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PROCESSING TEMPERATURE AND NUTRITIONAL QUALITY OF *Moringa oleifera* LEAVES: A COMPARATIVE ANALYSIS OF 30°C VERSUS 50°C

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Abstract

***Moringa oleifera* leaves are widely recognized as a rich source of protein, vitamins, minerals, and bioactive compounds with potential health benefits. However, drying temperature may influence their nutritional composition and bioactive properties, making the selection of an appropriate processing condition essential. Although previous studies have investigated the effects of drying on moringa leaves, limited information is available regarding the simultaneous evaluation of total tannin and essential minerals under low-temperature (30°C) and moderate-temperature (50°C) drying conditions. Therefore, this study contributes to existing knowledge by providing an integrated comparison of these quality parameters. This study aimed to compare the effects of processing temperatures of 30°C and 50°C on the nutritional content of moringa leaves. A laboratory experimental design was applied, with moringa leaves processed at the two drying temperatures. The measured parameters included total tannin and the mineral contents of magnesium (Mg), sodium (Na), calcium (Ca), potassium (K), and iron (Fe). Data were analyzed quantitatively to compare nutrient composition between treatments. The results showed that *Moringa oleifera* leaf powder dried at 50°C had higher measured concentrations of total tannin, Mg, Na, Ca, K, and Fe than that dried at 30°C. These findings indicate that moderate-temperature drying can enhance the measured retention of both bioactive compounds and minerals. Overall, drying at 50°C can be considered a practical processing condition for producing moringa leaf powder with higher measured tannin and mineral contents while maintaining processing efficiency for food and dietary supplement applications.**

Keywords: Drying temperature; Mineral content; *Moringa oleifera*; Nutrient retention; Tannin content.

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1. INTRODUCTION

Moringa oleifera leaves are rich in vitamins, minerals, proteins, and bioactive compounds that contribute to physiological functions and protection against chronic diseases (1,2). Important components include tannins and essential minerals such as Magnesium (Mg), Sodium (Na), Calcium (Ca), Potassium (K), and Iron (Fe) (3,4).

Drying is commonly used to extend the shelf life of moringa leaves, reduce microbial spoilage, and facilitate storage and distribution (5). In addition to their mineral content, moringa leaves contain phenolic compounds and antioxidants that support their potential use as functional food ingredients and natural sources of health-promoting compounds (6,7).

Drying conditions must be carefully controlled because temperature can affect nutrient stability, bioactive compounds, product quality, and processing efficiency. Higher temperatures generally accelerate moisture transfer and shorten drying time (8). In contrast, low-temperature drying may better preserve heat-sensitive nutrients but requires a longer processing period, making it less efficient for large-scale production (9). Low-temperature drying may also maintain vitamins and antioxidant activity more effectively than excessive thermal exposure (10). Nevertheless, studies on other plant materials indicate that moderate temperatures can provide effective drying while retaining phenolic compounds, flavonoids, and antioxidant activity (11).

Maintaining mineral content during processing is important because iron contributes to blood formation and anemia prevention, while calcium and magnesium support bone, cardiac, neurological, and metabolic functions (12). Previous research showed that drying temperatures of 45°C, 50°C, and 55°C significantly affected moisture content, drying rate, and moisture ratio in moringa leaves (13). Low-temperature air drying has also been reported to retain higher Fe and Ca contents than hotter drying methods (14). Therefore, selecting an appropriate drying method and temperature is essential for maintaining the nutritional value of moringa leaf products (15).

Physicochemical characterization has confirmed that moringa leaves contain important minerals, including Ca, Mg, K, Na, and Fe (16). However, higher processing temperatures and direct sun drying may reduce certain nutrients because of thermal degradation (17). These findings demonstrate the importance of balancing nutrient preservation with drying efficiency.

The temperatures of 30°C and 50°C were selected to represent two distinct and practical processing conditions. A temperature of 30°C represents gentle, low-temperature drying that may better protect heat-sensitive nutrients but requires a longer drying time. In contrast, 50°C represents moderate-temperature drying that accelerates moisture reduction while limiting excessive thermal exposure. An intermediate temperature of 40°C was not included because the study was designed to provide a clear comparison between two contrasting drying conditions. Meanwhile, 60°C was excluded because greater heat exposure may increase the risk of degradation of phenolic compounds, antioxidants, and other thermally sensitive constituents. Thus, comparing 30°C and 50°C provides a practical basis for evaluating the balance between nutrient preservation and processing efficiency.

Previous research has demonstrated that drying temperature can influence the phenolic content, antioxidant activity, and biological properties of *Moringa oleifera* leaf extracts (18). However, direct comparisons between 30°C and 50°C that simultaneously evaluate total tannin and selected minerals, including Mg, Na, Ca, K, and Fe, remain limited.

This study aimed to compare total tannin and selected mineral concentrations in moringa leaves dried at 30°C and 50°C. Drying at 50°C was hypothesised to produce higher measured concentrations, although individual components may respond differently. The findings are expected to support efficient and nutritionally appropriate processing for food, supplement, and functional product applications.

2. METHOD

This study used a laboratory experimental design by Suwandono et al. (2025) (19) with two drying temperature treatments, namely 30°C and 50°C (20,21). Each treatment was conducted in triplicate to improve measurement reliability and allow statistical comparison under controlled laboratory conditions. *Moringa oleifera* leaves were dried using a blower oven with accurately monitored temperature settings (22).

The independent variable was drying temperature, while the dependent variables were total tannin and the concentrations of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and iron (Fe) in moringa leaf powder. Both treatments were conducted under the same laboratory conditions so that differences in nutritional composition could primarily be attributed to drying temperature. Because the study involved only two temperature levels and three replications, the findings were interpreted by considering statistical significance as well as the direction and magnitude of the observed differences.

a. Processing Procedure

Fresh moringa leaves were selected, thoroughly washed, drained, separated from the stems, and sorted before drying. The leaves were placed in a drying oven at either 30°C or 50°C for approximately 5–7 hours until the moisture content reached approximately 2–10%. This moisture reduction was intended to inhibit microbial growth while maintaining nutritional quality.

After drying, the leaves were ground and sieved to obtain moringa leaf powder with a uniform particle size. Drying at 30°C required a longer processing time, whereas drying at 50°C removed moisture more rapidly. Therefore, the selected temperatures represented a balance between nutrient preservation and processing efficiency.

b. Nutritional Content Analysis

Analysis was conducted on the dried moringa leaf powder from the two temperature treatments as follow: Tannin analysis in the laboratory was conducted using UV-Vis spectrophotometry according to the Indonesian Herbal Pharmacopoeia (FHI) Edition II, 2017. This is an analytical technique used to measure the absorbance of a compound at ultraviolet (UV) and visible light wavelengths by a sample solution. In principle, compounds with specific chromophore groups will absorb light at specific wavelengths, and the level of absorption is directly proportional to the concentration of the compound in the solution.

This method is used for the quantitative analysis of flavonoids, tannins, vitamins, and other bioactive substances due to its speed, sensitivity, and ease of operation. The procedure includes the following steps: Taking a sample of 1.00 mg of tannin acid powder and dissolving it in 10 mL of ethanol p.a. solvent, determining the maximum wavelength (λ max) at which the compound absorbs light most strongly, calibrating the UV-Vis spectrophotometer using a standard solution at a parent concentration of 100 ppm to create a calibration curve, measuring the absorbance of the sample solution at the specified λ max, and calculating the compound concentration in the sample based on the absorbance and calibration curve using the linear equation Y = AX + B. The equation Y = Ax + BY = Ax + BY = Ax + BY = Ax + B is a linear equation, where:

A = 0.0051

B = 0.0245

R^2 = 0.9965

Y is the dependent variable (the value to be predicted or observed),

X is the independent variable (the value of the that affects Y),

A is the slope of the line or gradient, which shows the change in Y with respect to the change in X.

B is the constant or intercept, which is the point where the line intersects the Y-axis when X=0X = 0X=0.

c. Ca, Mg, K, Na, and Fe Analysis Methods

The mineral contents of Ca, Mg, K, Na, and Fe were analysed using Atomic Absorption Spectrophotometry (AAS) or Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). These methods were selected because of their accuracy in detecting micro and macroelements in plant materials.

The dried samples were ground and subjected to acid digestion to dissolve the minerals before being introduced into the analytical instrument. Mineral concentrations were determined from light absorption at element-specific wavelengths, including approximately 422.7 nm for Ca and 285.2 nm for Mg. K, Na, and Fe were measured using their respective standard wavelengths. Sample absorbance was compared with the calibration curves of standard solutions to calculate mineral concentrations.

d. Data Analysis

Total tannin data were analysed using an independent-samples t-test to compare mean tannin concentrations between the 30°C and 50°C treatments. Mineral data for Ca, Mg, K, Na, and Fe were analysed using analysis of variance (ANOVA). When significant differences were identified, further testing using Duncan's or Tukey's test was conducted to determine differences between treatment groups.

The results were presented as mean values with their corresponding variation, and statistical significance was set at $p < 0.05$. Because each treatment was conducted in triplicate, the statistical findings were interpreted cautiously as preliminary evidence obtained under controlled laboratory conditions. Statistical results were also evaluated together with the direction and magnitude of change in each parameter to determine which drying temperature produced more favourable tannin and mineral concentrations.

3. RESULTS AND DISCUSSION

Results

a. Ca, Mg, K, Na, and Fe Content

The concentrations of Ca, Mg, K, Na, and Fe were higher in moringa leaf powder processed at 50°C than in powder processed at 30°C. Based on the measured values, the increases ranged from 3.6% to 19.3%, indicating that drying at 50°C produced a more mineral-dense final powder. Iron showed the largest increase, rising from 6,278.50 mg/100 g at 30°C to 7,493.00 mg/100 g at 50°C. In contrast, calcium showed the smallest increase, from 458.56 mg/100 g to 474.87 mg/100 g. The complete results are presented in Table 1.

Table 1. Results of Ca, Mg, K, Na, and Fe Analysis

No.	Parameter	Unit	30°C	50°C	Increase (%)
1	Calcium (Ca)	mg/100 g	458.56	474.87	3.6
2	Magnesium (Mg)	mg/100 g	736.50	779.40	5.8
3	Potassium (K)	mg/100 g	238.34	248.78	4.4
4	Sodium (Na)	mg/100 g	89.90	93.45	3.9
5	Iron (Fe)	mg/100 g	6,278.50	7,493.00	19.3

Sources: Primary Data, 2026

As shown in Table 1, all measured minerals increased under the 50°C treatment. Calcium, magnesium, potassium, and sodium showed moderate increases, whereas iron exhibited the greatest increase among the analysed minerals. Because the mineral contents were expressed per 100 g of moringa leaf powder, the higher values at 50°C should primarily be interpreted as higher measured mineral concentrations in the final dried product.

The observed pattern suggests that drying at 50°C removed water more effectively, thereby increasing the relative concentration of non-volatile mineral components in the powder. When moisture content decreases, the dry matter becomes more concentrated, causing mineral values expressed per 100 g of dried material to appear higher. Therefore, these differences are more likely associated with the concentration effect caused by moisture reduction than with the formation of new minerals during processing.

Final moisture content and water activity were not included as primary parameters because the analysis focused on total tannin and selected mineral concentrations. Consequently, the contributions of actual nutrient retention and moisture-related concentration could not be distinguished using dry-matter-corrected values. This limitation should be considered when interpreting the mineral results. Future studies should include final moisture content, water activity, and dry-matter conversion to provide a more comprehensive assessment of drying performance and nutrient retention.

The higher iron concentration at 50°C is particularly important because iron contributes substantially to the nutritional value of moringa leaf powder. Meanwhile, the increases in calcium, magnesium, potassium, and sodium indicate that these minerals remained available in the final dried product. Overall, drying at 50°C produced moringa leaf powder with a more concentrated mineral profile than drying at 30°C.

Nevertheless, the results should not be interpreted as evidence of an absolute mineral gain. Instead, they demonstrate that the powder dried at 50°C had a higher measured mineral density. Further evaluation using moisture-corrected data is necessary to determine whether this increase was caused mainly by improved mineral retention or by greater water removal.

b. Tannin Content

The total tannin content of moringa leaf powder was also higher at 50°C than at 30°C. The 50°C treatment produced a total tannin concentration of 17.1863 mg TAE/g, compared with 15.3971 mg TAE/g at 30°C. This difference indicates that the moderate drying temperature of 50°C was more favourable for maintaining or concentrating tannin compounds in the dried moringa leaf powder. Although phenolic compounds may be sensitive to excessive thermal exposure, the temperature of 50°C used in this study may still represent a moderate drying condition that promotes moisture reduction and improves the extractability or relative concentration of tannin compounds without causing an apparent decrease in the measured total tannin value.

Table 2. Results of Total Tannin Analysis

Parameter	Method	30°C	50°C
Total tannin	UV-Vis spectrophotometry based on the Indonesian Herbal Pharmacopoeia, 2nd Edition (2017)	15.3971 mg TAE/g	17.1863 mg TAE/g

Sources: Primary Data, 2026

Although phenolic compounds are sensitive to excessive heat, drying at 50°C can still be considered a moderate condition that promotes moisture reduction and increases tannin extractability or concentration without causing an apparent decline in total tannin. The higher value likely reflects greater concentration in the lower-moisture powder rather than the formation of new tannin compounds.

Moderate heating may also facilitate the release of bound phenolic compounds and reduce enzymatic oxidation. However, this explanation remains preliminary because individual tannin fractions, total phenolic content, antioxidant activity, bioavailability, and changes in biological activity were not assessed.

Overall, drying at 50°C reduced moisture efficiently while maintaining higher measured total tannin and selected mineral concentrations than drying at 30°C. These findings support 50°C as a practical drying condition for producing nutritionally concentrated moringa leaf powder, although further analysis is required to confirm its functional benefits.

Discussion

The results support the initial hypothesis that drying moringa leaves at 50°C produces higher measured tannin and mineral concentrations than drying at 30°C. Moderate drying temperatures can reduce water content more effectively, resulting in higher nutrient concentrations in the dried material without necessarily causing extensive degradation of important bioactive compounds (17,23). Nevertheless, the term "higher nutritional content" in this study refers to higher measured concentrations in the final powder and should be interpreted in relation to the possible concentration effect caused by water removal.

All measured minerals were higher at 50°C. Iron showed the largest relative increase of 19.3%, followed by magnesium at 5.8%, potassium at 4.4%, sodium at 3.9%, and calcium at 3.6%. This pattern suggests that drying at 50°C promoted more effective water removal and increased the concentration of non-volatile mineral components in the final powder.

The different magnitudes of increase indicate that the responses of the analysed minerals were not uniform. Iron showed the greatest increase, whereas calcium showed the smallest change. These differences may be associated with the concentration of each mineral in the reduced-moisture matrix rather than an identical response of all components to temperature.

This finding is important because the selection of drying temperature should consider the nutritional characteristics expected from the final product. When moringa leaf powder is intended as a mineral-dense ingredient, particularly for products targeting higher iron content, drying at 50°C may provide a more favourable processing condition than drying at 30°C.

Previous research reported that optimal drying temperatures in the range of approximately 40–55°C could maintain essential nutrients while providing better processing efficiency (12,24). Drying at 50°C may therefore represent a compromise between the risk of nutrient degradation caused by heat and the need for efficient moisture reduction.

However, drying performance is influenced not only by temperature but also by heat and mass transfer conditions, raw-material characteristics, and the drying technique used. Increasing temperature can accelerate moisture removal and improve drying efficiency, but the process must remain controlled to minimise undesirable changes in nutrient quality and antioxidant properties (25).

Different drying techniques may also affect colour stability, phenolic retention, and the functional quality of moringa leaf products. Therefore, drying temperature should be evaluated together with the type of drying equipment and processing method employed (26). Variations in leaf maturity, cultivation region, regrowth age, and seasonal conditions may also influence biochemical markers and antioxidant potential (27). Thus, the quality of dried moringa leaves is determined by both processing conditions and raw-material characteristics.

Drying at a relatively low temperature such as 30°C may preserve some heat-sensitive compounds but requires a longer processing period and may be less effective in rapidly reducing moisture and concentrating nutrients (28). Conversely, excessively high drying temperatures may damage phenolic compounds and reduce antioxidant activity. Therefore, 50°C appears to provide a balance between moisture reduction, nutrient concentration, and controlled thermal exposure.

The higher tannin content at 50°C may result from moisture reduction, plant-matrix disruption, and preservation of phenolic compounds, although further analysis of individual tannins, total phenolics, and antioxidant capacity is needed to confirm its functional bioactivity. The increased iron, calcium, and magnesium concentrations also support the potential use of moringa leaf powder as a mineral-rich functional food ingredient. However, industrial application requires process validation because larger material loads, airflow, humidity, bed thickness, drying uniformity, and energy requirements may affect nutrient concentration and product stability.

A study using a fluidised-bed dryer demonstrated that drying temperature could affect both drying behaviour and the macronutrient profile of moringa leaves. This finding indicates that dried-leaf quality should not be assessed using only one parameter (29). Similarly, dehumidified drying research showed that increasing temperature improved moisture removal and thermal efficiency, although the influence of dehumidification was more pronounced at temperatures below 50°C (30).

From a processing perspective, the higher nutrient concentrations observed at 50°C should be evaluated alongside drying rate, energy efficiency, and overall product quality. Drying at this temperature may shorten processing time and reduce energy use while maintaining nutritional value, but its economic and sustainability benefits must also be assessed through moisture content, water activity, microbial safety, sensory quality, and nutrient stability. Therefore, 50°C should be considered a practical reference for pilot-scale optimisation rather than a final industrial standard.

Research Limitations

This study was limited to the laboratory analysis of total tannin and selected macro- and microminerals (Mg, Na, Ca, K, and Fe) in *Moringa oleifera* leaf powder processed at two drying temperatures (30°C and 50°C). Other important quality attributes, including the complete phytochemical profile, total phenolic content, antioxidant activity, moisture content, water activity, nutrient bioavailability, colour, sensory properties, microbial quality, and storage stability, were not evaluated. Therefore, the conclusion that drying at 50°C produced more favourable nutritional characteristics applies only to the measured tannin and mineral concentrations and should not be interpreted as a comprehensive assessment of overall product quality.

The higher measured tannin and mineral concentrations observed at 50°C may partly reflect greater moisture removal and concentration effects rather than improved nutrient retention. Because moisture content, water activity, drying kinetics, particle characteristics, phenolic composition, and antioxidant capacity were not determined, the present study could not distinguish actual nutrient preservation from concentration caused by water loss. In addition, the findings are limited by the use of only two drying temperatures, a fixed drying duration, triplicate measurements, and controlled laboratory conditions that may not represent industrial-scale processing.

Future research should employ broader experimental designs incorporating different drying temperatures, drying durations, air velocities, and drying technologies, such as tray, cabinet, fluidised-bed, and dehumidified drying. Comprehensive evaluations integrating chemical, physical, sensory, microbiological, storage-stability, and nutrient bioavailability assessments, together with in vivo or clinical studies, are also needed to determine whether the higher measured nutrient concentrations translate into improved nutritional benefits and to establish optimal processing conditions for *Moringa oleifera* leaf products.

4. CONCLUSIONS

Drying *Moringa oleifera* leaves at 50°C resulted in higher measured concentrations of total tannin and essential minerals (Ca, Mg, K, Na, and Fe) than drying at 30°C, suggesting that moderate-temperature drying is a practical processing condition for producing moringa leaf powder with improved nutritional characteristics. The higher measured mineral concentrations may be associated with greater moisture removal during drying; therefore, the results should be interpreted within the scope of the measured parameters. Drying at 50°C may be recommended as a practical processing temperature for moringa leaf powder intended for food and dietary supplement applications. Future studies should evaluate additional quality attributes, including antioxidant activity, vitamin retention, moisture content, nutrient bioavailability, storage stability, sensory properties, and in vivo health effects, to establish optimal processing conditions and confirm the functional benefits of dried moringa leaf products.

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