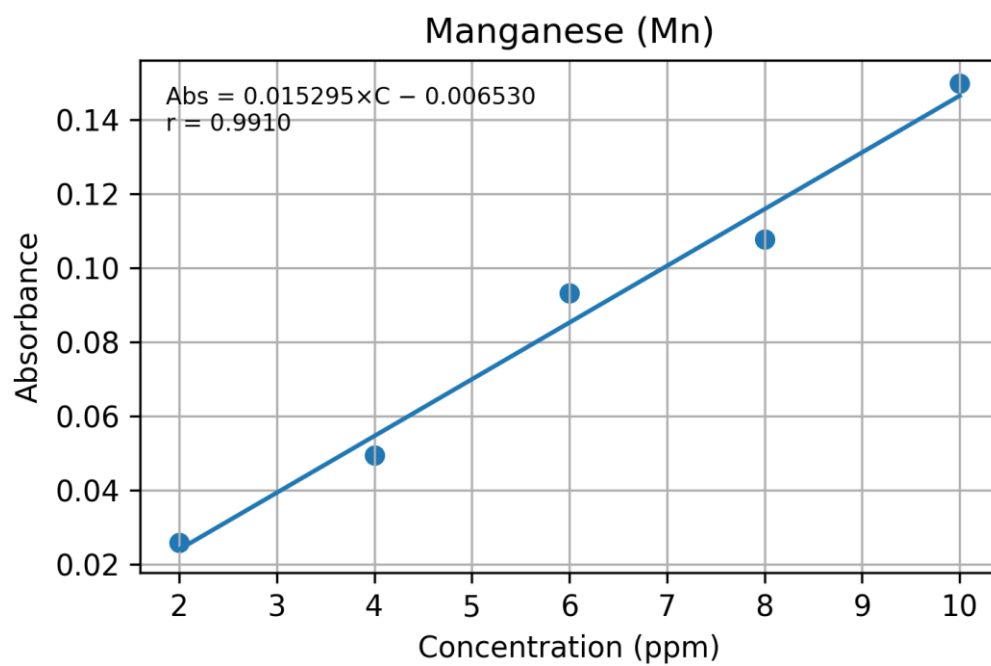
Standard concentration (ppm)	Absorbance
2	0.0077
4	0.0188
6	0.0361
8	0.0514
10	0.0686

Zinc (Zn)



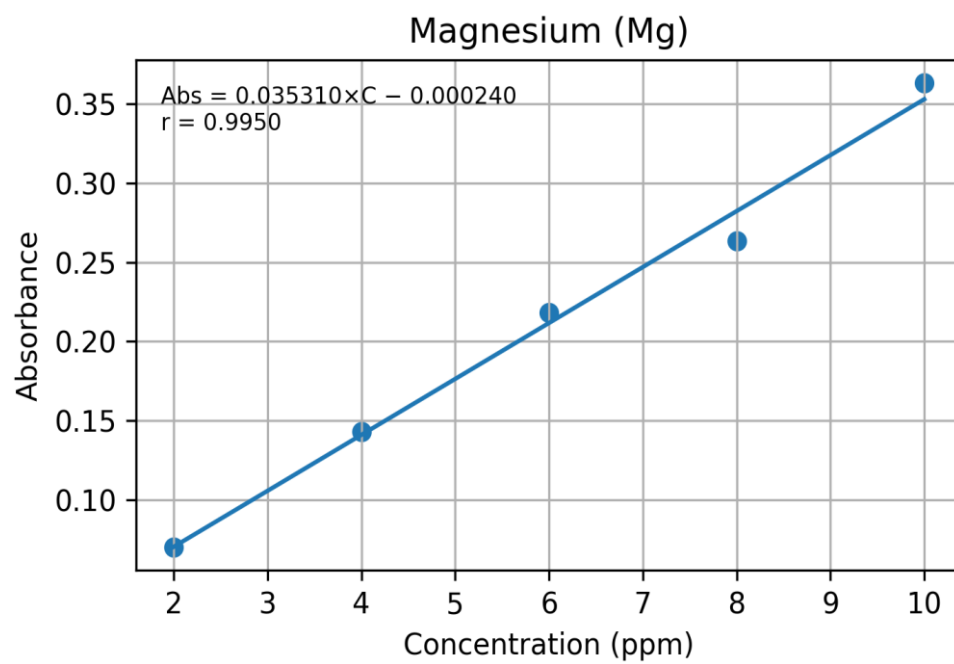
Standard concentration (ppm)	Absorbance
2	0.0635
4	0.1531
6	0.2216
8	0.3010
10	0.3818

Manganese (Mn)



Standard concentration (ppm)	Absorbance
2	0.0259
4	0.0495
6	0.0933
8	0.1078
10	0.1497

Magnesium (Mg)



Standard concentration (ppm)	Absorbance
2	0.0702
4	0.1430
6	0.2183
8	0.2636
10	0.3630

Appendix 2: Research authorization



MURANG'A UNIVERSITY OF TECHNOLOGY

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Murang'a, Kenya

Ref: MUT/ARP/PGS/19/2020 /VOL.1

Date: 12th February, 2025

Mr. Morris Murimi- AS401/5709/2021

School of Pure, Applied and Health Sciences,
Murang'a University of Technology,
P.O. Box 75-10200
Murang'a.

Dear Mr. Murimi,

RE: APPROVAL OF RESEARCH PROPOSAL AND SUPERVISORS.

I am pleased to inform you that the Directorate of Postgraduate Studies on 10th February 2025 considered and approved your Master research proposal entitled ***"Determination of Nutritional profiles of Some Maize(Zea Mays) Varieties grown in Kirinyaga County Kenya."*** and appointed the following as supervisors:

1. Dr. Warren Andayi- Murang'a University of Technology
2. Prof. Eric Chomba Njagi- Murang'a University of Technology

You may now proceed with your data collection subject to obtaining research permit from NACOSTI, if required. You should also begin consulting your supervisors and submit through them quarterly progress reports to the Director Postgraduate Studies through your CoD and School Dean. Progress Reports forms can be accessed in the Student Portal.

It is the policy and regulations of the University that you observe deadlines. The guidelines on Postgraduate supervision can be accessed in the post graduate Handbook.

Your responsibilities as a student will include, among others;

- i. Maintain regular consultation with your supervisor(s), at least once a month
- ii. Submit quarterly reports on time, through your supervisors, CoD, Dean and to the Director of Postgraduate Studies;

- 7
- iii. Ensure quality work all through;
 - iv. Present your research findings at 2-3 seminars/conferences prior to thesis examination.
 - v. Publish one articles from your research findings in a refereed journal prior to thesis examination.

For any further clarification please contact the undersigned.

Yours Sincerely,



Prof. Geoffrey Muchiri, PhD

Director, Postgraduate Studies

GM/MDMK

Copy to:

1. Registrar – Academics and Students Affairs
2. Dean, School of Pure, Applied and Health Sciences

Appendix 3: Publication

This research has produced the following publication:

Murimi, M. M., Andayi, W., & Chomba, E. N. (2025). Rapid Macronutrient Profiling of Maize Varieties Grown in Kirinyaga County, Kenya Using Atr-Ftir Spectroscopy and Chemometric Techniques. *International Journal of Research and Innovation in Applied Science*, 10(8), 1226-1234.