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Effect of Drying Temperature and Time Using a Solar Thermal Dryer on Moisture Content, Color, and Proximate Properties of Moringa (*Moringa oleifera*) Leaves

Fitrah Evar[1,✉], Radhiansyah[2]

[1] Bacharuddin Jusuf Habibie Institute of Technology, South Sulawesi, INDONESIA.

[2] Energy Systems Engineering, Bacharuddin Jusuf Habibie Institute of Technology, South Sulawesi, INDONESIA

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Corresponding Author:
✉ fitrawatyorista@ith.ac.id
(Fitrah Evar)

ABSTRACT

Moringa leaves are highly nutritious and are often used as a raw material for various processed products. Drying is a crucial step in preserving the leaves before further processing. Solar thermal dryers are an environmentally friendly drying technology that has the potential to help maintain the color and nutritional stability of Moringa leaves through more controlled drying conditions. This study aims to evaluate the effects of solar thermal drying on the nutritional content and color characteristics of Moringa leaves to support the development of appropriate drying methods for maintaining product quality. The study was conducted using a two-factor split-plot design: temperature (40 ℃, 44 ℃, and 47 ℃) as the main plot and time (3 h, 5 h, and 7 h) as the subplot, yielding nine treatment combinations with three replications. The results showed that the treatment conducted at 44 ℃ for 7 h produced lower moisture content and a better stable color, while the treatment conducted at 40 ℃ for 7 h produced the highest moisture content and the least stable color. Furthermore, the treatment conducted at 44 ℃ for 7 h showed higher dietary fiber, ash and lower moisture content compared with the treatment conducted at 47 ℃ for 7 h while protein, fat and carbohydrate contents were not significantly different between the two treatments. Overall, drying at 44 ℃ for 7 h resulted in lower moisture content, acceptable color characteristics and higher dietary fiber and ash content compared with the other tested conditions.

1. INTRODUCTION

Moringa leaves (*Moringa oleifera*) are a rich source of nutrition, offering protein, fiber, vitamins, and minerals, making them a promising ingredient in various processed food products (Oyeyinka & Oyeyinka, 2018). The bioactive components in these leaves are sensitive to heat (Fombang *et al*., 2021) and light (Sadiah *et al*., 2022) necessitating careful postharvest management to preserve their physical and nutritional properties (George *et al*., 2021). Without proper handling, moringa leaves are prone to rapid deterioration particularly in terms of color changes and nutrient loss (Krah *et al*., 2022) which can diminish their shelf life and economic value.

Drying is an important postharvest process used to reduce moisture content and extend the shelf life of moringa leaves before further processing. However, drying may also alter the physical and nutritional quality of *Moringa oleifera* leaves because bioactive compounds and pigments are sensitive to heat, oxygen, and prolonged processing conditions (Ramarao *et al*., 2022). Conventional open sun drying is still commonly applied because of its simplicity and low operational cost, although this method is highly dependent on environmental conditions and may expose the product to dust, microorganisms, and excessive ultraviolet radiation (Joel *et al*., 2022).

In addition, uncontrolled drying conditions can accelerate chlorophyll degradation, discoloration, and the loss of heat-sensitive compounds, thereby reducing the quality of dried herbal products (Chaves *et al*., 2023; Djaeni, *et al*., 2025; Potisate *et al*., 2015) also reported that inappropriate drying conditions may adversely affect moisture content and the overall quality of dried moringa leaves.

Solar drying technologies have been developed as an alternative drying method to improve the handling of heat-sensitive agricultural products, including leafy vegetables and herbs. Compared with conventional open sun drying, solar dryers provide a more protected drying environment and allow better control of drying temperature and airflow, thereby reducing contamination risks and minimizing direct exposure to sunlight (Koehuana *et al*., 2022). Several studies have reported that controlled solar drying can provide more stable drying conditions and may reduce excessive thermal and oxidative damage during processing of plant materials (Muchoki *et al*., 2025). In addition, solar thermal drying systems have attracted attention because they can utilize renewable solar energy while supporting more consistent drying conditions for agricultural products (Nnamchi *et al*., 2025).

Although various drying methods have been applied to *Moringa oleifera* leaves including tray dryers, cabinet dryers, fluidized bed dryers and conventional solar dryers, most previous studies primarily focused on moisture reduction and general drying performance (Adekanye *et al*., 2023; Mishra *et al*., 2022; Ortolá *et al*., 2023) Studies evaluating controlled-temperature solar thermal drying systems and their effects on color characteristics and selected nutritional properties of moringa leaves remain limited. In particular, information regarding the combined effects of drying temperature and drying time under controlled solar thermal drying conditions is still insufficient. Therefore, further studies are needed to evaluate the influence of controlled solar thermal drying conditions on the moisture content, color characteristics, and selected nutritional properties of moringa leaves.

Based on this context, this study aimed to evaluate the effects of drying temperature and drying time using a solar thermal dryer on the moisture content, color characteristics, and selected nutritional properties of *Moringa oleifera* leaves. The result of this research are expected to provide information regarding controlled solar thermal drying conditions for moringa leaf processing.

2. MATERIALS AND METHODS

2.1. Research Location

This research was conducted from August to November 2025. Drying of *Moringa oleifera* leaves was carried out in West Bacukiki District, Parepare City, Indonesia. Moisture content, color and proximate analyses were performed at the Food Technology Laboratory, Hasanuddin University and the Makassar Public Health Laboratory, Indonesia.

2.2. Materials and Equipment

The moringa leaves used in this study were obtained from the Bukit Harapan area in Parepare. The materials used were fresh, uniform and free from damage, distilled water, H_2SO_4, boric acid, NaOH 30%, Conway indicator, HCl 0.1 N, PP indicator, petroleum benzine. The main equipment used was a solar thermal dryer with schematic arrangement as presented in Figure 1 and technical specification detailed in Table 1. Other supporting equipment including colorimeter (CHNSpec CS-10, China), and moisture analyzers (FAITHFUL F-110MW, China).

2.3. Design of Experiment

The study was designed using a two-factor factorial CRD (temperature and time). Factor temperature (S) was arranged in the main plot with three levels (40, 44 and 47 ℃). Factor time (W) was placed as a subplot and also consisted of three levels (3 h, 5 h, and 7 h) to obtain nine combinations (Table 2). Each treatment was repeated three times. The collected data was analyzed using two-way ANOVA. Significant differences were further tested using the Duncan Multiple Range Test (DMRT) at $\alpha = 5\%$. All calculations were performed using IBM SPSS 23 and Microsoft Excel.

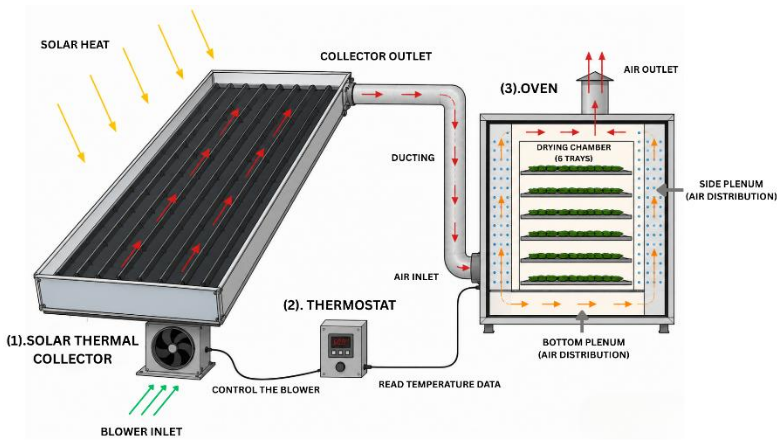

Figure 1. Schematic diagram of Solar Thermal Dryer

Table 1. Technical specifications of the Solar Thermal Dryer

Parameter	Specification
Dryer Type	Indirect forced convection tray dryer
Working Principle	Solar air heater heats the air, which is circulated by an axial fan through ducting into the drying chamber using a plenum airflow system
Airflow Direction	Bottom collector inlet → upward airflow through collector → top collector outlet → ducting → rear-bottom oven inlet → bottom plenum → side plenum → perforated wall → drying
Temperature Control	Thermostat controller
Capacity	900 g fresh moringa leaves (150 g/tray × 6 trays)
General Dimensions	Oven: 70 × 70 × 70 cm; Solar air heater: 120 × 170 cm
Fan Configuration	Axial fan mounted on the solar air heater collector
Ducting Length	1.5 m

Table 2. Treatment combinations executed to evaluate drying characteristic of Moringa leaves

Temperature	Drying Time		
	W1 (3 h)	W2 (5 h)	W3 (7 h)
S1 (40 °C)	S1W1	S1W2	S1W3
S2 (44 °C)	S2W1	S2W2	S2W3
S3 (47 °C)	S3W1	S3W2	S3W3

Proximate analysis and dietary fiber analysis involved only two treatment combinations: S2W3 and S3W3 due to the relatively high cost and time requirements of nutritional analysis. These two treatment combinations were selected based on the results of moisture content and color evaluation, which represented drying conditions with comparatively better quality characteristics among the tested treatments. The average difference between the two treatments was tested using an independent two-sample *t*-test at the 5% significance level.

2.4. Research Stages

(1) Sample preparation: Fresh moringa leaves were washed using water and then drained at room temperature for approximately 15–20 minutes. Samples of about 30 g were used for each treatment.
(2) Drying process: Moringa leaves were evenly arranged in the tray dryer (Figure 2), without any piles, to ensure optimal hot-air circulation during drying. After drying, the samples were cooled and weighed to calculate yield as the difference in weight before and after drying.
(3) Grinding: The dried moringa leaf samples were ground using a dry mill to obtain a more homogeneous sample prior to moisture content and proximate analyses. The ground samples were then stored in labeled containers at room temperature and protected from direct light.

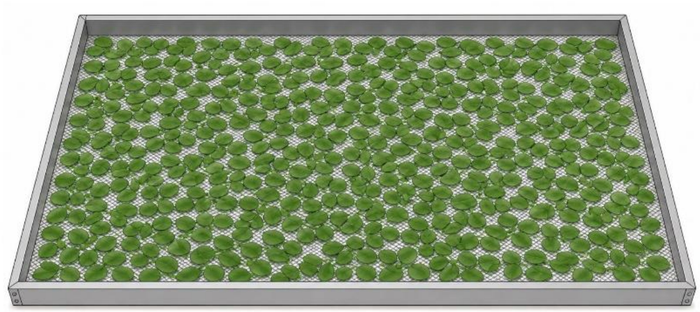

Figure 2. Distribution of moringa leaves on a drying tray

2.5. Research Parameters

(1) Moisture content (%wb) was determined using a moisture analyzer (Faithful Type F-110MW, China) at a drying temperature of 105 °C based on thermogravimetric weight loss. The dried moringa leaf samples were heated until a constant weight was achieved and the moisture content was automatically calculated by the instrument based on the mass reduction during heating.

(2) Yield was calculated using the following formula:

$$Yield = \frac{final\ weight}{initial\ weight} \times 100\% \quad (1)$$

(3) The color of dried moringa leaves was measured using a colorimeter (CHNSpec type CS-10, China). A representative bulk sample of dried leaves from each treatment was randomly selected, and the color was measured directly on the leaf surface. The measured values: L^* (brightness: 0 = black, 100 = white), a^* (green for negative values (-) to red for positive (+) values), and b^* (blue for negative (-) values to yellow for positive (+) values). The color changes reflect the physiological condition of the material (Kasajima, 2019).

(4) Proximate analysis of dried moringa leaves included ash, fat, crude fiber, protein and carbohydrate contents. Ash content was determined using the gravimetric furnace method, fat content using the Soxhlet extraction method, crude fiber using the Weende gravimetric method and protein using the Kjeldahl method according to AOAC standard procedures (AOAC, 2016). Carbohydrate content was calculated by difference. All analyses were conducted at the Makassar Public Health Laboratory under standard laboratory operating procedures.

3. RESULTS AND DISCUSSION

3.1. Moisture Content

Table 3 shows effect of drying treatment combinations (temperature and drying duration) on the moisture content of the resulted moringa leaves. The results of ANOVA indicate that both factors and their interactions are statistically significant on the moisture content with calculated F-value of 458.46 for temperature, 331.50 for drying duration, and 58.72 for the interaction. The p-values are < 0.001 for all factors and the interaction, implying very significant effect. Specifically, moisture content decreased as temperatures increased and drying times extended. However, this came at the expense of yield parameters. Mechanistically, the drying rate increases at higher temperatures because the vapor pressure gradient between the material surface and the drying air increases, thus driving faster water evaporation. This

Table 3. Effect of drying treatment combinations on the moisture content (%) of moringa leaves

Temperature	Moisture Content (%)		
	W1 (3 h)	W2 (5 h)	W3 (7 h)
S1 (40 °C)	52.73±1.04^{a}	31.93±2.37^{b}	21.50±1.35^{c}
S2 (44 °C)	34.80±3.29^{b}	12.40±1.92^{de}	8.63±0.15^{f}
S3 (47 °C)	13.40±1.73^{d}	9.40±1.06^{ef}	10.20±0.61^{ef}

Note: numbers followed by the same lowercase letter in the same column are not significantly different at the 5% level according to the DMRT test.

phenomenon has been explained by (Guiné & Lima, 2020; Hii *et al*., 2023; Ievinsh, 2023) who state that temperature is the most dominant factor in accelerating mass transfer during food drying. In Moringa leaves, water-rich parenchyma cells release water vapor more quickly when they receive more heat energy.

The S1W1 treatment, conducted at 40 °C for 3 hours, resulted in the highest moisture content of 52.73%, suggesting that these conditions were insufficiently aggressive to dehydrate the moringa leaves effectively. This is attributed to the low temperature, which slows evaporation and provides less drying energy, hindering the movement of water from leaf tissue to the surface. This phenomenon is in accordance with a study conducted by (Giang & Hang, 2021) that increasing the drying temperature accelerates water removal, although in that study the temperature used was higher, the basic mechanisms of evaporation and mass diffusion still apply, namely higher temperatures increase the evaporation gradient and reduce the time to reach the target moisture content.

A significant decrease in moisture content was seen in the S2W3 (44 °C, 7 hours) and S3W2 (47 °C, 5 hours) treatments, indicating that the combination of moderate temperature (44 °C) with a longer drying time (7 hours) was able to reduce the moisture content of Moringa leaves to the lowest value of 8.63%. A higher temperature (47 °C) with a shorter drying time (5 hours) was also effective in reducing the moisture content to 9.4%. The low moisture content obtained was considered safe for long-term storage of dried Moringa leaves and directly contributed to extending the product's shelf life. This is in line with what was stated by (Pin, 2024) that the critical residual moisture content (RMC) in leafy materials is generally in the range of 8–12%. This value is consistent with the results of this study, which show that the moisture content of dried leaves falls within that range.

An interesting finding was that at 47°C, the final moisture content tended to be slightly higher than at 44°C for the same drying duration, with S3W3 at 10.2% compared to S2W3 at 8.63%. This phenomenon may be associated with surface hardening effects during drying, where rapid moisture removal at higher temperatures can reduce moisture migration from the inner material layers (Leelawat & Taikerd, 2024; van der Sman *et al*., 2024).

Overall, the moisture content results indicate that increasing drying temperature generally enhanced water evaporation and reduced final moisture content. However, excessively high temperatures may contribute to less uniform moisture removal, highlighting the importance of appropriate temperature selection during drying.

3.2. Yield

The yield data (Table 4) showed a general tendency for yield values to decrease as drying temperature increased, although the pattern was also influenced by drying time. Higher yield values at 40 °C were mainly associated with slower moisture removal, resulting in higher residual moisture content in the dried samples. In contrast, lower yield values observed at higher temperatures were likely related to greater water evaporation during drying. Similar trends have been reported in drying studies of leafy materials, where increasing drying temperature generally reduced the final product weight due to enhanced moisture removal (Ambawat *et al*., 2022; Gębczyński *et al*., 2024).

The yield parameter showed different trends compared to moisture content. The obtained yield values were more complex, as they were influenced by tissue shrinkage and structural damage of the leaves during the drying process. The highest yield was found in treatment S1W3 (40 °C, 7 hours) at 56.47%, while the lowest yield was in S2W1 (44 °C, 3 hours) at 25.09%.

In addition to temperature, drying time also contributes to yield. A temperature of 40 °C with drying durations of 3 and 7 hours increases the yield because the dehydration process occurs slowly, thereby maintaining the stability of the leaf structure. However, the effect of drying time at higher temperatures is less optimal. This is evident from the slight

Table 4. Effect of treatment combinations on the yield of moringa leaves

Temperature	Yield (%)		
	W1 (3 h)	W2 (5 h)	W3 (7 h)
S1 (40 °C)	56.46±0.63^{a}	36.62±1.36^{b}	30.78±0.29^{d}
S2 (44 °C)	33.90±2.20^{c}	26.82±1.74^{ef}	25.09±0.48^{f}
S3 (47 °C)	28.82±1.81^{de}	26.55±0.22^{ef}	27.19±1.17^{ef}

Note: numbers followed by the same lowercase letter in the same column are not significantly different at the 5% level according to the DMRT test.

differences between S2W2 and S2W3, as well as S3W2 and S3W3. This indicates that after reaching a certain point, additional drying no longer increases yield because most of the water and volatile mass has been removed (Belwal *et al*., 2022). This phenomenon supports the fact that once most of the free and bound water is removed, further drying has only a limited effect on reducing water activity and product stability (He *et al*., 2021).

The interaction between temperature and drying time also shows that optimum yield does not always occur in treatments with the lowest moisture content. For example, a temperature of 44 ℃ for 7 hours had the lowest moisture content (8.63%) but not the highest yield (36.69%). Therefore, it can be seen that yield is not only determined by moisture content, but also by the stability of the dry biomass, which is affected by temperature. A study (Samad *et al*., 2023) reported that excessively high drying temperatures can reduce the stability and dry mass of moringa leaves. Based on the results obtained, it can be seen that drying temperature has a significant impact on moringa leaf yield. The evaporation process occurs more rapidly at higher temperatures, but this also increases biomass degradation, resulting in a tendency for yield to decrease. Conversely, using lower temperatures and longer drying times allows for more stable drying of the moringa leaves, resulting in a tendency for higher yield.

3.3. Leaf Color

Table 5 shows an interesting color trend in moringa leaves after being tested at various temperatures and drying times. The *L** (brightness) values ranged from 47.58 to 55.12, indicating significant variations in the brightness of dried Moringa leaves depending on the temperature and drying time used. A low temperature (40 ℃) and a drying time of 7 hours showed a relatively high *L** value of 55.12, meaning the leaves were brighter. Conversely, a high temperature (47 ℃) with a drying time of 3 hours gave a lower *L** value of 47.58, indicating darker leaves. This suggests that high temperatures and short drying times cause a decrease in brightness values due to faster pigment degradation at high temperatures (Tanggasari *et al*., 2023).

Table 5. Average color (*L* a* b**) of dried moringa leaves at different temperatures and drying time treatments

Treatments	*L**	*a**	*b**
S1W1	51.16±2.83	-11.03±1.07	12.22±1.69
S1W2	51.86±4.00	-11.80±0.31	13.48±2.50
S1W3	55.12±4.29	-12.86±0.88	14.86±2.19
S2W1	50.62±2.82	-10.56±1.61	12.51±1.96
S2W2	51.21±2.03	-11.92±0.32	12.50±0.76
S2W3	50.55±4.34	-12.34±1.20	12.66±2.00
S3W1	54.99±1.26	-12.51±1.12	14.98±1.98
S3W2	47.58±3.15	-10.66±0.31	10.14±1.34
S3W3	50.09±6.39	-11.79±1.18	12.36±3.10

Furthermore, the *a** value, which describes the dominance of red or green, shows that all drying treatments produced negative values. This indicates the dominance of green in the Moringa leaves after drying. Treatment with a temperature of 44°C and a time of 3 hours (S2W1) produced the highest *a** value (-10.56), indicating a more vigorous green intensity, while treatment with a temperature of 40 ℃ and a drying time of 7 hours (S1W3) produced the lowest *a** value (-12.86), indicating a lower green intensity. This phenomenon suggests that low temperatures with longer drying times are more effective at maintaining the green color of Moringa leaves, reducing chlorophyll degradation, and slowing color changes (Djaeni, *et al*., 2025).

The *b** value, which indicates the dominance of yellow or blue, shows an increase in the yellow hue in Moringa leaves after drying. The obtained *b** values ranged from 10.13 to 18.98. Drying at a high temperature (47 ℃) for 3 hours produced the highest *b** value (18.98), indicating an increase in yellow hue in leaves that dried faster at high temperatures. This suggests that high drying temperatures can accelerate chlorophyll degradation, leading to increased leaf yellowing. (Cai *et al*., 2023) suggested that high temperatures can damage chlorophyll and turn green leaves yellow more quickly.

The color changes that occur in moringa leaves after drying are indicated as a result of pigment degradation, especially chlorophyll. High temperatures often cause chlorophyll degradation during drying, so that chlorophyll degrades into pheophytin and causes the green color to turn paler or yellow (Thamkaew *et al*., 2020). The color values obtained in this study confirm that high temperatures cause the loss of most of the green pigment in moringa leaves. In contrast, low temperatures with longer drying times can slow chlorophyll degradation and maintain a better green color. (Hasizah *et al*., 2022) reported the results of their research, drying moringa leaves using the fluidized bed dryer method, and obtained an increase in L value (brighter), *a** becoming less damaging (decreasing green intensity), and *b** increasing (towards yellow), along with heating and drying time of moringa leaves.

Table 4 shows that a gradual drying or dynamic temperature strategy, starting with a high temperature and gradually lowering it, can produce better color quality than drying at a fixed temperature. (Raut *et al*., 2021) stated that this dynamic temperature strategy allows for more efficient drying in the initial stages while reducing pigment damage, making it effective in maintaining color quality in herbal products.

3.4. Proximate

The following proximate content data were obtained from two moringa leaf drying treatments, namely S2W3 (44°C, 7 hours) and S3W3 (44 °C, 7 hours), which each represent different drying temperatures and times. Proximate composition (Table 6) of dried moringa leaves shows that the drying treatment significantly affects several components, including dietary fiber and ash content. In contrast, protein, fat, and carbohydrates do not differ significantly.

The dietary fiber content in the S2W3 treatment was higher (8.65%) than in the S3W3 treatment (8.04%), and the difference was statistically significant with *p*-value of 0,02 (< 0.05). The high dietary fiber content at 44 °C indicates that complex polysaccharide structures such as hemicellulose and cellulose are relatively more stable at lower temperatures. Conversely, drying at 47 °C may trigger depolymerization of soluble fiber, thereby reducing its dietary fiber value. This phenomenon is in line with the finding that fiber components in leaves are more sensitive to overly aggressive thermal processes (Sui *et al*., 2025).

Table 6. Average values of proximate and dietary fiber content of dried moringa leaves

Treatments	Dietary fiber	Protein	Fat	Ash content	Carbohydrate
S2W3	8.65±0.29^{a}	22.10±1.93^{a}	1.82±0.07^{a}	9.68±0.11^{a}	49.12±1.47^{a}
S3W3	8.04±0.07^{b}	22.71±0.97^{a}	1.39±0.45^{a}	9.36±0.12^{b}	48.301.15^{a}
p-value	0.024	0.648	0.178	0.026	0.488

Note: numbers followed by the same lowercase letter in the same column are not significantly different at the 5% level according to Student's t-test.

The protein content of the two treatments did not differ significantly (*p*-value = 0.648), with values ranging from 22.09% to 22.71%. This lack of difference indicates that the drying temperatures of 44 °C to 47 °C have not reached a range that causes significant denaturation or degradation of leaf proteins. Plant proteins are generally stable under moderate heat treatments, so any small changes that occur are likely due to differences in final moisture content rather than molecular damage (Ma *et al*., 2022). Similarly, the fat content did not show significant difference (*p*-value = 0.178), and this can be explained by the fact that the lipid fraction of Moringa leaves is primarily composed of fatty acids, which are relatively resistant to oxidation at low to moderate drying temperatures (Sultana, 2020).

Unlike protein and fat, ash content showed significant differences with *p*-value of 0.026 (< 0.05). The S2W3 treatment showed a higher relative ash content compared to the other selected treatment. Variations in ash content may be associated with differences in moisture removal during drying, which can influence the relative concentration of mineral components in dried plant materials. Similar observations have been reported by (Calín-Sánchez *et al*., 2020; Sonkamble & Pandhure, 2017) who found that lower moisture content contributed to relatively higher ash concentrations in dried vegetable materials. The ash values obtained in this study were comparable to those reported in previous studies on dried moringa leaf products processed under moderate drying conditions (Jubaidah *et al*., 2026; Razzak *et al*., 2021). These findings indicate that controlled drying conditions may help maintain the mineral composition of dried moringa leaves.

The carbohydrate content did not differ significantly between the selected treatments ((p-value = 0.488). This result may be associated with the relatively moderate drying temperatures used in this study (44–47 ℃), which were likely insufficient to cause substantial changes in carbohydrate components. Similar observations were reported by (Saidu *et al*., 2023; Tjalo *et al*., 2024), who found that moderate drying temperatures generally maintained relatively stable carbohydrate levels in *Moringa oleifera* leaves and other plant materials. Since carbohydrate content was calculated by difference, variations in other proximate components may also have influenced the calculated carbohydrate values.

The overall proximate analysis results indicate that a temperature of 44 ℃ tends to yield more stable chemical composition in moringa leaves, particularly in dietary fiber, minerals, and moisture content. This stability reflects that moderate-temperature drying treatments are better able to maintain the structural and chemical integrity of the main nutritional components of moringa leaves, in line with various studies that emphasize the importance of temperature control in the drying process of leafy foods (Chen *et al*., 2022; Khatulistiwa *et al*., 2020; Losada-Echeberría *et al*., 2023; Sari *et al*., 2020). Therefore, a temperature of 44 ℃ with a drying time of 7 hours can be considered a more optimal drying condition than 47 ℃, especially for maintaining heat-sensitive nutritional quality.

4. CONCLUSIONS

The combination of drying temperature and drying time influenced the moisture content, yield, color characteristics, and selected nutritional properties of dried moringa leaves. Drying at 44 ℃ for 7 hours resulted in lower moisture content and better green color retention compared to several other treatments. This treatment also showed higher relative ash and dietary fiber contents among the selected proximate analysis treatments. These findings indicate that controlled solar thermal drying at moderate temperature conditions may help maintain the quality characteristics of dried moringa leaves.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION

Not applicable. The authors did not use any generative AI tools or services in the preparation of this manuscript. All content is entirely the intellectual work of the authors.

AUTHOR CONTRIBUTION

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
FE	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rad	✓	✓		✓		✓	✓	✓	✓	✓	✓		✓	

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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