**International Journal of Pharmacy and Pharmaceutical Research (IJPPR)**

Volume 31, Issue 6, June 2025 **ijppr.humanjournals.com** ISSN: 2349-7203

# Comparative Evaluation of Drying Techniques on Aqueous Extracts of Moringa for Medicinal Use

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Received: 2025-05-10 Revised: 2025-05-28 Accepted: 2025-06-05

**ABSTRACT**

Moringa oleifera Lam (M. oleifera) is a popular tropical and subtropical tree grown for its medicinal and nutritional benefits. This study studied the effects of tray, fluidized bed, and infrared drying on Moringa leaf powder at 40°C, 50°C, 60°C, and 70°C. Fresh leaves had a moisture content of 218.47% dry basis (db.) for the control, 269% for water-blanched, and 290.63% for chemical-blanched samples.

Drying reduced moisture in all methods, but moisture removal was faster at higher temperatures, particularly 60°C. Infrared drying was the most efficient in removing moisture, whereas tray drying varied with temperature. The increase in temperature (50°C-70°C) increased drying speed while decreasing protein, fibre, and iron content by 0.83%, 0.33%, and 0.35%, respectively. Drying at 60°C produced a fibre-rich product at 12.5%, whereas infrared drying at the same temperature produced a mineral-rich powder with a high calcium content of 2.93% and magnesium content of 26%. These findings consequently revealed infrared drying as the most dominant approach for retaining minerals in Moringa leaves.

**Keywords:** moringa leaves, fluidized bed drying, infrared dryer, tray dryer, nutritional composition, mineral content

## 1. INTRODUCTION

### 1.1. Background of Moringa

Moringa Oleifera Lam is the most common planted tree species in the Moringa genus, which belongs to the Moringaceae family. M. oleifera is a highly valued plant that grows in various tropical and subtropical climates across the world. The whole tree is edible and can be eaten by humans. The M. oleifera tree is known by several names, including Horseradish tree, Marango, Kelor, Drumstick tree, and Mlonge. M. oleifera is a highly important tree with various medicinal, industrial, and nutritional uses. `[2]

Moringa oleifera, commonly known as drumstick, is a perennial plant belonging to the Moringaceae family and is indigenous to regions such as India, Pakistan, Bangladesh, and Afghanistan. Its leaves, pods, and seeds are highly valued for their abundance of phytochemicals, making Moringa a powerful resource in combating malnutrition. Nutritionally, Moringa is exceptionally rich, providing nearly sevenfold the vitamin C of oranges, ten times the vitamin A found in carrots, 17 times the calcium of milk, nine times the protein present in yogurt, 15 times the potassium of bananas, and 25 times the iron contained in spinach. The leaves are particularly rich in β-carotene, protein, vitamin C, calcium, and potassium. In addition, they possess natural antioxidants like ascorbic acid, flavonoids, phenolic compounds, and carotenoids, which help extend the shelf life of foods rich in fats.(2)

### 1.2. Medicinal uses of Moringa

Moringa has received global attention due to its therapeutic potential. It is commonly used to treat malnutrition, particularly in poor countries where food insecurity is common. Its high concentration of vital elements, such as amino acids and micronutrients, aids in the treatment of nutritional deficits in vulnerable populations. Moringa's antioxidant qualities, ascribed to components like quercetin and chlorogenic acid, protect cells from oxidative damage, which contributes to aging and chronic diseases such as cardiovascular problems, diabetes, and cancer.

Another important medical benefit of Moringa is its anti-inflammatory properties. These effects are useful for treating arthritis, asthma, and inflammatory bowel illness. The leaves contain isothiocyanates, which are known to reduce inflammation at the molecular level. Furthermore, Moringa has been shown to have antibacterial activity against a variety of bacteria, fungi, and viruses, making it an effective natural cure for infections. Moringa also has hypoglycaemic qualities, which make it useful for diabetic people by helping to manage blood sugar levels. According to studies, taking Moringa extracts on a regular basis can enhance insulin sensitivity and lower blood glucose levels. Furthermore, the plant's lipid-lowering qualities help manage cholesterol levels, lessening the risk of heart disease. Moringa has the potential to help prevent and treat cancer, according to emerging data. Bioactive chemicals, such as niazimicin, have been demonstrated to have anticancer effects by triggering apoptosis and suppressing cancer cell proliferation. According to these findings, Moringa is a good candidate for integrative cancer therapy. Aside from its direct therapeutic benefits, Moringa promotes overall health and well-being. Its detoxifying capabilities aid in the removal of heavy metals and poisons from the body. Furthermore, its capacity to improve liver and renal function emphasizes its importance in overall health management. Moringa's versatility in medicinal applications highlights its importance as a functional food and therapeutic agent.(1)

### 1.3. Importance of Drying Techniques

Drying is crucial for keeping agricultural products as it reduces moisture levels. The drying process removes water from items by transferring mass and heat through evaporation. Drying alters food qualities such as colour, aroma, texture, nutritional content, and physical appearance/shape. While greater drying temperatures might shorten drying time, they can also lead to poor product quality, surface damage, and increased energy use. Mild drying conditions at lower temperatures can increase product quality but reduce drying pace, resulting in an extended drying duration.(2)

The preparation of Moringa-based products for therapeutic purposes involves several steps, one of which is drying. The correct drying of bioactive chemicals is required to guarantee that they are retained in the final product, resulting in an extended shelf life and efficacy. However, the drying procedure utilized may reduce the quality of the extract. For example, drying at high temperatures causes heat-sensitive minerals and phytochemicals to degrade.

In addition, insufficient drying may result in microbiological contamination. As a result, selecting the appropriate drying procedure is critical to preserving Moringa's medicinal properties. With the growing demand for natural treatments and plant-based vitamins, optimizing Moringa drying procedures has been a major research priority.

This study aims to thoroughly investigate how different drying methods affect the quality and therapeutic properties of aqueous Moringa extracts, while also exploring their possible uses in the pharmaceutical and nutraceutical sectors.(3)

Materials that are sensitive to high temperatures are often dried using fluidized bed dryers. These dryers consist of key components such as an air chamber, a control unit, a blower, and a heating element. Air is pushed upward from the base of the chamber by the blower and is then heated. The material to be dried is introduced through the opening at the top of the chamber. The control unit regulates the drying temperature to ensure optimal conditions. Tray dryers are enclosed insulated chambers that hold trays. Trolleys placed on top of one another. Tray dryers are used in industries that require heating and drying, including chemicals, dyes, pharmaceuticals, food goods, and colours.(2)

The purpose of this study was to evaluate the impact of different drying methods—tray, fluidized bed, and infrared at various temperatures (40°C to 70°C) on the moisture removal efficiency and nutritional composition of Moringa oleifera leaves. By comparing the effects of drying conditions on key nutrients such as protein, fibre, iron, calcium, and magnesium, the study aimed to identify the most effective technique for preserving the nutritional quality of Moringa leaf powder, with a focus on optimizing mineral retention.

## 2. LITERATURE REVIEW

### 2.1. Previous Studies on Drying Methods

One disadvantage of air drying is the loss of heat-sensitive nutrients. Moringa has high levels of vitamins, minerals, polyphenols, and other bioactive substances, which contribute to its therapeutic effects. Vitamin C and polyphenols (flavonoids and phenolic acids) are particularly sensitive to heat and air. Vitamin C is a potent antioxidant that degrades significantly during air drying, particularly if the drying process is prolonged. Prolonged drying exposes the vitamin to high temperatures and oxygen, resulting in oxidative destruction and reduced bioavailability of the vitamin. Polyphenols, which are crucial for their antioxidant, anti-inflammatory, and antibacterial activities, can be damaged by air drying. The concentration of polyphenols in Moringa leaves reduces as the temperature rises during drying. The longer it takes to dry, the greater the likelihood of damaging the beneficial chemicals. This indicates that drying the leaves with air at ambient temperatures will result in a significant loss of these essential chemicals. Microbial growth can also be favoured over time at ambient settings if not properly regulated.(2)

Freeze drying, also known as lyophilization, is the process of freezing an aqueous extract at extremely low temperatures (-80°C or below) followed by sublimation, which converts ice straight into vapor under reduced pressure. This technique reduces thermal degradation and oxidation while conserving heat-sensitive bioactive molecules like flavonoids and antioxidants. Freeze drying preserves the structural integrity of these chemicals, making it excellent for preserving Moringa's therapeutic value. However, this process is capital-intensive because it requires specialized vacuum systems and a lot of energy. It is used only in situations where compound stability is crucial, such as pharmaceuticals and high-value nutraceuticals.(4)

Spray drying is a procedure that involves spraying a liquid combination into hot air, causing moisture to evaporate quickly. The method retains delicate chemicals while providing a uniformly distributed powder. However, the inlet temperature and feed rate must be regulated within limits. A high inlet temperature may also degrade some sensitive substances, while an incorrect feed rate results in uneven drying. Proper optimization ensures that the goods are high-quality and stable, with no thermal degradation. (5)

**2.2. Drying Techniques in Herbal Medicine**

Drying is a significant operation in herbal medicine since it not only retains medicinal components but also influences the potency and shelf life of herbs. The type of herbal material, the required level of bioactive ingredient preservation, cost and scale considerations are some of the factors that influence the selection of specific procedures.

Extensive research has been undertaken on the effects of drying on the quality of herbal plants, as well as the factors influencing their yield. The complicated process of drying has hampered progress in optimizing food drying, particularly for medicinal plants and herbs. Standard drying methods like sun, shade, and oven do not account for the potential loss of beneficial chemicals included in these food varieties. Excessive loss of bioactive components can reduce herb quality, lower consumer value, and increase energy expenditure for achieving low quantities of desirable chemicals in dried products. Achieving an ideal drying regime for herbs remains challenging, largely because many variables affect how well key bioactive compounds are preserved. Over time, researchers have tested several approaches including sun drying, shade drying, freeze-drying, and hot-air dehydration. For small-scale laboratory work, hot-air ovens operated at 40 – 60 °C are still the go-to method. While this technique is common for herbs, vegetables, and fruits, it suffers from slow throughput and inefficient heat transfer, a consequence of the low thermal conductivity of plant tissue. To address these shortcomings, newer technologies such as microwave, solar-assisted, and infrared drying have been developed.

**Sun drying**

This conventional method of sun drying herbs and spices is still prevalent, particularly in regions with tropical and subtropical climates. Its popularity stems from the low cost and minimal equipment required. In this method, fresh plant materials are usually spread out on drying racks and exposed directly to sunlight. However, this approach is not suitable for all plant types, as it can negatively affect qualities like colour and aroma. Additionally, external factors such as dust, unpredictable weather conditions, and insect activity can compromise the quality of the dried product.

**Shade drying**

This method uses ambient solar energy while keeping the plant material in shaded conditions to preserve sensitive compounds. This approach requires low humidity and ventilation in the drying space because the herbs are dried by the surrounding warm air. It benefits light-sensitive materials and reduces chemical oxidation in plant essential oils. However, compared to sun drying, this approach requires a significantly longer drying duration.

**Convection drying**

Hot air drying, often known as oven drying, is a commonly utilized method in the manufacturing business due to the time-consuming nature of sun and shade drying. This process uses convection to transfer heat. This drying process is often employed in nontropical regions when sun and shade drying are inefficient. In contrast to older methods, this technique provides the ability to finely adjust key drying parameters such as heat, air circulation, and duration. Effort to improve the drying process have resulted in higher-quality dried herbs and plants. Moringa leaves are best dried at 50°C to preserve bioactive components and colour.

International Journal of Pharmacy and Pharmaceutical Research (IJPPR)
Volume 31, Issue 6, June 2025 ijppr.humanjournals.com ISSN: 2349-7203

**Microwave Drying**

Alongside hot air drying, microwave drying has become a widely adopted technique in industrial processing. This method rapidly removes moisture from plant materials, significantly reducing overall drying time. Consequently, products dried using microwaves often exhibit less shrinkage and better colour retention. Key factors such as microwave power and exposure time play a crucial role in determining product quality. In a study by Sarimeseli, increasing the microwave power from 180 W to 900 W (W=Watt) led to a noticeable decrease in drying time and rehydration capacity of coriander leaves, while also enhancing the effective moisture diffusivity.

**Vacuum Drying**

Vacuum drying is a cutting-edge drying technology that stands out from traditional methods like sun and shadow drying. This method of drying has been investigated for over 20 years; thus, it is not new. This drying procedure is ideal for thermally sensitive materials because to its absence of heat. Vacuum is commonly utilized in pharmaceutical and chemical industries because to its ability to maintain sub-atmospheric pressure. Microwave drying's benefits have led to innovative integration with other drying methods. The most typical method involves mixing vacuum and microwave drying. Using irradiation to deliver heat to materials and create a vacuum environment to remove moisture results in shorter drying times compared to traditional convective and microwave approaches.

**Freeze drying**

Freeze-drying or lyophilization is a drying procedure that differs from other methods previously covered. This approach utilizes cold temperatures and low pressure to induce sublimation, effectively removing moisture from the material. This drying procedure preserves volatile compounds in a solid state, making it ideal for plant drying Freeze-drying is more effective in retaining aromatic components in herbs than other drying processes, according to multiple studies.

**Solar drying**

Solar-assisted drying is a new technology that improves on previous methods. Solar energy, a sustainable and free energy source, has received attention among researchers as a potential solution to the challenges of sun-drying plants and herbs while improving efficiency. Solar drying methods can be classified into three categories: direct sun drying, indirect solar drying, and hybrid systems that combine both. In recent years, several solar-assisted drying technologies have been introduced, such as forced convection solar tunnel dryers, solar-assisted fluidized bed dryers, solar collector-based dryers, and forced convection greenhouse solar dryers.

**Infrared drying.**

Infrared drying is a relatively new technology used to dry plants and herbs, with research into its creation dating back 15 years. Infrared technology uses infrared wavelength radiation to generate heat through molecular vibration changes in materials.

This drying method stands out from others because to its rapid heating and drying rate, adaptability, simplicity, and energy efficiency.

**Heat Pump Drying**

As an emerging technology, heat pump-assisted drying enhances energy efficiency and performance over traditional hot air drying. It can dehumidify the outgoing air while operating under flexible temperature and airspeed conditions.

**Fluidized drying.**

Fluidized bed drying involves passing high-velocity hot air across a bed to heat the materials and speed up the drying process compared to traditional convective drying methods. Widely used in food processing, this method offers strong heat transfer, good gas-solid contact, and steady airflow. Yet, for herbs, the combination of high moisture and large surface area can restrict airflow through the material, potentially affecting drying performance. (6)

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**Table 1.Advantages and Disadvantages of Various Drying Methods.(6)**

| Drying method | Advantages | Disadvantages |
|---|---|---|
| **Sun Drying** | Low cost easy to use equipment | More drying time decline in bioactive ingredients. |
| **Shade Drying** | Good for light-sensitive compounds, less damage | Slow drying, loss of aroma, oxidation risk |
| **Convection Drying** | Precise control, faster drying | Loss of aroma, high energy use, needs optimization |
| **Freeze Drying** | Retains bioactive compounds, aroma, fast drying | Expensive, potential loss of aroma |
| **Microwave Drying** | Quick, preserves bioactive compounds, less shrinkage | High power damages volatile compounds, uneven heating |
| **Vacuum Drying** | Good for heat-sensitive compounds, quick drying | Expensive, depends on pump capacity |
| **Solar-Assisted** | Good than sun drying | selective research on its effectiveness |
| **Infrared Drying** | Quick heat transfer, preserves bioactive compounds | Limited research, uneven heating for thick materials |
| **Fluidized Bed Drying** | Reduces moisture well compared to conventional methods | Can be too harsh for small herbs |
| **Heat-Pump Drying** | Effective moisture reduction at all air velocities | High temperatures may damage volatile compounds |

## 3. Materials and Methods

### 3.1. Procurement of Moringa Specimens

**Harvesting:** Moringa leaves are collected in the morning for optimal freshness and moisture content. It can employ both young and aged leaves. To ensure maximum freshness, treat the leaves as soon as possible after harvesting.(7)

**Washing:** Rinse leaves under running water to remove dirt. Soak them in saltwater (1% saline) for 5 minutes to kill germs. Rinse with 70% alcohol, then wash twice with clean water.

Allow the leaves to dry quickly in sunshine to remove surface wetness.

**Drying:** Shade drying is essential for maintaining the nutrients in Moringa leaves, particularly vitamin A. This is accomplished by laying the leaflets on a clean, sterile net in an airtight, dust-free, insect-proof chamber. Mosquito nets, for example, can keep the leaves at a safe distance from the ground. Proper ventilation should be achieved via ceiling or floor vents, as well as a fan. However, avoid blowing air directly onto the leaves, as this can exacerbate contamination. The leaves should be entirely dry in three to four days. Workers must maintain strict personal sanitation and hygiene throughout the operation to avoid contamination.(8)

**Figure 1. Moringa dry leaves(7)**

**Grinding:** Moringa leaves can be crushed in small batches using a mortar and pestle. A pulveriser or grinding machine is more suitable for large-scale activities. Following grinding, run the powder through a filter with a pore size of 0.5-1.0 mm. This guarantees that the tiny powder is free of bigger particles, leaving it smooth and consistent.

**Final Drying**: Moringa leaf powder should be dried fully at 50°C for 30 minutes to ensure that there is little moisture left.

**Storage**: Store the powder in clean, sealed containers that are not exposed to light or moisture and store them in a cool area (below 24°C). When stored carefully, this powder can last for up to 6 months.

This approach maximizes nutrient retention and produces high-quality Moringa leaf powder.(7)

**3.2. Preparation of Aqueous Extracts**

To create the aqueous extract, mix 3g Moringa oleifera leaf powder with 30mL distilled water. To make the aqueous methanol extract, combine 3g Moringa oleifera leaf powder with 15ml of distilled water and 15ml of methanol. To make the acetone extract, combine 3g of Moringa oleifera leaf powder with 30ml of acetone. To make the chloroform extract, add 3g of moringa powder to 30 ml of chloroform. The extracts were left to incubate overnight before being filtered into conical flasks using Whatman No 1 filter paper. The filtrates were concentrated by immersing the flasks in a water bath at $100^{°C}$. The filtrate was then cooled to room temperature. Qualitative tests were conducted on the cold filtered extracts (solution). (9)

**Drying Techniques Used**

Tray drying

Infrared drying

Fluidized bed Drying

Moringa leaves were dried using tray and infrared methods at different temperatures (50, 60, and 70°C) to achieve optimal quality. Moringa leaf samples (50g and 20g) were correctly weighed for the tray and infrared drying processes. The dryers were pre-heated to the appropriate temperature prior to drying.

Tray drying: To dry Moringa leaves, pre-heat the dryer to the appropriate temperature and put 50g in thin layers on the trays. The sample was weighted every 20 minutes during the drying process until it attained a steady weight. The technique involved taking three 50g samples at three different temperatures: 50°C, 60°C, and 70°C.

Infrared drying: To dry Moringa leaves, pre-heat the infrared dryer to the desired temperature and put 20g in thin layers on a tray. The sample was weighted every 10 minutes during the drying process until it attained a steady weight. The technique involved taking three 20g samples at three separate temperatures: 50°C, 60°C, and 70°C.(10)

Fluidized bed drying: The leaves were dried using a tray dryer with a capacity of 2 kilogram. The tray was covered with approximately 100 g of leaves in a single layer. The drying process was conducted at 40ºC, 50ºC, and 60ºC, with a constant air velocity of 2 m/s. Moringa leaf samples were weighed at regular intervals using a top-pan electronics balance until the moisture content remained constant. The computation was based on an average of three replications.

The fluidized bed dryer was simple, portable, and easy to operate. The cabinet housed the air distribution system and electrical controls, including the capacity to alter air speed and drying temperature. (2)

**4. Analytical Methods for Evaluation**

Determining Proximate Analysis Moringa leaves were analysed using established methods.

Ash

The ash content of a material is the inorganic residue left after destroying organic materials or minerals in the sample. Place the silica dish in a muffle furnace at no more than 525°C for 4-6 hours. To calculate the percentage of ash, use the formula in the standard approach and weigh the ash.

$$\% \, Ash \, (dry \, basis) = \frac{Weight \, after \, Ashing}{Weight \, before \, Ashing} \times 100$$

Crude Fat

A Soxhlet Extraction device was used to extract ether-soluble materials from a dried food sample. After the ether was permitted to fully evaporate, the residual material was measured. The sample was completely dried prior to extraction with petroleum ether to prevent water-soluble compounds from being extracted concurrently. Cabinet drying produced a higher ash concentration than other drying processes.

$$\% \, Fat \, Content = \frac{Weight \, of \, ether \, soluble \, material}{Weight \, of \, the \, sample} \times 100$$

Protein

The sample's crude protein is digested with sulfuric acid and a catalyst at 380 degrees. Nitrogen liberated from the sample's proteins and non-protein components is transformed into ammonium sulphate. In the presence of NaOH, ammonia nitrogen combines with salicylate nitroprusside reagent, resulting in a green complex with an absorbance of 685nm. To compute the crude protein concentration, multiply the nitrogen concentration (Kjeldhal nitrogen-N) by a factor of 6.25.

Moisture content

The sample has been heated in an oven at $105^0 \pm 2^0$C for 6 hours, resulting in gravimetric assessment of mass losses. (11)

$$\% \, Moisture \, Content = \frac{Initial \, weight \, of \, sample \, - Final \, Weight \, of \, sample}{Initial \, weight \, of \, the \, sample} \times 100$$

Dehydration Ratio

To compute the dehydration ratio of moringa leaves, initial and final mass were measured as follows: (2)

$$\text{Dehydration ratio} = \frac{Weight \, of \, dehydrated \, sample}{Initial \, weight \, of \, fresh \, leaves}$$

Mineral Content Determination

Calcium precipitates as calcium oxalate. The precipitate is dissolved in hot, dilute H2SO4, then titrated with normal potassium permanganate.

$$Calcium \, (\frac{mg}{100g}) = \frac{Titer \times 0.2 \times total \, volume \, of \, ash \, solution \times 100}{Volume \, taken \, for \, estimation \times Wt \, of \, sample \, taken \, for \, ashing}$$

Iron

To detect iron in food, it is transformed into ferric form using oxidizing chemicals such as potassium per sulfate or hydrogen peroxide, then treated with potassium thioxepnate to generate red ferric thiocyanate, which is measured calorimetrically at 540nm.

(OD= Optical density)

$$Concentration\ of\ sample = \frac{OD\ of\ unknown\ sample}{OD\ of\ known\ sample} \times concentration\ of\ known\ sample$$

## 5. RESULTS AND DISCUSSION

The effect of drying at various temperatures using different dryers (Tray and Infrared dryer) is presented below.

**Drying Moringa leaves using a tray dryer**

Moringa leaves were dried using a tray dryer at temperatures of 50˚C, 60˚C, and 70˚C. The nutritional analysis of foods acquired at different temperatures is provided below.

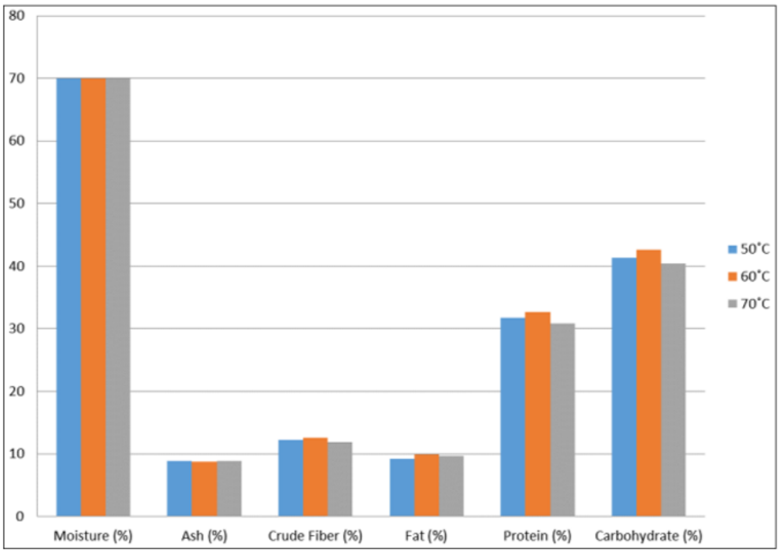


**Figure 2. Nutritional composition of Moringa leaves powder at Tray dryer using different temperatures(1)**

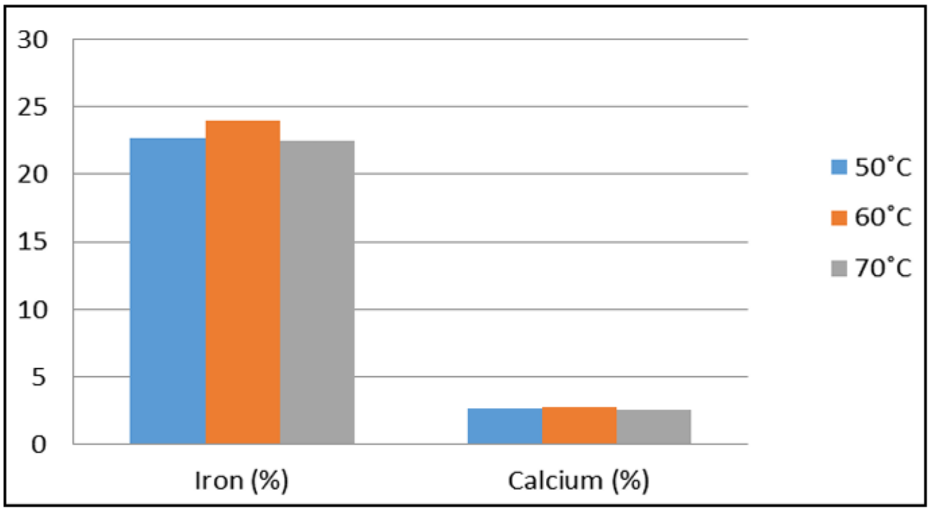


**Figure 3.Mineral composition of Moringa leaves powder at Tray(1)**

**International Journal of Pharmacy and Pharmaceutical Research (IJPPR)**
Volume 31, Issue 6, June 2025 **ijppr.humanjournals.com** ISSN: 2349-7203

The product from the tray dryer has a moisture content of 70%. Tray dryers at 60˚C have the crudest fibre (12.5%) and fat (9.85%), while those at 70˚C have more ash (8.89%) and less carbohydrate (40.4%) and protein (30.76%) compared to other temperatures. A tray dryer at 60˚C is ideal for achieving the highest percentage of iron (24%), and calcium (2.8%). (1)

**Drying Moringa leaves with an infrared dryer**

Moringa leaves were dried in an infrared drier at temperatures of 50˚C, 60˚C, and 70˚C. The nutritional analysis of items obtained at various temperatures is shown below.

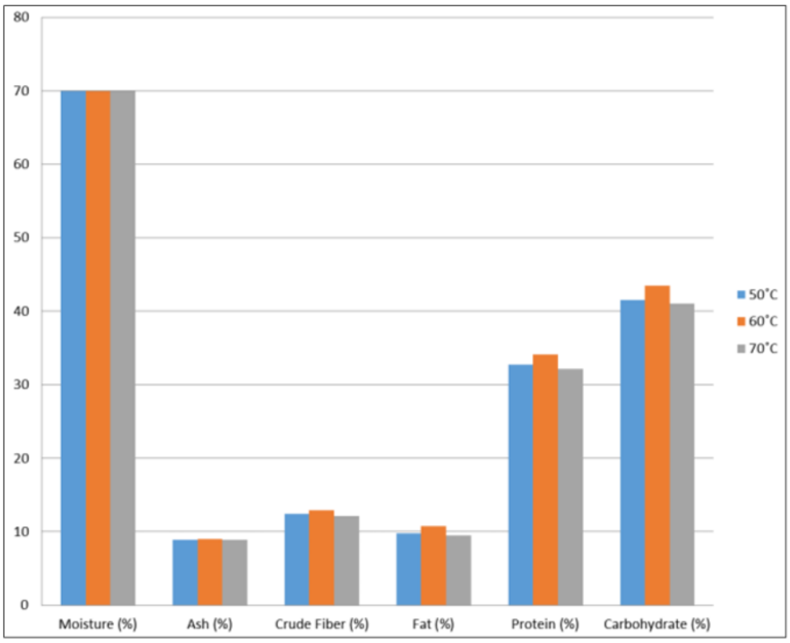


**Figure 4. Nutritional composition of Moringa leaves powder at Infrared dryer using different temperatures(1)**

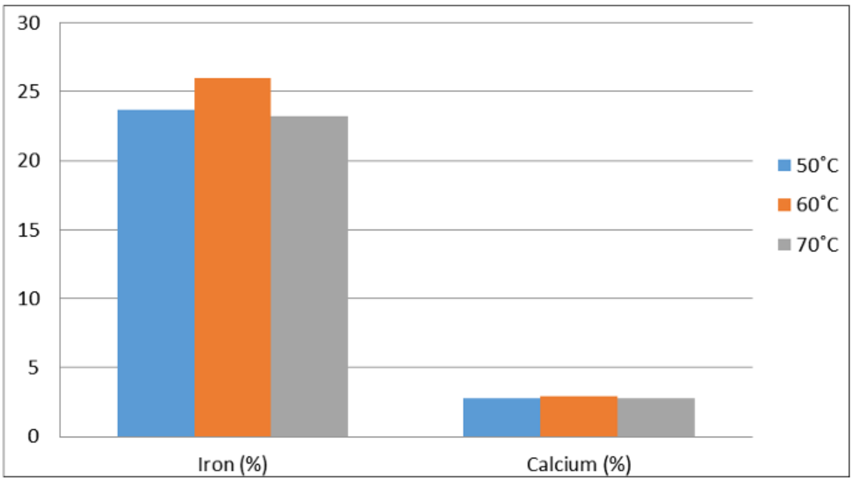


**Figure 5.Mineral composition of Moringa leaves powder at Infrared.(1)**

Infrared dryers produce products with a moisture content of 70%. At 60˚C, the dryer produces the most ash (8.97%), protein (34.12%), and carbohydrate (43.5%). At 70˚C, the dryer produces the least amount of crude fibre (12.09%) and fat (9.51%) compared to other temperatures. At 50˚C, the dryer produces slightly more iron (23.7%) than at 70˚C.

Samples dried in hot air oven had an average starting moisture content of 218.47 percent dry basis (db.). Drying was maintained until the samples reached a consistent weight The moisture content decreased to 5.89%, 5.73%, and 5.54% (on a dry basis) in the control and in samples dried at 40°C, 50°C, and 60°C, respectively. Using fluidized bed drying at 40°C, 50°C, and 60°C resulted in moisture reductions of 5.29%, 4.71%, and 4.59% (dry basis) in control samples. Among the tested temperatures, drying at 60°C resulted in the most rapid moisture removal, while the slowest rate was observed at 40°C (Figures 6 and 7).(1)

**Effect of drying temperatures Drying rates vary according to technique.**

Figures 8 and 7 show how moringa leaves dry at varying air temperatures. Maximum drying rates for control samples at 40, 50, and 60ºC were 2.058, 2.328, and 2.748 g water/g-DM-h (grams of water per gram of dry matter per hour) for tray drying, respectively.

Figures show that the control sample had the highest drying rate (6.474 g-water/g-DM-h) at 60ºC, followed by 5.442 g-water/g-DM-h at 50ºC and the lowest (4.394 g-water/g-DM-h) at 60ºC for fluidized bed drying. (2)

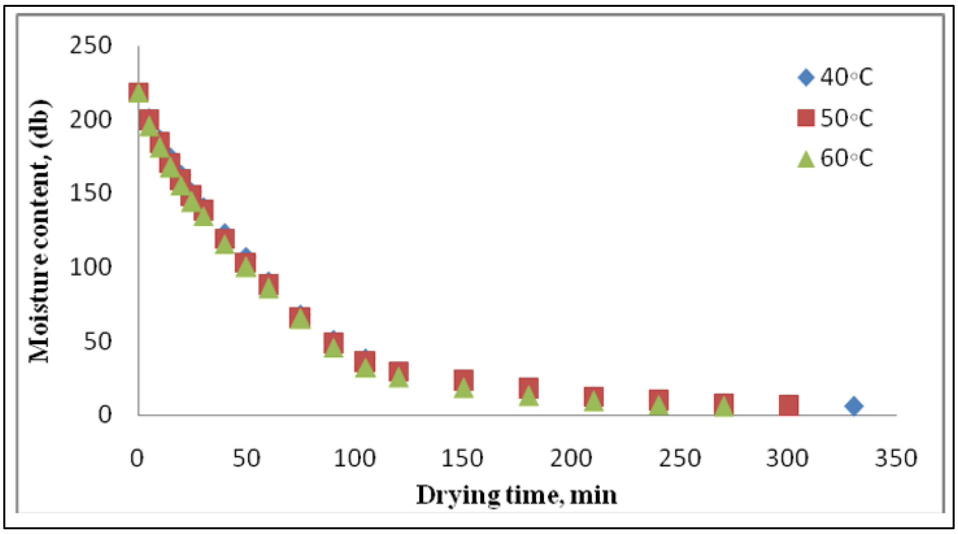


**Figure 6.Variation in moisture content with time for tray drying of moringa leaves.(1)**

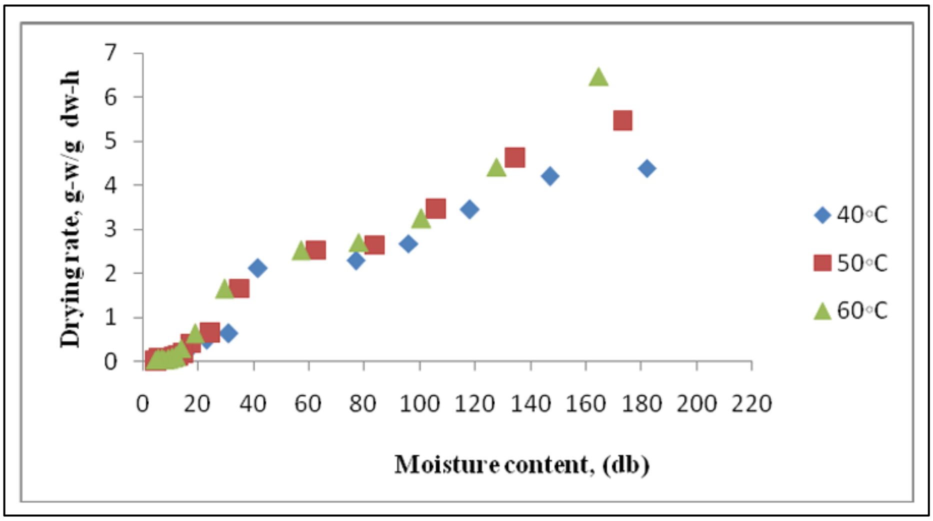


**Figure 7.Variation in drying rate with moisture content for fluidized bed drying.(2)**

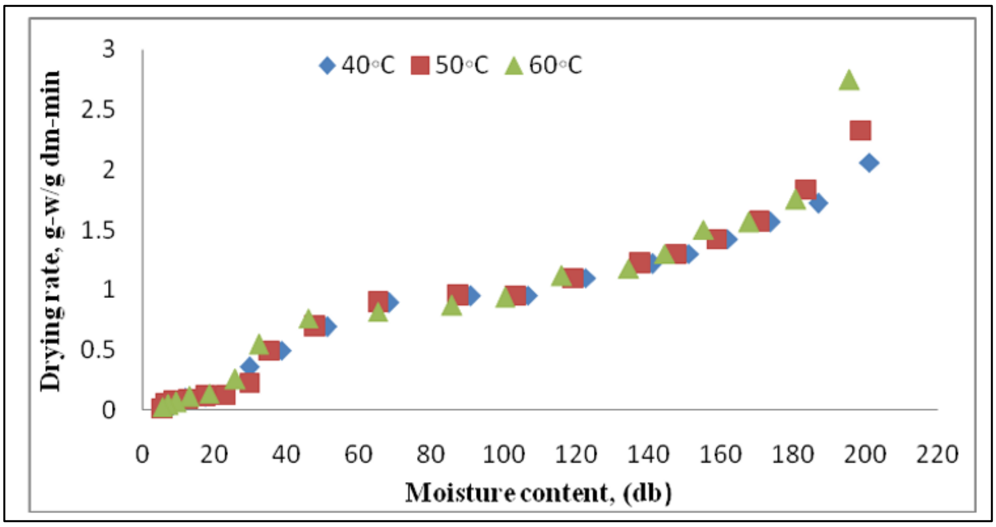


**Figure 8.Variation in drying rate with moisture content for tray drying of moringa leaves(2)**

**The effect of drying temperatures on moisture ratio varies according to the drying procedure.**

Figure 9 illustrates this. The moisture ratios of Moringa leaves declined exponentially with drying time, with values ranging from 1.0 to 0.00005, 1.0 to 0.00003, and 1.0 to 0.00005 at various air temperatures.

Moisture ratios for fluidized bed drying varied from 1.0 to 0.00002, 1.0 to 0.001, and 1.0 to 0.0061, depending on the drying air temperature. Figure 5 depicts how the moisture ratio of moringa leaves decreased with drying time, regardless of air temperature.(2)

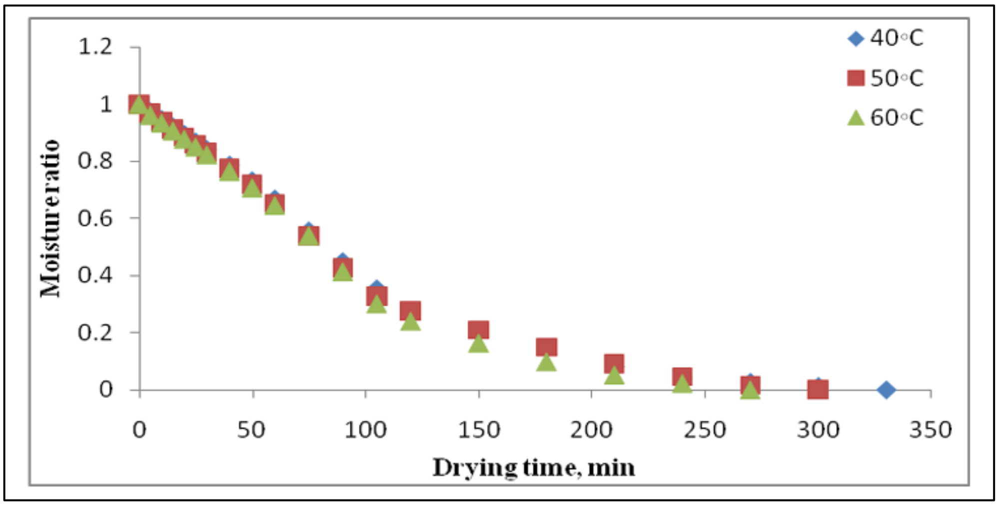


**Figure 9.Variation in moisture ratio with time for tray drying of moringa leaves.(2)**

**Why were these three techniques chosen?**

**Table 2.Rationale for Selection of Drying Methods.**

| Criteria | Tray Drying | Fluidized-Bed | Infrared |
|---|---|---|---|
| Industrial Use | Widely used; easy scale-up | Common for heat-sensitive products | Energy-efficient; retrofittable |
| Heat Transfer | Slow, uniform convection | Fast gas–solid contact | Rapid radiant heating |
| Key Advantages | Highest fibre (12.5%) and iron (24%) retention | Shortest drying time (≈150 min) | Best protein (34%), Ca (2.93%), Mg (26%) retention |

**Table 3.Implications of Drying Methods for Product Formulation and Shelf Life**

| Aspect | Preferred Method | Rationale |
|---|---|---|
| High-protein nutraceuticals | Infrared | Minimizes denaturation; improves dispersibility |
| Fibre-fortified bakery mixes | Tray | Higher fibre retention; enhances dough water-holding |
| Instant sachets / RTD drinks | Fluidized bed | Low bulk density; faster rehydration; good flowability |
| Oxidative stability | Infrared | Retains antioxidants; better shelf life with $N_2$-flushed packaging |
| Storage-induced browning | Infrared | ~8% less browning after 6 months vs. tray (fewer Maillard products) |
| High throughput / uniformity | Fluidized bed | Ideal for scale-up and particle uniformity (e.g., tablets, capsules) |

## 6. Conclusion

Infrared drying shown to be the most effective approach for removing moisture content from Moringa leaves. Tray drying at 60°C yields a fibre-rich product of 12.5%. Using an infrared drier at 60°C resulted in a mineral-rich product with higher levels of calcium (2.93%) and magnesium (26%), compared to other temperatures. As temperature climbed from 50°C to 70°C, protein, fibre, and iron levels fell by approximately 0.83%, 0.33%, and 0.35%, respectively.

Moringa leaves dried completely in a falling rate period for both tray and fluidized bed drying, regardless of pretreatments or temperatures. This indicates that the initial moisture content was less than the essential moisture content. Fluidized bed drying required shorter time to decrease moisture than tray drying, regardless of pretreatments or temperature.

**Table 4.Comparison of Drying Methods at 60 °C.**

| Parameter | Tray | Fluidized-Bed | Infrared |
|---|---|---|---|
| Drying Time | 270 min | 150 min | <150 min |
| Dehydration Ratio | 0.331 | 0.320 | — |
| Protein (%) | — | — | 34.1 |
| Fibre (%) | 12.5 | — | 12.1 |
| Iron (%) | 24.0 | — | 23.7 |
| Calcium (%) | 2.8 | — | 2.93 |
| Magnesium (%) | — | — | 26.0 |

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How to cite this article:
Vishwajeet Singh et al. Ijppr.Human, 2025; Vol. 31 (6): 439-451.

Conflict of Interest Statement: All authors have nothing else to disclose.




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