

**INFLUENCE OF DRYING METHODS ON THE NUTRITIONAL COMPOSITION OF  
MORINGA (*Moringa oleifera*) LEAVES**

by

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## DECLARATION

I, Mahlogonolo Neria Raphela, declare that the mini dissertation hereby titled: **THE INFLUENCE OF DRYING METHODS ON THE NUTRITIONAL COMPOSITION OF MORINGA (*Moringa oleifera*) LEAVES** has not previously been submitted by me for a degree at this or any other University; that it is my dedication in planning and executing, and that all material carried in this document had been properly recognized.

.....  
Raphela Mahlogonolo Neria

.....  
2024

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University of Limpopo



Food-Bev SETA

## **DEDICATION**

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## LIST OF ACRONYMS AND ABBREVIATIONS

<b>ANOVA</b>	Analysis of variance
<b>AOAC</b>	Association of Official Analytical Chemists
<b>Ca</b>	Calcium
<b>CP</b>	Crude protein
<b>Cu</b>	Copper
<b>°C</b>	Degree Celsius
<b>Fe</b>	Iron
<b>g</b>	Gram
<b>K</b>	Potassium
<b>kg</b>	Kilogram
<b>LSD</b>	Least significant difference
<b>Mg</b>	Magnesium
<b>mg</b>	Milligram
<b>Mn</b>	Manganese
<b>Na</b>	Sodium
<b>Zn</b>	Zinc

## ABSTRACT

*Moringa (Moringa oleifera)* is a multipurpose tree that has amazing nutritional, healing, and preventative potentials. It has been identified as one of the most assuring species in ameliorating/improving micronutrient malnutrition. However, the fresh *Moringa* leaves tend to lose quality over time due to short shelf-life, approximately 2 to 3 days. Therefore, in this study, different drying methods were investigated to assess the preservation of nutrients. *Moringa* leaves were harvested during the summer season from December 2022 to March 2023 and taken to the University of Limpopo Plant Production laboratory, where the treatments were laid out in a Complete Randomized Design (CRD). *Moringa* leaves were subjected to sun drying (1), shade drying (2), oven drying at 30 °C (3), and oven drying at 60 °C (4) to determine the influence of drying methods in terms of maximum preservation of nutrients. Each treatment had 5 replications of trays for precision and validation of the results. The nutrients of the leaves were determined using standard analytical methods. Data were analysed and interpreted using one-way ANOVA using GenStat (2018). The differences between the treatment means were compared for significance at a 5 % probability level using the Least Significant Difference (LSD) test. The findings from this study revealed a significant difference ( $p < 0.05$ ) among the drying methods in moisture, fat, ash, magnesium (Mg), phosphorous (P), potassium (K), and calcium (Ca). Iron (Fe) at 94.5 mg, ash at 12.17 %, potassium (K) at 1.43 %, and phosphorous (P) at 0.32 % were found statistically superior from samples dried in the oven at 30°C. The study revealed the shortest drying period from the leaves dried in the sun and oven at 60 °C drying method, which took 24 hours for the complete moisture loss. There was no significant difference among the drying methods in the Protein, zinc (Zn), and Sodium (Na) content. The study showed a significant influence of drying methods on the composition of chemicals and nutrients in *Moringa* leaves. Therefore, oven drying method at 30 °C is recommended to enhance the quality of dried *Moringa* leaves to meet standards of food security in terms of nutrient retention.

**Key Words:** Drying methods, *Moringa oleifera*, Nutritional composition, Temperature

# CHAPTER 1

## GENERAL INTRODUCTION

### 1.1 Background of the study

One of the fundamental factors influencing the stability and advancement of enough food availability has been the demand to satisfy nutritional needs through sufficient food sources and appropriate diet choices (Mbah *et al.*, 2012). According to Govender *et al.* (2017), an estimated 47-53 % of South African communities are affected by a lack of balanced diets, manifested as malnutrition, with poverty being the primary cause. This leads to a greater demand for nutritious food that is affordable and widely available to eradicate this poverty (Chakona and Shackleton, 2018). There are many edible and pleasant plant foods, however, extraordinarily little is consumed as part of the daily diet primarily due to their unavailability throughout the year (Mbah *et al.*, 2012). This simply means due to their unavailability; they cannot be consumed into satisfaction. Except for a few communities in the provinces of Limpopo and Mpumalanga, Moringa is one of the less well-known trees in South Africa's environment (Otun, 2015). Hence the tree is still not widely used in other regions of the country. Moringa also known as the miracle tree, is the most cultivated species in the Moringaceae family. This tree can support rural development, increase food security, and improve nutrition (Moyo *et al.*, 2011). However, most South Africans are unaware of the potential health benefits of eating Moringa, an edible tree with numerous medicinal and nutritional uses, as well as one of the most promising crops that could lead to greater consumption of micronutrients. Minerals, fibre, and proteins, among other elements, are abundant in Moringa and can be crucial components of a person's diet. Cooked Moringa leaves are used like spinach. Furthermore, its leaves are frequently dehydrated before being ground into a powder for supplementation and enrichment, particularly in complementary infant meals (Hasizah *et al.*, 2022).

Moringa leaves can be edible all year round, which makes them a valuable addition to a household's nutrient-dense diet. However, research indicated that harvested Moringa leaves' nutritional and physical quality can be significantly and rapidly degraded before being consumed (Hasizah *et al.*, 2022). This is primarily because, at high moisture content, there are high microbial, enzymatic, and physiological activities causing Moringa leaves to be susceptible to rapid deterioration (Babu *et al.*, 2018).

However, improper processing techniques and environments can also eliminate the leaves' nutritional value. One of the reported forms of degradation in Moringa leaves includes colour and nutritional contents (Hasizah *et al.*, 2022). As a result, in order to minimize post-harvest losses and lower the danger of contamination, these extremely perishable leaves need to be processed properly after harvest, increasing the duration of their shelf life (Hasizah *et al.*, 2022). One of the most popular processing techniques for extending the shelf life and preparing Moringa leaves for use as a food and beverage additive is drying (Babu *et al.*, 2018; Satwase *et al.*, 2013). This procedure, which is crucial since Moringa leaves have a high moisture content when harvested, entails using various temperature regimes that may have an impact on the nutritional value of the leaves (Olabode *et al.*, 2015).

Several studies reported various drying methods for Moringa leaves, including traditional methods used in most rural communities of South Africa, including sun drying and shade drying (Calín-Sánchez *et al.*, 2020; Alakali *et al.*, 2015).

## 1.2 Problem Statement

Studies have shown that South Africa, among other developing countries, still has the challenge of shortage of food, because of nutrient deficits and increasing population (Altman *et al.*, 2009; Maseko *et al.*, 2017). Moringa is a versatile shrub that offers a number of benefits, particularly in the domain of human and animal health. As one of the most nutrient-dense crops on earth, it is grown as a main source of food and nutrition in impoverished countries. The entire plant, from seeds to roots, is valuable in addressing various health issues. Its leaves, flowers, and pods are consumed as nutritious vegetables, while others use it as a nutritious feed for livestock, highlighting the plant's comprehensive utility and importance (Osewa *et al.*, 2013). Most communities lack knowledge of the proper food-processing techniques that will assist in fighting food insecurity by increasing the shelf-life of highly nutritious leaves of the Moringa plant (Aremu and Akintola, 2014). This is evidenced by the Owolarafe *et al.* (2021) study, where it was reported that many rural farmers experience substantial post-harvest losses due to exposure of products to contamination. This leads to a need to ensure food security by fighting malnutrition and starvation for the growing population, through availing dry leaves in dry seasons.

The introduction of food-processing methods will increase the shelf life, digestibility, and nutritious value of a less studied but locally known and adapted Moringa as food (Mbah *et al.*, 2012; Aremu and Akintola, 2014). Leaves are the most edible parts of the Moringa plant consumed in diverse ways in rural communities due to their ease of processing and cooking. However, the green, fresh Moringa leaves tend to easily spoil because of their high-water content and are also not always available in *enough* quantities throughout, due to seasonal harvesting (Babu *et al.*, 2018). During storage, the presence of moisture within the green fresh leaves of Moringa evaporates into the air, which leads to bacterial growth in the leaves causing them to wilt and decay (Satwase *et al.*, 2013). Therefore, the high essential moisture quantity in the Moringa leaves needs to be lowered rapidly to an accepted water activity level to avoid the growth of microorganisms and enzyme activity (Babu *et al.*, 2018).

### 1.3 Rationale

Moringa leaves are highly nutritious, and the cheapest edible plant grown by rural farmers to utilize the available nutrients that will supplement those needed, however, they are not easily accessible, especially in the winter season due to a continual increase in microbial growth in fresh leaves (Mashamaite *et al.*, 2021). Processing of dry Moringa leaves contributes to food security and income generation from the agricultural standpoint (Mbah *et al.*, 2012). Drying leaves is one of the oldest known food processing practices for preserving nutrients. It ensures the reduction of water activity to a safe level and improves the storage quality of the dry leaves (Satwase *et al.*, 2013; Yashaswini *et al.*, 2021).

Dry leaves of Moringa have been reported to have a higher shelf-life and more nutritional content than fresh leaves (Olayemi *et al.*, 2011; Yashaswini *et al.*, 2021). This results in the availability of food throughout the year and a reduction of poverty as the dry Moringa leaves can be consumed in various preparations even in the off-season (Olayemi *et al.*, 2011). The plentifully available cheap leaves of Moringa can be used in rural areas in fighting against macronutrient deficits as they serve as a pool house of nutrients (Satwase *et al.*, 2013). **In South African rural areas, sun and shade drying are the common techniques practiced by farmers to preserve leaves for off-season utilization (Aremu and Akintola, 2014).** However, improper preparations and preservations may significantly result in a delayed drying period, and low-quality leaves associated with a loss of nutritive quantity (Yashaswini *et al.*, 2021). One of the goals of drying leaves is to reduce the colour and aroma changes during dehydration (Thamkaew *et al.*, 2021). Some studies have documented the losses of nutrients, colour, and smell from leaves during the dehydration process, hence it is important to study the best drying methods, which will retain nutritional content as well as not support microbial growth during the dehydration process (Foline *et al.*, 2011; Aremu and Akintola, 2014). An appropriate drying method must not affect active nutrients and have the moisture reduced to the determined level achievable (Babu *et al.*, 2018). The shedding of moisture during the dehydration process must make sure that no undesirable chemical reactions take place, and nutrients, colour, and smell are preserved in the dried leaves (Babu *et al.*, 2018), which can be attained by the precise and best drying conditions (Olayemi *et al.*, 2011). Alakali *et al.* (2015) revealed that the best drying method to preserve more nutrients in Moringa leaves in a shorter time

is oven drying at 40°C compared to shade drying which took two weeks. Umar *et al.* (2015) results, however, contradict Alakali *et al.* (2015) where it was revealed that the shade drying method retained more cumulative nutrients than the oven and sun drying methods in Moringa leaves. The use of appropriate drying methods on Moringa leaves will encourage farmers to adopt them as the most adequate food processing methods to retain high nutritional content without supporting microbial growth thereby improving their nutrient uptake and health status, also fighting food insecurity.

## 1.4 PURPOSE OF THE STUDY

### 1.4.1 Aim

To assess the influence of drying methods on the nutritional composition of Moringa leaves.

### 1.4.2 Objective

To determine the influence of drying methods on the nutritional composition of Moringa leaves.

### 1.4.3 Hypothesis

Different drying methods will not influence the nutritional composition of Moringa leaves.

## 1.5 Significance of the study

The significance of this study is to develop a quality Moringa leaf processing method for nutrient preservation and retention, particularly for human consumption. This leafy vegetable is an exceptional resource for developing countries. Processed Moringa leaves is not only a new, promising source of income and employment but also an outstanding, nutritionally rich vegetable for families and businesses.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Overview

In recent years, there has been a growing interest in using natural plant-based products with minimal side effects. Certain foods, known as functional foods, offer health benefits that go beyond basic nutrition (Otun, 2015). Moringa stands out for its exceptional nutritional and medicinal properties, making it a valuable resource with vast potential. Many studies have been conducted on the Moringa tree, and the various applications, background contexts, and health advantages of the plant are documented in this chapter in an effort to demonstrate the plant's potential as a means of reducing poverty and raising awareness of its many advantages.

#### 2.2 Geographical classification of Moringa tree

The highly prized Moringa tree, which is native to Northern India, is widely found in many tropical nations (Omotesho *et al.*, 2013; Stohs and Hartman, 2015). Other names for the Moringa tree include the horseradish tree, drumstick tree, the Ben oil tree, miracle tree, mother's best friend tree, and radish tree. This tree is one of the 13 species of Moringa trees and it's one of the widely known and greatly disseminated, neutralized, and grown species (Ashfaq *et al.*, 2012; Omotesho *et al.*, 2013). The corky bark of the Moringa tree produces coarse fibre that can be used to make paper, ropes, and mats. Additionally, it was stated that stem bark can treat eye conditions. Additionally, stem bark juice has been shown to reduce fever, eliminate tumours, and treat ulcers in addition to preventing spleen enlargement. The wood of the Moringa tree has a density of 0.5 to 0.7 g/cm<sup>3</sup>, making it light and flexible. It is sporadically used for light building and is hardly ever utilized as fuel wood (Omotesho *et al.*, 2013).

The scientific classification of the Moringa plant is summarized in Table 2.1.

Table 2.1: Scientific classification of Moringa tree

Kingdom: Plantae	Plants
Subkingdom Tracheobionta	Vascular plants
Superdivision Spermatophyta	Seed plants
Division Magnoliophyta	Flowering plants
Class Magnoliopsida	Dicotyledons
Subclass	Dilleniidae
Order	Capparales
Family	Moringaceae
Genus	Moringa
Species	<i>M. oleifera</i>
Binomial	Moringa

(Otun, 2015).

### 2.3 Morphology and description of Moringa tree

The Moringa tree is a small, slender, deciduous, perennial tree that reaches a height of roughly 10 m. Its branches and stem have corky bark and are fragile (Omotesho *et al.*, 2013; Dixit *et al.*, 2016). When produced from seedlings, the Moringa tree has a small number of lateral roots and an enlarged, white taproot with a characteristic pungent scent. However, when Moringa trees are planted from seeds, they develop a robust and deep taproot with an extensive network of thick, tuberous lateral roots that spread widely, creating a sturdy root system (Omotesho *et al.*, 2013). This tree consists of green leaves that are very pale and arranged in a tripinnate compound structure. The leaves of Moringa can grow up to 60 cm in length, having small numerous lateral leaflets that are oval-shaped, While the terminal leaves are egg-shaped and moderately larger than the lateral ones. The leaves have finely hairy branches, arranged alternately and spirally, with leaflets measuring 1.3 to 2.0 cm in length and 0.6 to 1.0 cm in width.

The leafstalks of lateral leaflets measure 1.5 to 2.6 mm in length, while the terminal leaflets measure 3 to 6 mm. The lateral leaflets of a Moringa leaf are oval, while the terminal ones are obovate. The leaves of Moringa have a coarsely hairy green colour, hairless on top, pale and hairless below, and have mid-veins that are reddish-tinged and have whole borders. The apex of the leaves is blunt-pointed or rounded, while the base is short-pointed.

The diameter of a Moringa seed is around 1 cm, and it has three pale, papery wings on each angle. Varieties vary in the number of seeds they contain per kilogram, ranging from 3000 to 9000 seeds. Moringa seeds offer versatile uses: they can be eaten fresh like peas, pounded, roasted, or pressed into a sweet, non-drying oil, commonly known as 'Ben oil'. Interestingly, the seed appears dry and hard but can still be pressed into a cake. Moreover, crushed they have shown remarkable anticoagulant properties, making them an effective natural coagulant for water treatment, thanks to their polypeptide content. This feature makes Moringa seeds a valuable resource for purifying water (Omotesho *et al.*, 2013; Dixit *et al.*, 2016).

The Moringa flower is a fragrant, bisexual bloom that grows in clusters, measuring 10-25 cm in length. Each flower has a hairy stem and is nestled in a small cup-shaped base. The petals are yellowish white, veined, and spatula-shaped, with five unequal petals and five stamens, plus smaller sterile stamens. The flower also features a single-celled ovary and a slender style, making up the pistil (Omotesho *et al.*, 2013). The pods of the tree are green and turn brown as they dry, dropping, triangular, and split into three parts in length when dry. They can grow from 30 to 120 cm in length and 1.8 cm in width, becoming narrower at the ends. They are long and slender and grow up to 50 cm in length, with three sides and nine longitudinal ridges. The tender pods are edible and taste like asparagus, making it a nutritious and flavourful vegetable that can be cooked or pickled, they are a valuable addition to a healthy diet (Omotesho *et al.*, 2013; Bopape-Mabapa *et al.*, 2019).

## 2. 4 Cultivation and production of Moringa tree

Moringa tree grows very fast, is drought tolerant and can tolerate marginal conditions of different changes in the seasonal rainfall, soil types having pH of 5.0 to 9.0 (Moyo *et al.*, 2011; Otun, 2015; Dixit *et al.*, 2016). Moringa proficiently grows in regions with average temperatures of 25-30°C and annual precipitation of 250- 1500 mm. These conditions, however, do not limit the growth of this tree because it can survive well in regions with altitudes of 1200-200 m in some tropical areas (Otun, 2015). The cultivation of Moringa can be done both sexually and asexually and has an exceptionally low requirement of nutrients and water, which eases its production and management (Mishra *et al.*, 2012; Dixit *et al.*, 2016).

In direct seeding of the Moringa tree, the seeds must be freshly maintained so there may be a good seedling stand. Wood lizards and mice are the main insects feeding on the Moringa seeds are nutty and are considered mouthful and tasty. Therefore, it is crucial to keep them out of the reach of these scavenging pests. When propagating through the cutting of stems, the recommended length is 10-60 cm for great growth, which can be done in hot seasons (Mishra *et al.*, 2012; Dixit *et al.*, 2016). Moringa is largely grown in regions that are characterized by warm temperatures. The tree can adjust to the cold conditions of winter seasons, however, still will go through a dormant stage at this period. As this tree is greatly known for its ability to grow well in dry soils, it can also grow well in varying soil conditions apart from those that are waterlogged, primarily due to the high chances of the roots decaying in the soil from poor aeration. Good drainage soils are the best conditions for the growth of the Moringa tree (Dixit *et al.*, 2016).

## 2.5 Nutritional Benefits of Moringa leaves for human consumption

Moringa leaves are considered an essential vegetable that contributes natural nutrients in the tropics hence known as the efficient treatment to mitigate malnutrition (Moyo *et al.*, 2011). All parts of the Moringa tree are considered a depot of all essential nutritional elements, having a high composition of protein, vitamin C, calcium, and potassium. When prepared like spinach, new leaves of Moringa are an excellent source of provitamins, vitamins B and C, minerals, and amino acids cystine and methionine (Olabode *et al.*, 2015; Bopape-Mabapa *et al.*, 2019; Aggarwal *et al.*, 2021).

The leaves are also known for their consistent foundation of natural substances that inhibit oxidation such as phenolics, flavonoids, ascorbic acids, and carotenoids (Dixit *et al.*, 2016; Gopalakrishman *et al.*, 2016); hence they are often used to counteract the deterioration of food that contains fat to boost their shelf-life in storage. Several reports indicated that the content of potassium in Moringa leaves is four times greater than in bananas, calcium is fourteen is greater than in milk, vitamin A is two times greater than in carrots, fibre is four times greater than in oats, and iron that is nine times greater than in spinach (Ashfaq *et al.*, 2012; Olabode *et al.*, 2015; Gopalakrishman *et al.*, 2016). Moringa leaves have an incredibly low calorific value, hence they are used in the diet of the obese (Gopalakrishman *et al.*, 2016). The easiness of this tree to be cultivated and grown in marginal areas makes it a natural treatment for the mitigation of malnutrition in marginal areas. There is an exponential rise in demand for nutritional supplements in diets to protect against various diseases such as heart problems, cancer, and sugar diabetes. Hence Moringa leaf powder is used in many dishes of salads, vegetable soups, soft porridges and yoghurts to supplement the essential nutrients required for a healthy diet (Moyo *et al.*, 2011). The role that Moringa leaves to play in the daily intake of a normal diet is to act as a booster that adds more nutrients. In other countries, for instance in India, Moringa is also consumed as a powder mixed in juices and infants' food to add nutrients without a change in the taste of the original food. The Moringa leaves powder is one of the sources of nutrients that is cheap and readily available for consumption even in the off-season, improving the daily consumption of essential nutrients (Moyo *et al.*, 2011; Mishra *et al.*, 2012).

## 2.6 Medicinal properties of Moringa tree

Moringa is also known as a universal cure-remedy, which is key for all difficulties/diseases and can be used to treat more than 300 ailments. Reports have confirmed that Moringa leaves have the ability to shield animals and cells against oxidative DNA damage linked to degenerative illnesses and cancer (Ashfaq *et al.*, 2012). This is due to the availability of biologically active compounds which give a good label for the tree to a great agent of medication. These biologically active compounds are the chemicals which have an impact on the health, flavouring, quality, or appearance of the tree material, except that are not required by humans as important nutrients (Ashfaq *et al.*, 2012). Moringa leaf juice has been found to have a

stabilizing effect on blood pressure. The leaves contain bioactive compounds which have been identified as the key contributors to the blood pressure-lowering effect. These compounds have been isolated and studied, confirming the potential of Moringa leaves to support cardiovascular health (Kumar *et al.*, 2010).

Many Indians and Africans traditionally used Moringa as a herbal medicine. The anti-diabetic properties of Moringa have been scientifically documented to cure diabetes type 1 and 2 (Gobopalakrishnan *et al.*, 2016; Fatoumata *et al.*, 2020). Type 1 Diabetes is a kind that involves a person suffering due to no production of insulin. Insulin is the hormone which sustains the sugar levels in the blood to a normal degree. On the other hand, diabetes type 2 involves a person suffering from the inability of the beta cells to detect the rising sugar levels due to dysfunction, leading to a reduction in signalling the insulin which subsequently causes high blood sugar levels. According to Gobopalakrishnan *et al.* (2016) and Fatoumata *et al.*, (2020), it has been demonstrated that Moringa lowers insulin resistance type 2 diabetes and type 1 diabetes in rats caused by streptozotocin. Further information said that there was an increase in the serum antioxidant enzyme when the rats received 500mg of Moringa seed powder per kilo gram of body weight. This is a definite sign that the antioxidants in Moringa can reduce reactive oxygen species (ROS) produced in the beta cells. Patients who are hyperglycaemic experience beta cell death. According to Gobopalakrishnan *et al.* (2016), these people have a condition where too much glucose circulates in the blood plasma and their blood sugar level is more than 11.1 mmol/L. Because there are fewer antioxidants in beta cells, this results in excessive glucose accessing the mitochondria and releasing reactive oxygen species (ROS), which causes beta cells to apoptosis. As a result, there will be a decrease in the production of insulin, which will lead to hyperglycemia and Type-2 diabetes. The Moringa flavonoids, such as the phenolics, are thought to serve as antioxidants by scavenging reactive oxygen species. According to reports, to protect beta cells and maintain control of hyperglycaemia, the flavonoids in Moringa scavenge the release of reactive oxygen species from mitochondria (Gobopalakrishnan *et al.*, 2016).

One in seven fatalities from cancer, a frequent disease, is attributed to incorrect medicine. This condition is brought on by a variety of circumstances, including smoking, inactivity, and radiation exposure. Although there are various cancer therapies available, including chemotherapy, surgery, and radiation, not everyone can

afford or use them, especially those from impoverished nations. Moringa acts as a natural, trustworthy, and affordable anticancer agent that is safe and accessible at predetermined quantities (Fatoumata *et al.*, 2020). According to Gobapalakrishnan *et al.* (2016) and Ma *et al.* (2020), Moringa can be utilized as an anti-neo-proliferative medication to stop the proliferation of human cancer cells because of its chemopreventive qualities. According to Ma *et al.* (2020), these cells exhibited low cell survival, high apoptosis, and G2/M enrichment after being treated with extracts from Moringa leaves and bark. Treatment also decreased colony formation and cell motility. In a different study, it was discovered that Moringa leaf extract exhibited strong anti-cancer cell proliferation, significant antioxidant activity, and quinone reductase induction (Charoensin, 2014). Abdull *et al.*, (2014) have reported that Moringa pods may have chemopreventive properties. They further mentioned that controlling boiled Moringa in a dose responsive way resulted in a significant decrease in tumor incidence and multiplicity, with the highest dose (6.0 %) showing the most pronounced effect. Additionally, the number of tubular adenocarcinomas was found to be lower in the high-dose group compared to the lower-dose groups, indicating a potential anti-tumor effect.

## 2.7 Economic value of Moringa tree

The renowned mother tree is widely grown throughout the world for commercial and larger-scale reasons. When the Moringa tree is cultivated in homesteads, around cow sheds, on homestead borders, it begins to produce (Omotesho *et al.*, 2013). This further prompted the processing of the tree using a variety of techniques, which had the indirect effect of increasing employment and decreasing poverty. Fresh Moringa leaves are sold and distributed by a variety of small-scale farmers, most of whom are women (Omotesho *et al.*, 2013). These farmers make their living by providing daily supplies to urban neighbourhoods. The Moringa tree has been hailed as a superb local source of highly digestible protein, calcium, iron, and vitamin C for humans, appropriate for use in many underdeveloped nations, including South Africa, where malnutrition is a critical concern (Omotesho *et al.*, 2013; Otun, 2015). As a result, Moringa usage and cultivation have gained popularity in South Africa, and numerous health benefits have been touted. According to Otun (2015), to combat hunger in South Africa's underprivileged neighbourhoods, the government encourages farmers

to grow Moringa trees. It was also mentioned that the tree is now recognized as established plant, which indicates that this plant is becoming more socially acceptable. This is evidenced by the most visible inclusion of Moringa in diets and medication, either in the form of powder for nutrient supplementation or dairy drinks and capsules.

## 2.8 Benefits of Moringa plant

### 2.8.1 Moringa leaf extract (MLE): a natural growth enhancer

In addition to other growth-promoting substances like ascorbates, polyphenols, and minerals like calcium, potassium, and iron, it has been found that Moringa leaves contain an exceptional amount of zeatin, a cytokinin, which makes them a superb crop growth enhancer. Ashfaq *et al.* (2012) indicated that the extract of Moringa leaves is one of the best-used plant growth enhancers. It was further reported that a Moringa leaf extract at 25 g in 100 mL of water showed a considerable influence in the yield of radish and bean yields with 94 % and 64 %, respectively. More studies also revealed that lab experiments successfully showed that Moringa extract has wide beneficial effects on the growth and health of plants. Young plants also showed accelerated growth after the application of Moringa extracts. They showed more resistance to pest damage, heavier roots, and more development of stems and leaves, as well as more production of fruits in size and quantity (Ashfaq *et al.*, 2012). Additionally, it was found that Moringa leaf extract increases the Rhizobium root nodulation, nodule weight, and nitrogenase activity in mung beans (Omotesho *et al.*, 2013). This positively indicates that Moringa extract has the potential to increase yields in the larger fields, leading to the food availability for many developing countries.

### 2.8.2 Moringa as livestock fodder and feed

The leaves and twigs of Moringa are used as feed for cattle, sheep and goats in many parts of the world (Omotesho *et al.*, 2013). Moringa leaves are so nutrient-rich, hence, they are ideal for a livestock weight gain of up to 32 % and an increase in milk production of 43 % to 65 % (Ashfaq *et al.*, 2012). Moringa is also rich in iron, potassium, calcium, and multivitamins. Ashfaq *et al.* (2012) reported that there could be prevention of untold sufferings of protein deficiency in developing countries when Moringa is fed to dairy cows. This is because reports indicated that Moringa foliage intake by dairy cows increases their digestibility, milk production and milk composition,

leading to more availability of milk in the developing regions, thus fighting food insecurity. Nouman *et al.* (2014) reported that the leaves of Moringa have 21.8 % crude protein, 22.8 % of acid detergent fibre 30.8 % neutral detergent agents, also 412 g/kg of crude fat, 211.2 g/kg of carbohydrates, and 44.3 g/kg of ash. These compounds are all essential in increasing the production of livestock. Additionally, the application of Moringa leaves into the low-quality livestock fodders as a supplement can improve the quality of rations of fodders, which in turn increases the intake of dry matter (DM) and the digestibility of the fodder by livestock and increases the intake of protein in the diet of fish. Moringa leaves can be fed to ruminants instead of soybean and rapeseed meals Because of their high protein content, and they can also enhance the microbial protein synthesis in the rumen. (Nouman *et al.*, 2014). Research showed that different mixture combinations with various Moringa parts have different nutritional values. Moringa fodder leaves showed a higher content of crude protein of 27.87 % than Moringa oleifera tree leaves which contained 23.54 % (Nouman *et al.*, 2014). Moreover, Moringa fodder leaves also showed lower NDF and ADF contents, showing the best quality of fodder. That is why the combination of mixtures with different proportions of Moringa parts (leaves, twigs, or branches) consists of different contents of crude protein and NDF. The decision of the farmer to feed which animals can utilize is dependent on the quality of different Moringa combinations, for instance, feed containing lower crude proteins can be easily consumed by dry cows as they need lower nutrient fodders (Nouman *et al.*, 2014).

## 2.9 Moringa leaves preservation methods

Long-term storage of Moringa is possible without nutritional loss. Moringa leaves can be stored in a variety of ways, including drying. One of the earliest ways of food preservation to stop post-harvest loss is still in use today (Ahmed *et al.*, 2013; Babu *et al.*, 2018). To prevent the growth of enzymes and bacteria, food must be dried by passing heated air through it (Olabode *et al.*, 2015; Babu *et al.*, 2018). Fresh produce is sufficiently wet to sustain both enzyme activity and the growth of microbes because it contains up to 95% water (Ahmed *et al.*, 2013; Olabode *et al.*, 2015). Due to their longer shelf life, dehydrated goods are more readily available. Since dehydrated goods have a longer shelf life, they can be found all year long. Even during the off-season, these dehydrated products can be employed in a variety of recipes (Babu *et al.*, 2018).

Lowering the product's water activity or moisture level is the primary goal of drying. To increase shelf life and limit post-harvest decays of the product at room temperature, it is necessary to block the growth of microorganisms and reduce chemical reactions (Ahmed *et al.*, 2013; Caln-Sánchez *et al.*, 2020). Minimal processing is preferred to assure product safety and great quality over an extended shelf-life period because existing processing processes could diminish the levels of certain health-beneficial nutrients or the availability of these substances. The method of drying to be used is determined by the plant material's harvesting window, the plant organ being used, and the active substances that must be kept (Caln-Sánchez *et al.*, 2020). After harvest, food can be processed using a variety of drying techniques that are well-recognized around the world.

### 2.9.1 Room-drying

Room drying is a type of natural drying method that utilizes ultra-violet light and ambient air in a shaded place that is far from sun exposure and where there is enough ventilation (Babu *et al.*, 2018; Nurhaslina *et al.*, 2022). Other common names used for this natural drying process involve room drying, shadow drying, indoor dehydration, and sheltered air drying (Babu *et al.*, 2018). It is typically advised to dry items in the shade in gloomy, low-humidity and heavily polluted locations. It is possible to dehydrate most leaves in the shade to preserve their colour and flavour better. The leaves are spread out on trays or strung in bunches on sturdy thread and dried in the shade. It is recommended to turn the leaves over at least once while wearing sterile gloves to ensure even drying. It should take no longer than 14 days for the leaves to be fully dry. To prevent mould from growing, the loading density shouldn't be more than 1 kg/m<sup>2</sup>. However, room-dried leaves cannot be guaranteed to be mould-free, even with the maximum suggested moisture content of 10% above the level needed to process food after harvest (De Saint Sauveur and Broin, 2010). Some researchers suggest that hanging the leaves in the shade is much better and leads to faster drying than when the leaves are spread in a tray due to when leaves are hanging on a thread, air travels around them more freely than when they are dried on a rack (Babu *et al.*, 2018). In certain places, paper bags with holes punched through them are used to hang leaves to dry in the shade. As large bunches will mould due to inadequate air circulation, it is advised to place a small cluster of leaves inside the bag. A rubber band

holds the top of the bag in place (Babu *et al.*, 2018). Compared to other natural drying processes, shadow drying of leaves takes longer, Nonetheless, the majority of the nutrients can be retained with a discernible change in the mineral, ascorbic acid, and proximate concentrations (Babu *et al.*, 2018).

### 2.9.2 Sun-drying

Sun drying is the most affordable and oldest method of food drying, it is mostly utilized in rural areas and underdeveloped nations to preserve many grains, vegetables, fruits, and other agricultural items (Nurhaslina *et al.*, 2022). Products are laid out on the ground or left hanging in the air to be directly exposed to the sun during the sun-drying process. The main drawbacks of this method of drying include the need for floor space, inability to control temperature changes, product losses, contamination by insects and birds, and foul Odours in the air. The likelihood of spoiling during the drying process is increasing, and the pace of drying is frequently slow (Babu *et al.*, 2018). Days that are hot, dry, and breezy are perfect for sun drying. A minimum need of 30 °C is required; higher temperatures are preferred (Ahmed *et al.*, 2013; Babu *et al.*, 2018). The weather is so variable, and for that reason, the sun drying method could be risky. Furthermore, high humidity is an issue; yet sun drying is optimum when the relative humidity is around 60 % (Ahmed *et al.*, 2013; Babu *et al.*, 2018).

A tray constructed of screens or wooden dowels must be used to spread out agricultural items that are drying in the sun (Ahmed *et al.*, 2013). The greatest screens are made of polycarbonate or stainless steel. Hardware cloth screens should not be used since they are made of zinc-coated galvanized metal cloth. This substance frequently erodes or wears away, leaving harmful residues on the meal. Additionally, materials consisting of copper and aluminium should not be used because copper oxidizes and depletes vitamin C, while aluminium corrodes and discolours (Ahmed *et al.*, 2013). The best materials for sun drying are those made of wood; however, redwood, pine, and green wood should not be utilized because they flavour the items or stain them (Ahmed *et al.*, 2013). For improved dehydration, the trays should be placed on concrete rather than the ground because it may be wet or humid (Ahmed *et al.*, 2013). Ahmed *et al.* (2013) claim that leafy vegetables should not be dried in the direct sun, since they have lower sugar and acid content than fruit goods, which

increases the risk of food deterioration through exposure to oxygen, which causes oxidation reactions that affect food colour, flavour, and nutritional value.

### 2.9.3 Oven-drying

Oven drying is a recent substitute type of conventional drying and has been reported to have enormous potential in dehydrating agricultural products as it dries rapidly is energy efficient, has great utilization of space, and prevents food decomposition (Mali and Butale, 2019). The other advantage of this method is that all the trays get equal heat and therefore the drying is uniform, and it is also considered as the method that dries faster than traditional drying methods (*Babu et al.*, 2018). This is also confirmed by Mali and Butale, (2019), whereby it is reported that microwave or oven drying is quicker than sun drying or employing a food drier. The large volume of heat wave penetration, which heats food both on the surface and within, is what has generated so much interest in this technique. According to *Babu et al.* (2018), this can hasten the drying process and enhance the quality of the finished product. It is frequently utilized in the food sector due to its shortened processing times and lower processing costs, improved product consistency and yields, improved distinctive micro-structure, and defence against crusting and surface browning of food. Temperature, humidity, air velocity and dispersion, air exchange, product shape, characteristics, and thickness all affect how quickly a product dries in an oven (*Nurhaslina et al.*, 2022). The rate at which the drying process proceeds increases with the applied air temperature (Mali and Butale, 2019). Like how air velocity affects the drying rate, air humidity also affects the drying rate. The higher the air velocity, the faster the drying process. In addition to producing a concentrated form of food, drying stops the growth of microorganisms and autolytic enzymes, moreover, after drying, more nutrients are retained (*Nurhaslina et al.*, 2022).

### 2.9.4 Freeze-drying

The low-air environment drying methods include freeze-drying. By lowering the product's temperature, freeze drying is done to make most of the moisture deposit elsewhere in a solid state. By lowering the surrounding pressure below 610 Pa at 0 °C, it is possible to melt ice into vapour (*Babu et al.*, 2018). Freeze-dried high-quality dried items including heat-sensitive components such as vitamins, antibiotics, and

microbial culture. By limiting microbial development and delaying lipid degradation, the technique increases shelf-life longevity (Nurhaslina *et al.*, 2022). The product is prevented from deteriorating due to oxidation or chemical change by the low temperature and absence of air. To maintain the quality of active substances intended for use in pharmaceuticals, freeze-drying is a highly recommended drying technique. However, when compared to other drying procedures, its energy consumption is high (Nurhaslina *et al.*, 2022).

#### 2.10 Effect of drying on microbial activity

Because of the growing population, there is an increasing need for the consumption of wholesome food. Due to their high-water content and association with Gram-negative bacteria, fresh and raw Moringa leaves frequently become infected with microflora during storage. These are what shorten the lifespan of most vegetable leaves since they decay more quickly due to microbial activity fuelled by high wetness. microbial cells are more alive and durable when the products are dried, hence dry heat is less effective than moist heat at inactivating microbial cells (Alp and Bulantekin, 2021). According to reports, the structure of the microbe changes because of dehydration. As the water content is decreased, the alterations include denatured protein and broken cell walls (Nurhaslina *et al.*, 2022). Some food items, commonly referred to as low-acid food with high pH, contain sugar and amino acid components, which delay down the death of bacteria. Low pH levels in acid-rich fruits, combined with other drying techniques, hasten the demise of the microbe. Therefore, the structure of the dried materials can influence the survival and distribution of microbes after drying.

The majority of agricultural products must be dried properly to remove moisture to an acceptable activity value in order to prolong their shelf life and make them easily accessible for off-season use without significantly lowering nutritional content.

Products created from dried leaves with low moisture content have a longer shelf life and require less shipping weight, thereby minimizing transport costs (Alp and Bulantekin, 2021). The required water content from the leaves is removed using a regulated heat treatment method. To preserve leaves and produce concentrated nutrients, a drying process must be improved. It must also use as little energy as possible to be environmentally friendly (Alp and Bulantekin, 2021).

## 2.11 Product quality parameter affected by drying methods

Food drying typically leads to product deterioration from physicochemical and nutritional perspectives in addition to sensory ones. (Calín-Sánchez *et al.*, 2020). The final dried product is likely to degrade in its physical and chemical form when dried using conventional drying methods compared to when using natural methods. This is primarily due to increased temperatures to reduce the drying period and to meet the quantity demand of the product (Calín-Sánchez *et al.*, 2020). As a result, it's critical to choose suitable drying conditions and an acceptable drying procedure for each product in order to minimize potential alterations.

A consumer's initial impression of a product is frequently based on its appearance, hence the retention of natural colour in dried food products is the quality criterion that matters most. Size, shine, form, and other elements all affect appearance, and colour is a key suggestive parameter for quality assurance (Babu *et al.*, 2018; Calin-Sanchez *et al.*, 2020; Nurhaslina *et al.*, 2022). Finding a drying method that will provide a high-quality colour for the finished product is one of the trickiest parts of the process. The leaves contain the green pigment known as the chlorophyll content. The chlorophyll content of leaves during process and storage is likely to decline. Dehydration time and temperature regimes are the primary causes of changes in the colour of the drying products (Babu *et al.*, 2018). Babu *et al.* (2018) further reported that dried leaves, tend to lose colour because of wearing off the highly unsaturated molecules. The green pigment preservation is found to be high in shade drying and least in sun drying.

Low-temperature drying techniques like shade are observed to have superior colour and scent, which increases their overall acceptance among consumers (Nurhaslina *et al.*, 2022). Although drying in the shade takes a long time overall, drying at low temperatures may be favoured because it retains colour and aroma better (Babu *et al.*, 2018). Drying methods such as oven drying, and microwave vacuum drying tend to result in optimum colour changes (Babu *et al.*, 2018). This is because drying leaves in the oven causes the waves to remove moisture on the surface of the leaves and convert it into water vapour, which results in drying without overheating situation. Therefore, it has been discovered that microwave drying effectively preserves product colour in terms of surface colour degradation (Babu *et al.*, 2018). However, this can be maintained at optimum temperatures, as temperature increases there may be

changes in the surface colour of the leaves. The drying temperature has a greater impact on leaf discolouration than the drying method (Nurhaslina *et al.*, 2022).

The green pigment in the leaves is overly sensitive to heat and degrades quickly at elevated temperatures. Browning processes, which can result from both enzymatic and non-enzymatic reactions, are linked to colour changes during drying, this is according to Calin-Sanchez *et al.* (2020), fruits and vegetables experience enzymatic browning because polyphenol oxidase oxidises phenolic substances, which triggers the production of the brown pigments (melanin) known as o-quinones. The changing of colour from green to brown in agricultural products is an increased level of water content in the leaves is slowly reduced or is intermediate. Due to the leaves' low levels of moisture remaining at the end of the drying process, browning is consequently harsh (Calin-Sanchez *et al.*, 2020; Nurhaslina *et al.*, 2022).

## CHAPTER 3

### MATERIALS AND METHODS

#### 3.1 Study site description

Moringa leaves used in this study were collected from the University of Limpopo Syferkuil Experimental Farm located 10km from the main campus in the Limpopo province of South Africa, located at 23°50'37''S, 29°40'55''E. The experimental farm experiences an annual rainfall of 350-500 mm with the average minimum and maximum summer temperature of 19 °C to 28 °C. The soil on the farm is classified as Hutton with a granular soil structure with an effective depth of 90 cm and with good infiltration rate (Phefadu and Kutu, 2016). The irrigation of Moringa trees relies on rainwater during rainy seasons. Fertilizers were not used during the growth of the tree, and weeds were cleared using mechanical methods.

#### 3.2 Treatment and experimental design

Moringa leaf samples were harvested during the summer season of 2022-2023 (December – March) and taken to the University of Limpopo Plant Production laboratory, where the treatments were laid out in a Completely Randomized Design (CRD). Treatments that were utilized on the Moringa leaves were sun drying (1), room drying (2), oven drying at 30 °C (3), and oven drying at 60 °C (4) to determine their influence on the nutritional composition or retention. The two temperatures were investigated to check the influence of different temperature conditions on the nutritional composition of Moringa leaves. Each treatment had 5 replications for precision and validation of the results.

#### 3.3 Research sampling procedure

##### 3.3.1 Leaf harvesting

An established plot of 2.4 m<sup>2</sup> where Moringa trees were planted in 2016 was used for the collection of fresh and healthy leaf samples. The trees were randomly selected in the plot to manually harvest the leaf samples. The leaves were harvested using pairs of shears from a height of 30 cm to 1 m above the ground, at the coolest time when temperature is below 10 of the

day, in the morning as they are overly sensitive to losing moisture after harvesting due to their high susceptibility to spoilage and oxidation. Moringa leaves samples for each drying method were collected on the same day to avoid the storage condition effects. Both young and old leaves were used in this study and are reported to be suitable for making leaf powder. Fresh, green, and undamaged leaves were harvested while the injured or broken, dirty, mouldy, and floppy leaves were separated and removed manually. The small stems of the leaves were removed from the main twigs and the leaves were transferred directly to the lab to be dried in the sun, room, oven at 30 °C and 60 °C .

### 3.3.2 Washing

To prevent contamination, 70% ethanol was used to disinfect the bench area and the sink before the leaves were washed. This stage is essential for getting rid of any pathogens, dust, and microorganisms that could be on the sink or bench's surface. After being harvested, the leaves were cleaned with running tap water to get rid of any undesired particles. When washing the leaves, thin branches of the leaves were cut off to make the leaves easier to handle or pick and to prevent damage to the leaves while being washed.

### 3.3.3 Draining

After washing, the leaves were removed and placed on a paper towel for the removal of excess water. After the complete removal of excess water, the leaves were divided into a sample weighing 350 g per replicate and spread in a tray for the actual drying process according to the treatments. The moisture content for all samples in each treatment was calculated by weight each day until constant weight was reached. To be certain that the Moringa leaves samples were completely dry the moisture content was calculated and recorded by weighing the fresh samples before drying and weighing them during drying everyday until the constant value of weight was reached. The duration of drying was recorded by counting after every 24 hours for each treatment and dried leaves were sent to the lab for the analysis of proximate composition and minerals.

The normal moisture content that can be used to determine that the samples were completely dry was calculated according to the formula below.

$$\%MC = \frac{\text{initial weight of samples (g)} - \text{final weight of samples (g)}}{\text{The intial weight of samples (g)}} * 100 \dots\dots\dots(1)$$

### 3.3.4 Drying procedure

The freshly washed leaves were weighed and divided into portions of 350 g per replicate for each of the four drying methods, sun drying, shade drying, and oven drying at 30 °C and 60 °C which were employed to dry the leaves samples as per the treatment.

a) Sun-drying: The 350 g portion samples of the Moringa leaves were distributed in a tray and enclosed with a netted cloth to keep back dust and pests whilst subjecting it to direct daylight between 10h00 to 15h00 every day until the leaves were completely dry. To avoid the effect of air humidity on the drying leaves, the samples were not placed before the radiation was moderately hot and humidity was reduced, meaning they were positioned when the sun reached moderate temperature, and the humidity level had decreased . The trays were placed at a spot where there was an adequate amount of sunlight without any effect of shade and strong wind that may disturb the heat circulation.

b) Room-drying: The 350 g portion of samples of Moringa leaves were distributed in trays and dried until the leaves were completely dried and have reached a constant weight in a well-aerated room where the natural flow of air and the measured standard room temperature of 23 °C was dominant.

c) Oven-drying 30 °C: The 350 g portion samples of Moringa leaves were distributed in trays and exposed to a constant temperature of 30 °C. The temperature in the oven was maintained at 30 °C until the leaves were completely dried and reached a constant weight.

d) Oven-drying at 60 °C: The 350 g portion of Moringa leaves were distributed in trays and exposed to a constant temperature of 60 °C. The temperature in the oven was maintained at 60 °C until the leaves were completely dried and have reached a constant weight.

### 3.3.5 Grinding.

The dried leaves were ground using an electric grinding machine into a powder for nutritional analysis and packaged into of 60 g of each zip log bags where they were labelled according to treatments and replicates.

## 3.4 Data Collection

### 3.4.1 Proximate and Elemental Analysis

#### a) Moisture Content

Using an automatic halogen moisture analyser (HX204 Mettler Toledo), three grams of each Moringa sample were weighed into an aluminium dish and put inside to determine the moisture content of the samples. The outcomes were recorded in percentage.

#### b) Nitrogen Content

The Automated Dumas dry combustion method using a LECO CNS 2000 (Leco Corporation, Michigan, USA; instrument (Figure 3.1) is the technique used to determine the N. Moringa leaf powder samples were combusted in an induction furnace at 950 to 1050 °C in the presence of oxygen to form water, carbon dioxide (CO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>), various nitrogen oxides (NO<sub>2</sub>), and nitrogen gas (N<sub>2</sub>). Carbon dioxide (CO<sub>2</sub>) and sulphur dioxide (SO<sub>2</sub>) were removed, and oxygen is removed from the NO<sub>2</sub>. Total N<sub>2</sub> was then measured using a thermal conductivity detector (Manson and Robert, 2000; Manson *et al.*, 2020). The nitrogen content of the sample is then multiplied by the protein conversion factor (6.25) by Jones, (1931) to calculate the total crude protein content of the sample.

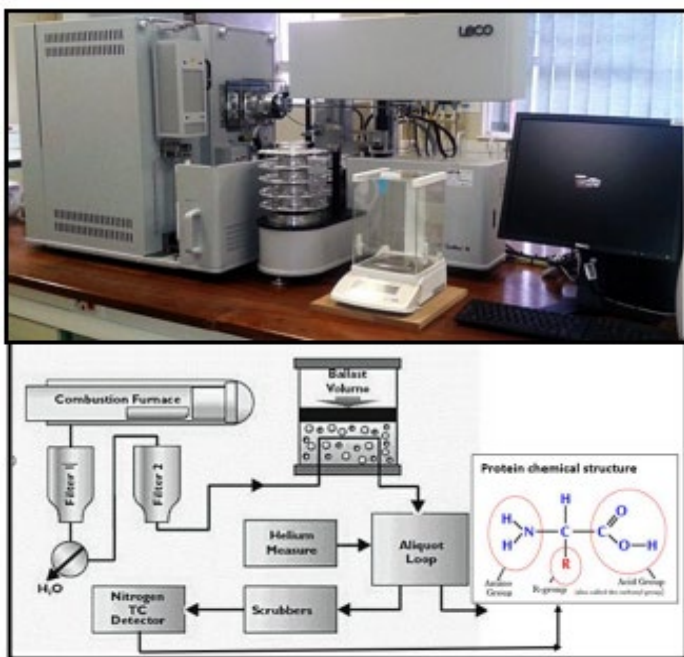


Figure 3.1 Schematic representation of Leco TruMac N combustion nitrogen analyser for the quantification of crude protein (Manson *et al.*, 2020).

c) Ash content

After being cleaned and dried for two hours at 55 °C in a muffle furnace, the crucibles were cooled in a desiccator. Three grams of the Moringa samples were distributed into each crucible, which was then weighed and the ash % was computed. The crucibles were then kept in a muffle oven at 550 °C for the entire night (AOAC, 1990).

$$\text{Ash content} = \frac{\text{Weight of crucible after ashing}}{\text{weight of crucible before ashing}} \times 100 \dots \dots \dots (2)$$

d) Fat content

Gas Chromatography-Mass Spectrometry (GC-MS) is a separating technique utilized for the identification and characterization of organic compounds used in the medical, cosmetic, detergent, coatings, and agrochemical industries (Figure 3.2). The Analytical Services laboratories use this technique for the qualitative determination of essential oils. When heated, a combination breaks up into its constituent elements. The hot gases are sent through an inert gas column (like helium). The separated materials flow into the mass spectrometry (MS) when they exit the column opening. Electron ionization (EI) is used to ionize and fragment analyte molecules before detection (Steegmans *et al.*, 2004).

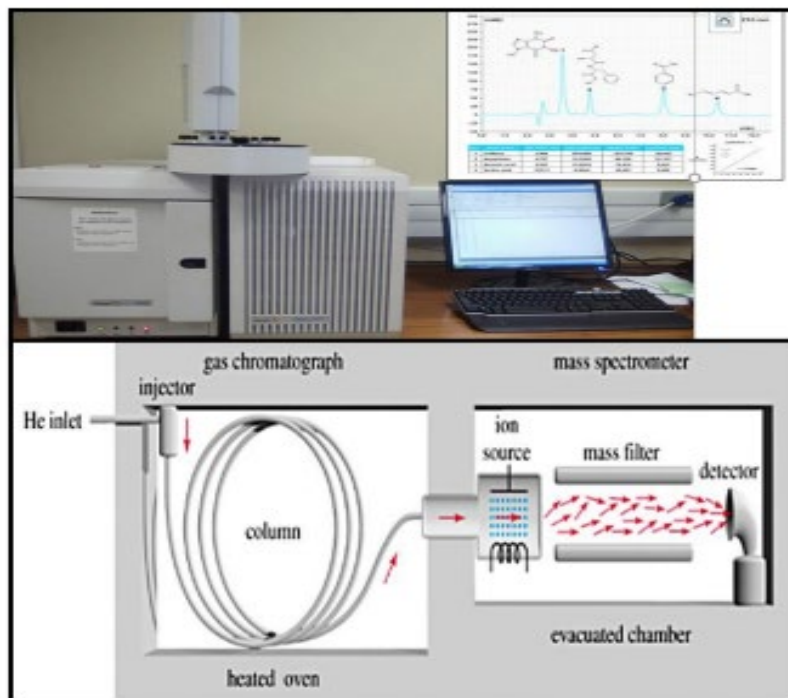


Figure 3.2 Schematic representation of Gas Chromatography-Mass Spectrometry (GC-MS) for qualitative identification of organic compounds (Steegmans *et al.*, 2004).

#### e) Macro- and Micro-Elements Concentrations

The Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) was utilized for the determination of plant elements phosphorus, potassium, calcium, magnesium, sodium, copper, zinc, iron, manganese, and aluminium (Figure 3.3). This method relies on the spontaneous release of photons from excited atoms and ions in an argon gas plasma at a temperature above 5000 °C. Samples are ashed and then extracted or acid digested; analytes of interest are present in a solution form. When the sample is introduced to the plasma energy, the atoms, or component parts, become energized. Emission rays, also known as spectrum rays, are emitted when the excited atoms return to a lower energy level, and the wavelength of the photon is determined by measuring these rays (Silva *et al.*, 2018).

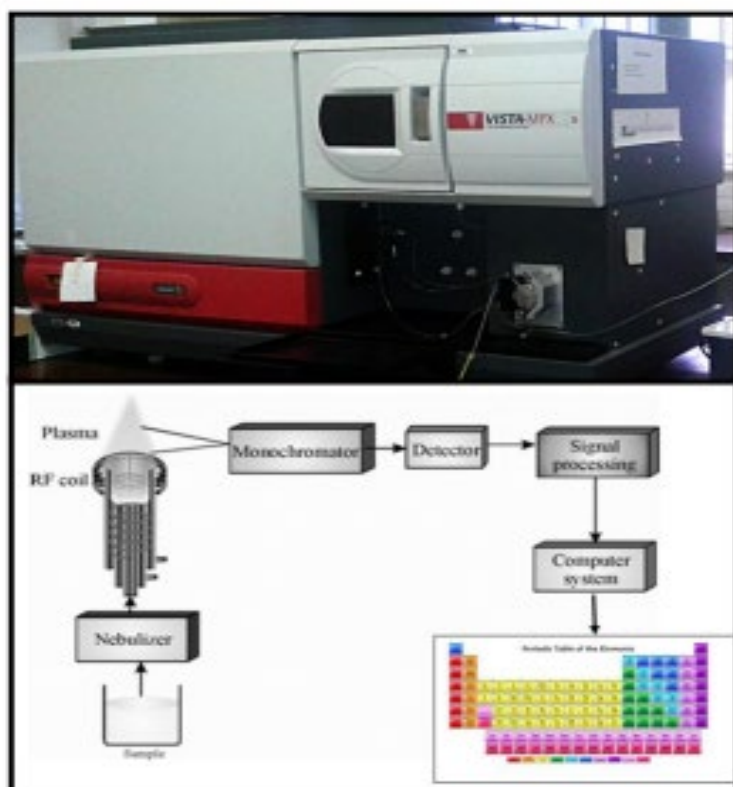


Figure 3.3 Schematic representation of Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) for quantification of macro- and microminerals in agricultural samples (Silva *et al.*, 2018).

### 3.5 Statistical Analysis

Data generated from the proximate was subjected to a one-way analysis of variance (ANOVA) using GenStat (2018). The differences between the treatment means were compared for significance at a 5 % probability level using the Least Significant Difference (LSD).

## CHAPTER 4

### RESULTS

#### 4.1. Effect of sun drying method on moisture loss of Moringa leaves

The difference in moisture loss of leaves as influenced by the sun drying method and their measured daily average temperatures was monitored and demonstrated as drying curves (Figure 4.1). The initial moisture was 100 %, however, within 72 hours (3 days) of drying in the sun, the Moringa leaves had a constant moisture content of 20.95 %. The average daily temperatures within the three-day period which Moringa leaves took to completely dry in the sun were 18.5 °C, 21 °C, and 19 °C, respectively. The observation shows a decreasing trend due to the reduction of moisture content every 24 hours.

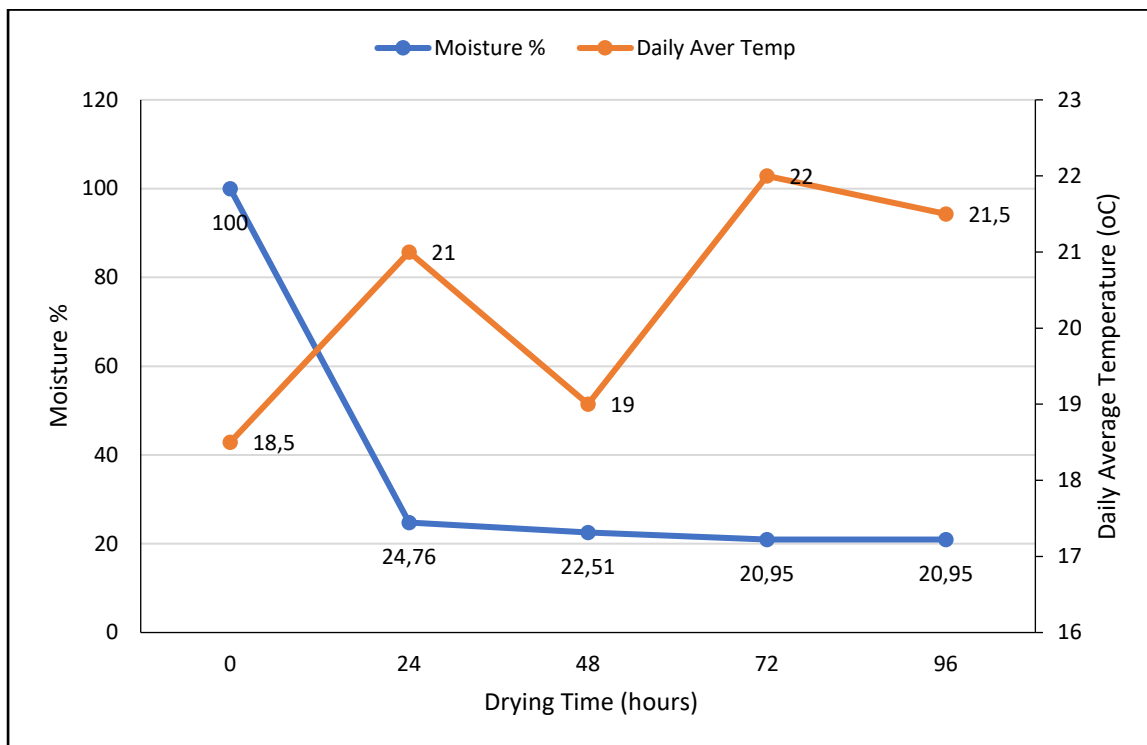


Figure 4.1 Moisture loss in Moringa leaves as influenced by sun drying method

#### 4.2 Effect of room drying method on moisture loss of Moringa leaves

The difference in moisture loss of leaves as influenced by room drying method and their measured daily average temperatures was monitored and demonstrated as drying curves (Figure 4.2). The initial moisture of fresh leaves was 100 %, then it took 144 hours (about 6 days) for the room temperature drying method to reach that constant moisture of 23.99 %. The average daily temperatures within the six days period which Moringa leaves took to completely dry at room temperature were 18.5 °C, 18.5 °C, 21 °C, 19.5 °C, 22 °C, and 21.5 °C, respectively. From the observations, there was a decreasing trend due to reducing moisture content every 24 hours (Figure 4.2).

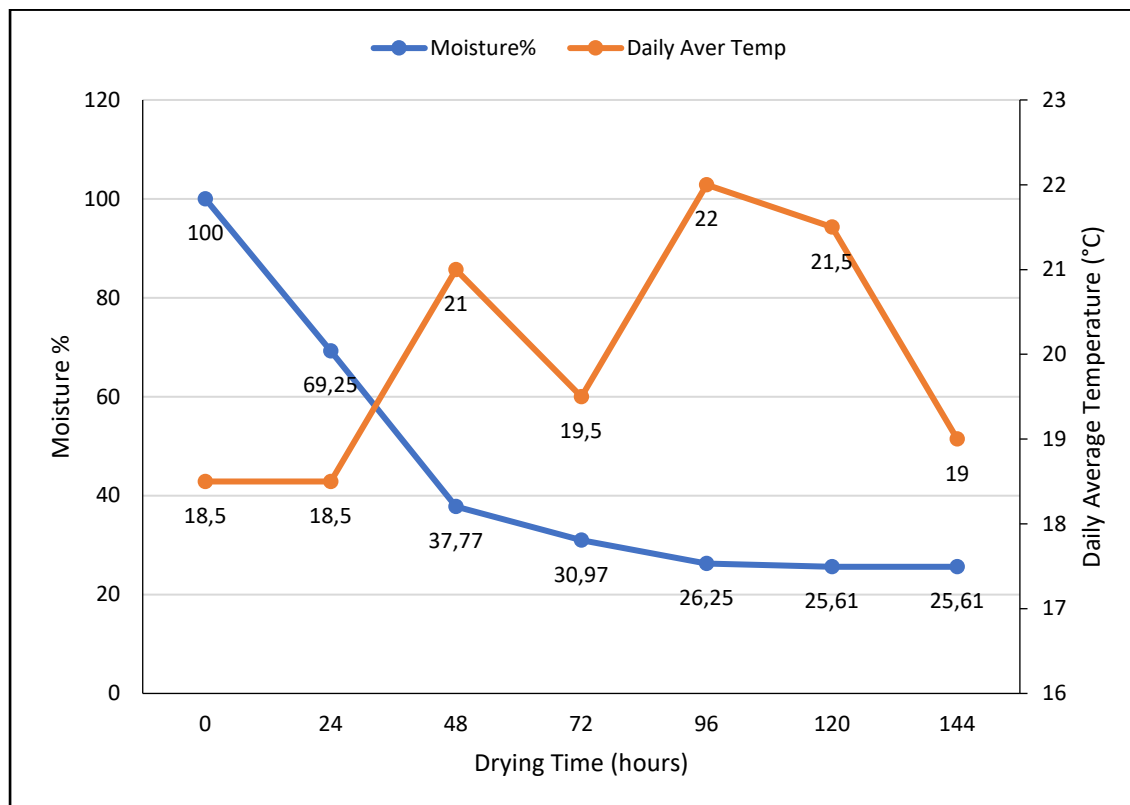


Figure 4.2 Moisture loss in Moringa leaves as influenced by room drying method

#### 4.3 Effect of 30 °C and 60 °C oven drying methods on moisture loss of Moringa leaves

The difference in moisture loss of leaves as influenced by oven drying at 30 °C and 60 °C was monitored and demonstrated as drying curves for Moringa leaves dried in the oven at (Figure 4.3). Because high heat was applied at a high (oven) temperature, more evaporation occurred. As a result, the initial drying rate was remarkably high at all drying temperatures. The rate of moisture loss dropped at both temperatures every

day during the drying process. The initial moisture was 100 % for both drying temperatures, however, within 48 hours (about 2 days) of drying in the oven at 60 °C, the Moringa leaves had a constant moisture content of 21.04 %, while for the leaves dried in the oven at 30 °C, it took 144 hours (about 5 days) to reach a constant moisture of 22.250 % (Figure 4.3).

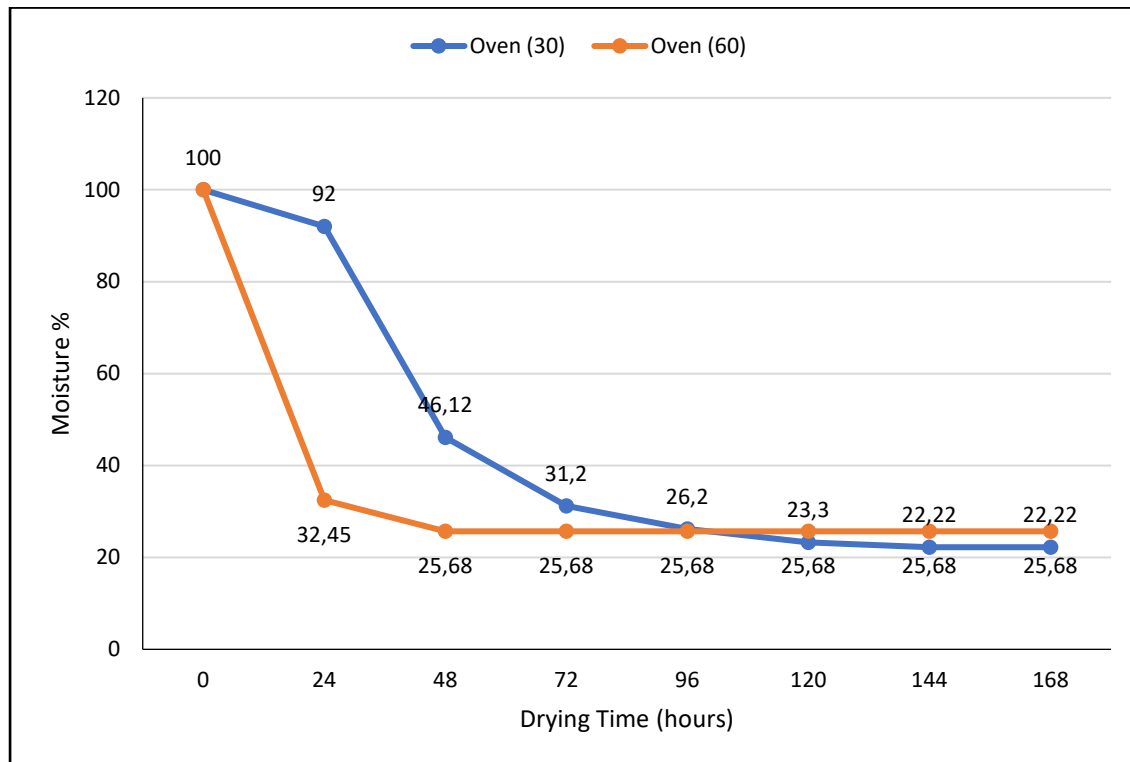


Figure 4.3 Moisture loss in Moringa leaves as influenced by oven at 30 °C and 60 °C drying methods

#### 4.4 Effect of drying methods on moisture content and weight of Moringa leaves

The average initial moisture content was 100 % at an initial weight of 350 g for Moringa leaves in all drying methods, The drying was continued till the constant weight achieved by the leaves and moisture contents were calculated. The moisture contents were reduced to 23.82 %, and 23.01 %, with their average constant weights of 71.68 g and 81.64 g for sun and room drying methods. Similarly, for oven at 30 °C and 60 °C methods, the moisture in Moringa leaves reduced to 22.22 %, and 23.04 % with their weights of 71.77 g and 70.93 g. The moisture removal was found insignificant among all drying methods; this means that moisture percentage by calculations was statistically the same despite different drying conditions. However, the constant

weights were significantly different with the room drying method being superior to other investigated methods as shown in Figure 4.4.

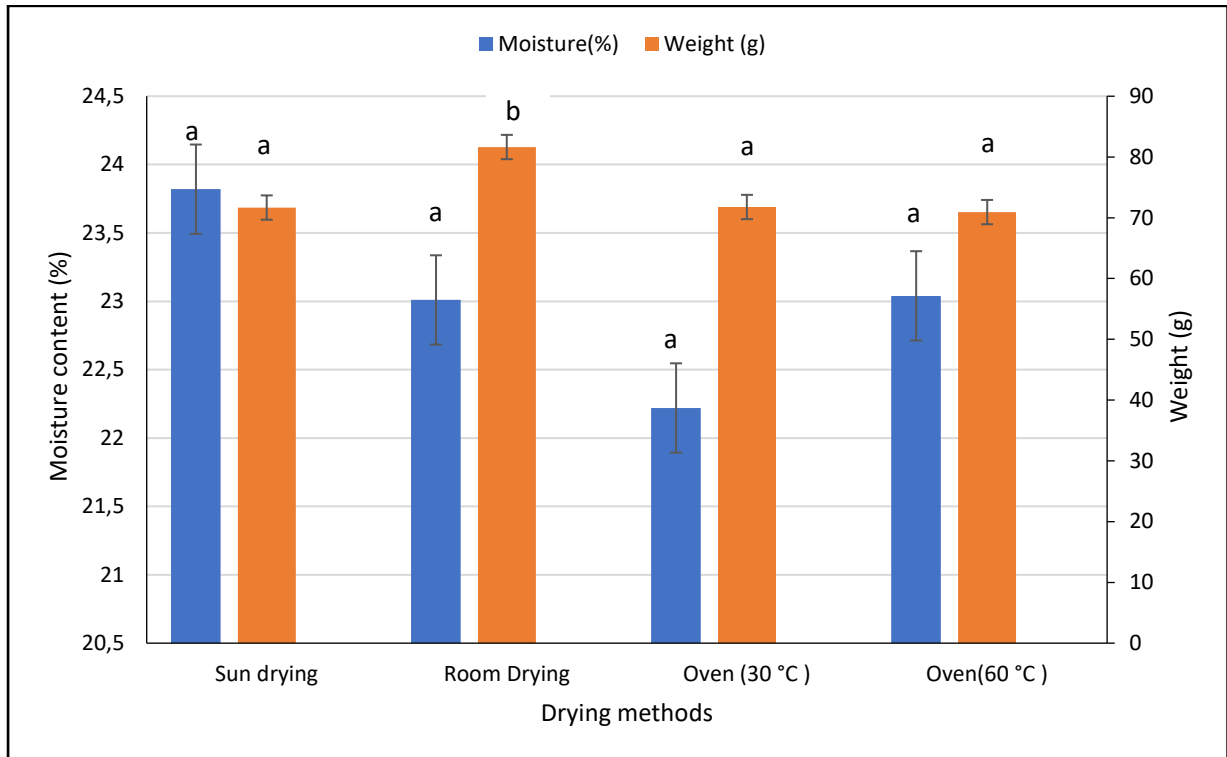


Figure 4.4 Moringa leaves moisture content and weight as influenced by drying methods

Different letters on the bars indicate significantly different ( $p < .05$ ).

#### 4.5 Effect of different drying methods on the chemical composition of Moringa leaves

The four drying methods had a significant difference in the content of moisture, fat, and ash (Table 4.1) in Moringa leaves. The sun drying method accounted for the lowest moisture content 5.876 % while the oven drying method at 60 °C had the highest fat and moisture content 8.10 % and 6.7 %. The oven drying method at 30 °C accounted for the highest ash content at 12.17%, while no significant difference was observed from the protein content by different drying methods (Table 4.1).

Table 4.1 Chemical composition in Moringa leaves as influenced by drying methods

Drying methods	Parameters (%)			
	Protein	Ash	Moisture	Fat
Sun drying	27.17 <sup>a</sup> ± 0.35	9.47 <sup>b</sup> ± 0.47	5.876 <sup>c</sup> ± 0.11	8.666 <sup>a</sup> ± 0.41
Room drying	27.23 <sup>a</sup> ± 0.23	10.30 <sup>b</sup> ± 0.03	6.186 <sup>b</sup> ± 0.06	7.318 <sup>b</sup> ± 0.24
Oven drying (30 °C)	27.57 <sup>a</sup> ± 0.40	12.17 <sup>a</sup> ± 0.39	6.028 <sup>ab</sup> ± 0.11	5.950 <sup>c</sup> ± 0.18
Oven drying (60 °C)	27.37 <sup>a</sup> ± 0.68	10.01 <sup>b</sup> ± 0.29	6.696 <sup>a</sup> ± 0.05	8.098 <sup>a</sup> ± 0.02
<i>p value</i>	0.934	<.001	<.001	<.001
CV%	3.9	7.2	3.2	7.5

*Means in the same row in each column bearing different letters differ significantly ( $p \leq 0.05$ ).*

#### 4.6 Effect of drying methods on the macro-nutrient elements of Moringa leaves

A comparative analysis showed a significant variation between the contents in macronutrients ( $P \leq 0.05$ ), except for Sodium (Na) which was found to be insignificant among drying methods as shown in Figure 4.6. This means that the element remains constant despite different drying conditions. The content of Calcium (Ca) has been 2.05 %, 1.66 %, 1.67 %, and 1.32 % for the oven at 30 °C, 60 °C, room, and sun drying methods, respectively. Amongst these investigated drying methods, the oven at 30 °C was the most abundant in containing Ca content in the Moringa leaves being statistically ( $P \leq 0.05$ ) superior in amount to other drying methods. The concentration of Magnesium (Mg) was found to be statistically superior ( $p \leq 0.05$ ) in the samples dried in the room (0.67 %), followed by 0.62 % from samples dried in the oven at both 30 °C and 60 °C, and lastly 0.53 % from samples dried in the sun. The concentration of potassium (K) significantly differed among drying methods. The concentration was found to be statistically higher ( $p \leq 0.05$ ) in sun drying method (1.47 %) and oven 30 °C (1.43 %), than by oven 60 °C (1.3 %) and room drying (1.3 %). The concentration of Phosphorous (P) was found to be statistically superior in the samples dried in the oven

at 30 °C (0.32 %), followed by sun drying (0.28 %), and least at oven 60 °C and room drying at both (0.26 %).

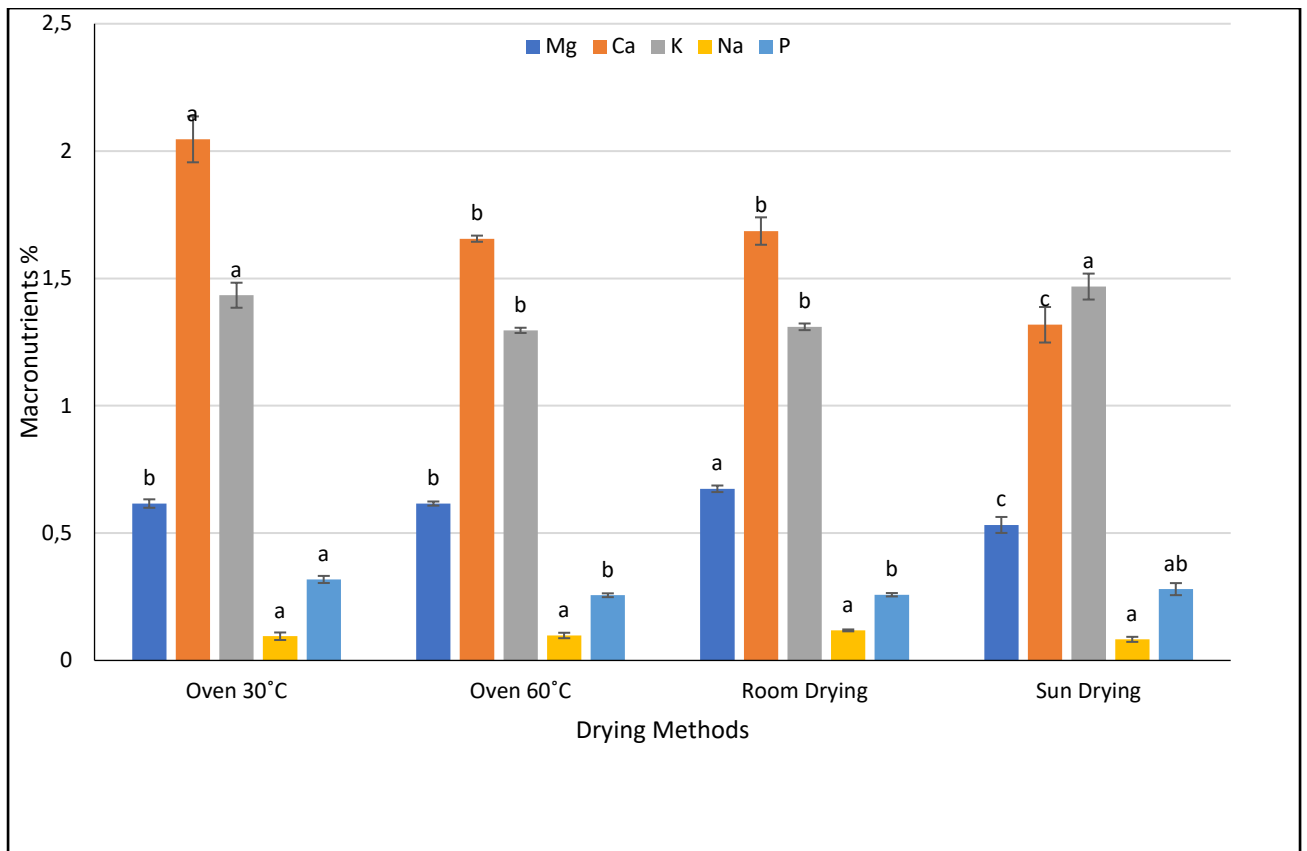


Figure 4.5 Macronutrient elements concentrations (%) in Moringa leaves as influenced by different drying methods

Different letters on the bars indicate significantly different ( $p < .05$ )

*Mg= Magnesium, Ca= Calcium, Na = sodium, K = Potassium, and P = phosphorous*

#### 4.7 Effect of drying methods on the micro-nutrient elements of Moringa leaves

The analysis of micronutrient composition in Moringa leaf powder showed notable concentrations of micro-nutrient elements (Figure 4.5). The results showed high concentrations of Manganese (Mn) at 35.3 mg in samples dried in the oven at 30 °C to be statistically superior ( $P \leq 0.05$ ), followed by oven 60 °C (32.5 mg) and room drying at room temperature (32.4 mg). In comparison, the lowest concentration (24.5 mg) was found in the sample dried in the sun. The analysis also showed a significant amount between the contents of zinc (Zn) which was found to be statistically superior ( $p \leq 0.05$ ) in the samples dried in the sun at 16.04 mg, than oven at 30 °C (11.5 mg), room drying (10 mg), and in the samples dried in the oven at 60 °C (9.5 mg). Iron (Fe) was found to be statistically higher ( $p \leq 0.05$ ) in the samples dried in the oven at 30 °C (94.5 mg), than by sun drying (92.3 mg), room drying (76.5 mg), and lowest in the oven at 60°C (72.5 mg). On the other hand, the Copper (Cu) content in the Moringa powder was found to be insignificantly affected by the drying methods (Figure 4.6). This implies that copper remained stable despite different drying conditions.

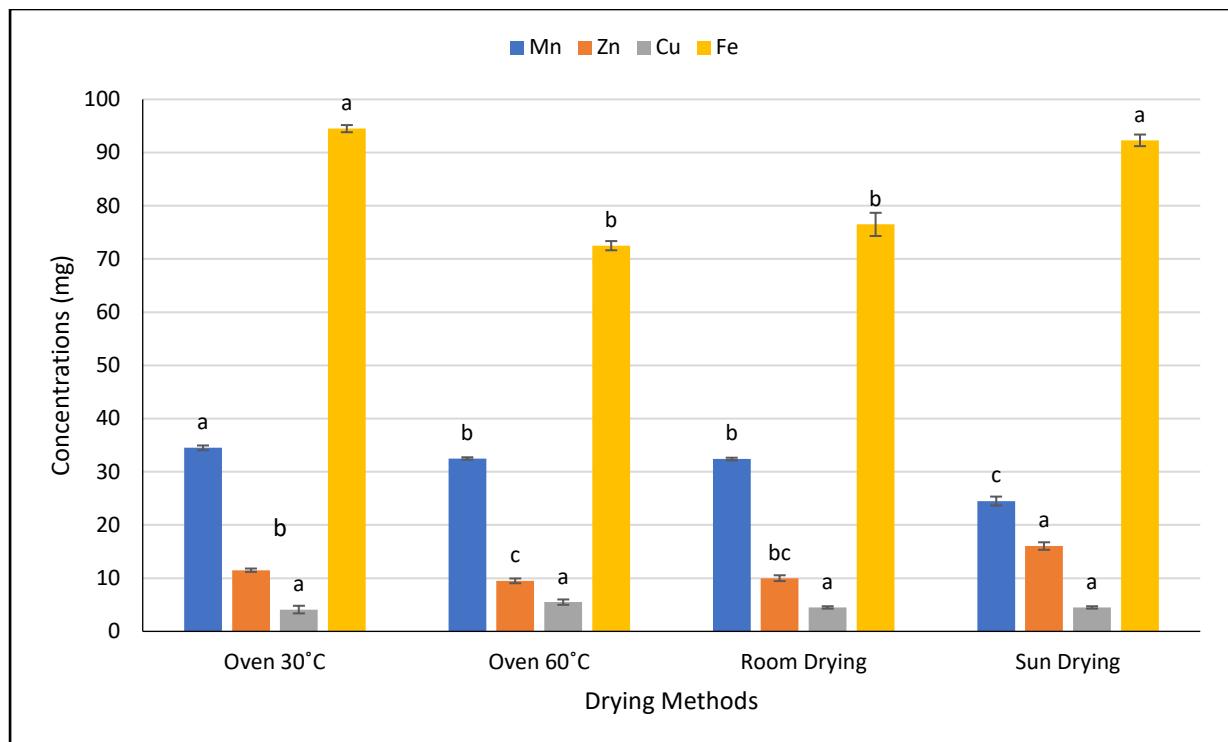


Figure 4.6 Micronutrient elements Concentrations (mg) in Moringa leaves as influenced by different drying methods

Different letters on the bars indicate significantly different ( $p < .05$ )

Mn = Manganese, Zn = Zinc, Cu = Copper, and Fe = Iron

## CHAPTER 5

### DISCUSSION

#### 5.1 Effect of different drying methods on the moisture loss of Moringa leaves

Variations in moisture loss content of the Moringa leaves were recorded with respect to time and the results showed that with the sun drying method, Moringa lost moisture content within 72 hours of drying which is approximately 3 days, while room drying took 144 hours which is 6 days. All drying techniques had a very high moisture loss rate because the heat was applied while the leaves' moisture content was high, which increased evaporation. The drying time for oven 30 °C and oven 60 °C up to the constant moisture reading took 144 hours and 24 hours to completely dry. These results are consistent with the drying experiment of Ramarao *et al.* (2021) where it was reported that the higher the drying temperatures, the more reduced drying times of Moringa leaves. In comparison to earlier research, a declining rate was measured, and steadily declined, and the curves are in good agreement with the study of (Ali *et al.*, 2014). The drying rate curves in Fig 1-3 agree with previous research conducted on Moringa leaves Ali *et al.*, (2014) where an initial increase in the drying rate occurred during the initial stages of drying for all drying methods. With the exception of the early stages, when an acceleration period was noted, drying occurred during the declining rate period. Since the leaf surface is no longer water-saturated during the falling rate stage, diffusion controls the flow of moisture from the leaf's interior to its surface (Ramarao *et al.*, 2021). The rate of moisture loss dropped, primarily due a decrease in the amount of moisture that was moving from the inside of the leaf to the surface (Suliman *et al.*, 2016). Higher temperatures may result in a shorter total drying time because of enhanced heat transfer inside the product, which accelerates moisture migration to the leaf surface (Ramarao *et al.*, 2021).

#### 5.2 Effect of drying methods on the moisture and weight content of Moringa leaves

It is recognized that dried Moringa leaves with high moisture content will have a high weight content. In this study, it was revealed that the room drying method had a significantly high weight content when compared to other drying methods, however,

the moisture content was not found to be significantly different from other drying methods. The result showed that the moisture content in Moringa leaves after the drying process varied with the oven at 30 °C containing the lowest water content of 22.22 % and sun drying containing high moisture of 23.82 %. This might be attributed to that the drying process was not evenly distributed due to the uneven drying temperatures and air circulation, which led to the differences in moisture contents of Moringa leaves after drying with different methods showing. This simply means that the drying methods were not used in not uniform manner where drying time differed according to the dominating temperatures. Aznury *et al.* (2021) found opposite results where drying Moringa leaves in the oven at 60 °C got the lowest moisture content and in the oven at 40 °C found the highest moisture content. The weight differences were found significantly different. The weight differences were found significantly different with Moringa leaves dried in the oven at 30 °C obtaining the highest weight of 81.68 g and the oven at 60 °C obtaining the lowest weight of 70.93 g.

### 5.3 Effect of different drying methods on the chemical composition of Moringa leaves

The chemical composition of Moringa leaves dried by different drying methods was determined in this study. Based on the results, the moisture percentage difference among the drying methods is highly significant, with the moisture content from the sun-dried Moringa leaves being the lowest compared to other investigated drying methods techniques. These findings showed that although the weight of the sun-dried powder is less, it would require massive amounts of it for each dough mixture if it were to be employed as a raw material in food processing. (Olabode *et al.*, 2015). The moisture content of the four dehydrated Moringa leaves ranged between 5.88 % to 6.70 %, which is in close agreement with the data reported by Peñalver *et al.* (2022), who established mean content of water between about 7.33 %. However, the results contradict the findings of Satwase *et al.* (2013) and Mansour *et al.* (2016), who found that shadow drying of Moringa leaves had the highest moisture content of 6.2 % and 6.77 % respectively compared with sun drying and oven drying at 60 °C. The lowest moisture content was found in the samples dried in the sun where the average temperature was 20.7 °C around 3 days. This may be explained by the fact that as drying proceeds, the moisture content decreases, and the concentration of soluble solids causes a proportional increase in the dry matter content. Since spoiling agents

like bacteria and autolysis will be less active at such low moisture levels, sun drying is projected to extend the shelf life of the leaves (Olabode *et al.*, 2015). However, reports mentioned that there may be an increase in the incidence of non-enzymic browning over time during storage according to Derossi *et al.* (2011), depending on the storage conditions and materials. A moisture content of less than 10 % is considered favourable for the quality of dried Moringa leaf powder (Kannangara *et al.*, 2018). The results of this study indicate that all the drying methods utilized were able to reduce Moringa leaves moisture by less than 10 % which is favourable for further processing.

The protein content of the different dried Moringa was found insignificant in all drying methods, this implies that protein remained stable despite the different drying conditions. However, the highest content was from leaves dried in the oven at 30 °C at 27.57 %. These results agree with those reported by Offor *et al.* (2014); and Mansour *et al.* (2016), who found that the protein content of dried Moringa leaves was 24.2 % and 22.90 %, respectively. Peñalver *et al.*, (2022) reported that the normal protein values are between 19.15 % and 28.8 %, this proves that Moringa leaves dried in the oven at 30 °C in this study have the potential to supply enough protein for human consumption.

Concerning the fat content in the Moringa leaves, the content ranged from 5.95 % to 8.66%, with the samples dried in the oven at sun drying containing the highest fat content while those dried in the oven at 60 °C had the lowest fat content. Mba *et al.* (2012) found that the Moringa leaves dried in the oven had the lowest fat of 2.11 %. In general, vegetables have a low-fat content, so from various reports (Mba *et al.* 2012; Olabode *et al.*, 2015) the fat content in Moringa is found to be very low (between 5 % - 6 %), of which physiology might differ across plants in the same family or species as a result of internal factors like age or environmental factors like humidity, nutrition, light, and temperature that affect how a plant's physiological processes grow. Because Moringa leaves have been reported by Peñalver *et al.*, (2022). high percentage of polyunsaturated fatty acids, therefore, it is advised that people include them in their daily diets Plant-based oils contain unsaturated fatty acids, which lower the risk of coronary heart disease and improve heart health. Omega-3 and omega-6 polyunsaturated fatty acids, which are included in Moringa leaves, have been shown to help prevent and treat cardiovascular disease. As a result, they may enhance heart

and bladder health and preserve the health of the circulatory system (Enyiukwu *et al.*, 2018; Peñalver *et al.*, 2022).

Regarding ash contents, the highest content was found in the leaves dried in the oven at 30 °C (12.17 %) and lowest at 60 °C dried samples (10.01 %). This makes the oven drying method at 30 °C exceptionally reliable sources of minerals, which are important for the maintenance of normal health. These findings are consistent with the study of Mansour *et al.* (2016) where it was found that Moringa leaves contained less content ash from leaves dried in the oven at 60 °C (7.83 %) when compared to lower temperatures. According to the study's ash content, Moringa leaves are a dependable supply of inorganic minerals (Peñalver *et al.*, 2022).

#### 5.4 Effect of drying methods on the macro- and micro-nutrient elements of Moringa leaves

According to reports, variations in food's mineral concentration can account for variations in its colour, texture, flavour, and durability. The body requires trace amounts of minerals, although they are vital components of food products. The mineral content of Moringa leaves dried in the room and oven at 30 °C shows the most highest contents compared to the sun-dried, oven at 60°C dried Moringa leaf leaves. This might have been attributed to the hot temperatures prevailing at 60°C and direct heat from the sun which made minerals become destructed. Dewi and Fadhilatunnur, (2020) reported that sun drying and oven drying decrease the mineral content of magnesium (Mg), zinc (Zn), manganese (Mn), and iron (Fe) in edible botanicals because they are destructed by hot temperatures. This agrees with the results obtained in this study. The content of minerals such as Zinc (Zn), and Iron (Fe) reduced significantly at oven 60 °C, while Manganese (Mn) reduced significantly in the sun drying method. However, in the same study, it is contradicted as it was also reported that because minerals are soluble in water, they can be removed but cannot be structured when exposed to heat, light, or oxidation.

Magnesium (Mg) in this study was found to be at 0.674 % from the room drying method and least at 0.532 % from the sun drying method in this study. These results are compatible with Sabi. (2015) reported that macronutrients decrease when dried under heat. Room-dried treatment in magnesium was found to be statistically superior to all other drying methods. These results agree with Babiker *et al.* (2018) study which

found that magnesium content was higher in shade drying and lower in the direct sun drying method. Magnesium plays a role in enhancing insulin sensitivity and generation during the metabolism of carbohydrates, which reduces Type-2 diabetes by 15 % (Weyh *et al.*, 2022). Thus, magnesium supports normal blood pressure and helps to regulate blood sugar levels.

Calcium (Ca) was detected in the samples dried in the oven drying at 30 °C (2.05 %) and least in sun-dried samples (1.32 %). Oven at 30 °C was the most abundant in containing Ca in the Moringa leaves being statistically ( $P \leq 0.05$ ) superior in amount to other drying methods. However, Babiker *et al.* (2016) found opposite results where calcium content was higher in the direct sun drying method and lower in shade drying. According to Afolabi *et al.* (2012), the recommended daily consumption of this nutrient for humans is 1200 mg for females and 1500 mg for males. This suggests that drying Moringa leaves at 30°C in the oven could efficiently meet human needs for calcium. While potassium helps to improve bone density, prevent osteoporosis and osteopenia, and reduce fracture and breaking, calcium plays a role in strengthening bone and tooth structure (Weyh *et al.*, 2022).

The highest concentration of 0.32 % of phosphorus (P) detected in the powder of Moringa dried in the oven at 30 °C was found in this study.

The concentration of Potassium (K) of 1.47 % of this essential macronutrient was detected in this study from the sun drying method, which was statistically superior to other drying methods. One of the seven macronutrients that the human needs, potassium is typically found in meals like leafy vegetables in the amount of 528–650 mg. This shows that Moringa leaves dried in the sun had an adequate amount recommended daily for intake amount of potassium for humans. The vitamin maintains the body's acid-base balance, modulates cardiac electrical activity, and regulates bodily fluids. It also lowers the risk of kidney stones and strokes (Enyiukwu *et al.*, 2018).

Sodium concentration was detected in this study, however, no statistical difference among the drying methods was found. One of the main electrolytes in bodily fluids that is necessary to control blood flow is sodium. Enzyme functions also benefit from it (Organic Facts, 2016). Fresh fruits and vegetables have a high salt content by nature. The recommended daily average is 2000–2300 mg; however, patients with kidney

disease, liver cirrhosis, and congestive heart failure require much less than this amount, as per Enyiukwu *et al.* (2018), because high doses of the mineral cause the kidneys to be unable to excrete the fluid, which builds up in the tissues. Conversely, a diet heavy in sodium may cause osteoporosis because of poor calcium metabolism, heart disease, stroke, and a 50 % increased risk of death over time (Enyiukwu *et al.*, 2018). If all else is equal, the sodium level found in this study might satisfy an average adult's daily sodium needs.

Iron (Fe) was highly detected at 94.5 mg/kg from the samples dried in the oven at 30 °C in this study. Babiker *et al.* (2016) study also revealed that iron is highly detected in shade drying methods. Reports showed that *Moringa oleifera* leaves have lower iron contents when exposed to higher temperatures, indicating that iron is a heat-sensitive element. Hence, in this study, it was detected lower from the oven 60 °C drying method (Yang *et al.* 2006; Babiker *et al.*, 2016). Energy intake and dietary iron consumption are related. In many underdeveloped nations, the daily iron intake is 15–50 mg (Afolabi *et al.*, 2012; Weyh *et al.*, 2022). The oven drying method at 30 °C showed a significant higher amount of iron content than the recommended intake. According to Afolabi *et al.* (2012), iron derived from plants is more bioavailable than iron derived from animal heme sources. Consequently, dried *Moringa* leaves at 30°C in the oven could readily and significantly aid in avoiding or reducing diseases caused by iron deficiency in poor countries.

Findings from this study revealed that zinc (Zn) detected at 16.04 mg shows that *Moringa* leaves dried in sun drying method is significantly superior to other drying methods. These results are consistent with Mba *et al.* (2012) and Emelike *et al.* (2016) whose studies revealed that the sun-drying method was found to be more effective in preserving Zinc content in *Moringa* leaves than other methods. Zinc is required by bodily tissues for normal cell division. Additionally, it inhibits the formation of tumours and stops the mutation of malignant cells (Moyo *et al.*, 2011; Weyh *et al.*, 2022)

The concentration of Copper (Cu) was highly detected at 5.5 mg from samples dried in the oven at 60°C, however, no significant difference was found among the drying methods. Since the body cannot produce copper on its own, enough must come from the diet. According to Afolabi *et al.* (2012) and Weyh *et al.* (2022), eating vegetables has been linked to dietary exposure to heavy metals, like copper (Cu), which poses a

risk to human health. Even at exceptionally low concentrations, heavy metals can be harmful and mutagenic; for copper (Cu), the maximum advised limit is 40 mg (Afolabi *et al.*, 2012). The lowest concentration of copper (4.1 mg) was found in samples dried in the oven at 30 °C, which means the amount is at the safety level. Zn and copper work together to support superoxide dismutase activity and the elimination of oxygen-free radicals. Findings from this study revealed that Manganese (Mn) was detected at 34.5 mg from Moringa leaves dried in the oven at 30 °C drying methods, which was found to be significantly superior to other drying methods.

## CHAPTER 6

### SUMMARY, CONCLUSION AND RECOMMENDATIONS

#### 6.1 Summary

This study was aimed at researching the influence of drying methods mostly utilized by rural farmers to preserve and improve the nutritional quality of Moringa leaves. There was a significant difference between drying methods in assessing the content of moisture, fat, and ash. Results revealed a significant difference ( $p < 0.05$ ) among the drying methods. The results also revealed a significant difference ( $p < 0.05$ ) among the drying methods in macro- and micronutrient elements. The method of oven drying at 30°C showed a higher composition of Fibre, Fat, Iron, Moisture, Magnesium, and Phosphorous than all other drying methods. Therefore, the null hypothesis in this study that says different drying methods has no influence on the nutritional composition of Moringa leaves, is then rejected, as the results have demonstrated that drying of Moringa leaves with different methods has a significant effect on nutrient retention.

#### 6.2 Conclusion

Overall, the study's findings showed that moringa leaves included a diverse range of micro- and macronutrients that are critical for good nutrition and that changed depending on the drying technique used. It revealed that substantial levels of ash, fat, and protein were present in all drying techniques. Furthermore, oven drying at 30 °C it has notable concentrations of various minerals such as calcium, sodium, potassium, phosphorus, iron, magnesium, and zinc. However, there are no significant differences between the four drying treatments on the protein, Copper, and Sodium contents of Moringa leaves. Consequently, from the overall study, it can be said that rapid dehydration of Moringa leaves can be successfully made with sun and oven 60 °C drying methods as they had shorter drying time of 48 and 72 hours. The oven drying method at 30 °C showed a highly significant amount of nutrients that are superior and abundant to other drying methods for most nutrients, followed by shade drying. Of the drying methods analysed, the drying of Moringa leaves is advised to be practised using oven drying at 30 °C due to the highest cumulative nutrient retention. When feed is limited, the method can be utilized to retain nutrients and Moringa leaves as it has also

been demonstrated to aid in nutritional concentration and facilitate conservation and consumption.

### 6.3 Recommendations

Based on the conclusions of this study, it is therefore recommended that Moringa leaves must be dried in the oven at 30 °C for maximum preservation of nutrients due to good and safe moisture content achieved after drying which is fit for long-term preservation and highest cumulative nutrient retention. Additionally, the method has been shown to assist in the concentration of nutrients and facilitate conservation and consumption, as such, it can be used during the time to preserve nutrients and Moringa leaves when feed is scarce. Additionally, it is suggested that Moringa should be consumed in powder form as it is easily stored and protected from moisture retention in storage. Further research must be carried out on the effect of the storage period on the nutritional composition and microbial accumulation, to assess the quality of Moringa powder over certain periods.

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## APPENDICES

### Appendix 1: Analysis of variance (ANOVA) for the content of Moisture % in Moringa leaves to different drying methods

Source of variation	DF	SS	MS	VR.	F pr.
Drying methods	3	1.9036	0.63454	16.04	<.001
Residual	16	0.63304	0.03956		
Total	19	2.5366			

### Appendix 2: Analysis of variance (ANOVA) for the content of Protein % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	0.467	0.156	0.14	0.934
Residual	16	17.721	1.108		
Total	19	18.188			

### Appendix 3: Analysis of variance (ANOVA) for the content of ASH % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	20.5385	6.8462	11.98	<.001
Residual	16	9.1452	0.5716		
Total	19	29.6838			

### Appendix 4: Analysis of variance (ANOVA) for the content of Fat % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	20.7626	6.9209	21.56	<.001
Residual	16	5.1371	0.3211		
Total	19	25.8997			

### Appendix 5: Analysis of variance (ANOVA) for the content of Calcium (Ca) % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	1.32782	0.44261	22.10	<.001
Residual	16	0.32044	0.02003		
Total	19	1.64826			

Appendix 6: Analysis of variance (ANOVA) for the content of Iron (Fe) in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	1838.150	2753.422	267.74	<.001
Residual	16	54.848	3.428		
Total	19	2808.270			

Appendix 7: Analysis of variance (ANOVA) for the content of Magnesium (Mg) % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	0.051255	0.017085	9.16	<.001
Residual	16	0.029840	0.001865		
Total	19	0.081095			

Appendix 8: Analysis of variance (ANOVA) for the content of Potassium (K) % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	0.112900	0.037633	5.70	0.008
Residual	16	0.105720	0.006608		
Total	19	0.218620			

Appendix 9: Analysis of variance (ANOVA) for the content of Sodium (Na) % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	0.0031962	0.0010654	1.91	0.168
Residual	16	0.0089168	0.0005573		
Total	19	0.0121129			

Appendix 10: Analysis of variance (ANOVA) for the content of Phosphorous (P) % in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	0.012440	0.004147	3.88	0.029
Residual	16	0.017080	0.001068		
Total	19	0.029520			

Appendix 11: Analysis of variance (ANOVA) for the content of Manganese (Mn) %  
in Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	353.4215	117.8072	168.18	<.001
Residual	16	11.2080	0.7005		
Total	19	364.6295			

Appendix 12: Analysis of variance (ANOVA) for the content of Copper (Cu) % in  
Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	5.350	1.783	1.66	0.216
Residual	16	17.200	1.075		
Total	19	22.550			

Appendix 13: Analysis of variance (ANOVA) for the content of Zinc (Zn) in Moringa  
leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	150.614	50.205	32.35	<.001
Residual	16	24.832	1.552		
Total	19	175.445			

Appendix 14: Analysis of variance (ANOVA) for the content of Moisture % in  
Moringa leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	6.420	2.140	1.13	0.367
Residual	16	30.359	1.897		
Total	19	36.779			

Appendix 15: Analysis of variance (ANOVA) for the content of weight in Moringa  
leaves to different drying methods

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Drying methods	3	390.674	130.225	106.32	<.001

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Residual	16	19.592	1.225
Total	19	410.267	

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