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Evaluation of Different Drying Methods and Leaf Age on the Retention of Phytochemical and Nutritional Attributes of Moringa Leaf Powder

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Authors' contributions

This work was carried out in collaboration among all authors. Authors KRA and AKD conceptualized the study. Author RS performed the methodology. Authors RS and JJ did the formal analysis and investigation. Authors RS and JJ wrote original draft. Authors KRA, AKD and PKS wrote, reviewed and edited the manuscript. Author KRA searched for resources. Author KRA supervised the study. All authors read and approved the final manuscript.

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ABSTRACT

Moringa (*Moringa oleifera*), indigenous to India and Africa, is esteemed for its dual utility as a minor timber source and, more importantly, as a vegetable crop. The leaves of the moringa tree are exceptionally nutrient-dense, containing essential elements such as iron, calcium, proteins, vitamins A, C, and E, dietary fiber, phosphorus, and potassium, all vital for human health. Furthermore, these leaves are rich in antioxidants, including flavonoids and phenolics, which endow them with significant medicinal properties. Despite its sporadic cultivation hindering global availability, the production of moringa leaf powder presents a viable strategy to bolster its international export potential. This study aims to assess the efficacy of various drying techniques in producing moringa leaf powder while preserving its nutritional integrity. Conducted at the Post-Harvest Technology Laboratory within the Department of Horticulture, Rajasthan College of Agriculture, and the Department of Processing and Food Engineering, College of Technology and Agricultural Engineering at Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India, this research evaluates the nutritional quality of moringa leaf powder produced via different drying methods and from leaves of varying ages. Our findings indicate that the fluidized bed dryer excels in preserving the nutritional quality of the powder compared to tray and heat pump dryers. Additionally, the study concludes that heat pump dryers are unsuitable for producing high-quality moringa leaf powder.

Keywords: Moringa; leaf powder; drying; fluidized bed dryer; quality; nutritional profile.

1. INTRODUCTION

Moringa (*Moringa oleifera*) is a tropical tree originating from India and Africa, valued for its role as a crucial vegetable crop despite its low-quality timber. Known as a "superfood" because of its nutrient-dense leaves, moringa has gained traction among small-scale farmers [1]. India stands as the largest producer, with an annual production of approximately 2.2 million tonnes of tender fruits from around 38,000 hectares of cultivated land.

Moringa leaves are an exceptional source of essential nutrients, including iron, calcium, proteins, vitamins A, C, and E, dietary fiber, phosphorus, and potassium, all crucial for human health. Their high antioxidant content, particularly flavonoids and phenolics, also provides significant medicinal benefits. The nutrient profile of moringa leaves effectively addresses global issues such as childhood malnutrition and anemia, and they are traditionally used to treat hypertension. Additionally, dried moringa leaves are utilized as raw materials in the pharmaceutical, confectionery, animal feed, and nutraceutical industries [1]. They are also versatile in culinary uses, with fresh leaves being added to soups, salads, fried foods, and curds [2].

Moringa is distinguished by its exceptionally high content of fat-soluble vitamins A, D, E, and K, as well as water-soluble vitamins B and C. It is also rich in essential minerals such as calcium, copper, iron, potassium, magnesium, manganese, and zinc. Dried moringa leaves are notable for their impressive micronutrient density, containing over 40 natural antioxidants. Remarkably, they provide ten times the vitamin A of carrots, 17 times the calcium of milk, 15 times the potassium of bananas, 25 times the iron of spinach, and nine times the protein of curd [3]. Drying, a preservation technique that dates back to prehistoric times, remains vital in the modern food supply chain.

Drying methods, including air/contact drying, freeze drying, and vacuum drying, function by reducing the water content in food, thereby preventing or slowing down spoilage caused by microorganisms [4]. Removing moisture inhibits microbial growth, mitigates moisture-related degradation, and decreases the weight and volume of the food. This reduction leads to lower costs for packaging, storage, and transportation, and enables prolonged storage at ambient temperatures. Various dryers, such as mechanical hot air dryers (tray, tunnel, and drum dryers), microwave dryers, solar dryers, freeze dryers, heat pump dryers, fluidized bed dryers, and vacuum dryers, are used to achieve this. Each drying technique requires specific parameters, including variety selection, slice size, drying time, microwave power settings, and dryer temperatures, to produce the highest quality end products. The main goals of crop drying are to extend shelf life, enhance quality, simplify handling, storage, and transportation, and prepare the product for further processing.

The tray dryer is frequently utilized in agricultural drying due to its straightforward design and capacity to dry large volumes. Nonetheless, its primary limitation is the uneven drying resulting from poor airflow distribution within the drying chamber. Conversely, fluidized bed dryers (FBD) are extensively used across various industries for drying particulate solids. They offer benefits such as effective mixing of solids, high rates of heat and mass transfer, and ease of handling materials. However, efficient operation of FBDs necessitates continuous monitoring and control of factors such as the fluidization regime, particle size distribution (PSD), moisture content, bulk density, and chemical properties of the product [5]. Heat pump systems, well-researched for applications including space heating, cooling, and dehumidifying, have been adapted and integrated with other mechanisms to improve performance. Specifically, heat pump dryers are advantageous for preserving the quality of food and agricultural products by allowing precise control over drying parameters such as temperature, relative humidity, moisture extraction, air velocity, and drying duration [6-9].

Moringa leaf powder, valued for its nutritional benefits, needs to be stored in airtight containers, shielded from direct heat, humidity, and light. Improper drying or storage conditions can foster the growth of harmful molds or mildews, leading to issues such as unpleasant odors and the production of health-threatening chemicals. Considering the nutritional importance of moringa leaves and the diversity of drying methods, this study aims to standardize drying techniques for both fresh and two-month-old moringa leaves and to assess the quality of the stored dried moringa leaf powder

2. MATERIALS AND METHODS

The experimentation was conducted at the Post-Harvest Technology Laboratory within the Department of Horticulture, Rajasthan College of Agriculture, and the Department of Processing and Food Engineering, College of Technology and Agricultural Engineering, Maharana Pratap University of Agriculture and Technology, situated in Udaipur, Rajasthan, India. Freshly sprouted (7-10 days) and two-month-old leaves of *Moringa oleifera* were procured from the Horticulture Farm of Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India. The drying process was executed using three distinct drying apparatuses: the tray dryer, heat pump dryer, and fluidized bed dryer. In the tray dryer, a quantity of 100 grams of moringa leaves was evenly distributed on a tray, forming a single layer, and subjected to a temperature of 60°C with a constant air velocity of 2 meters per second. In the fluidized bed dryer, moringa samples weighing 100 grams were dried at 60°C with an air velocity of 10 meters per second. Subsequently, the dried leaves from each drying method were pulverized using both a mortar and pestle and a Cyclotech grinder, followed by filtration through a 32-mesh sieve to obtain a fine powder. The resulting powder was then packaged in 80-micron LDPE (Low-density polyethylene) bags and stored for a period of 90 days under ambient conditions within the Post-Harvest Technology Laboratory.

The methodologies employed for conducting both physical and biochemical analyses are delineated as follows. The drying rate of the samples was calculated utilizing the formula proposed by Kadam et al. [10]. The moisture content of moringa leaves was assessed employing the standard hot air oven method in accordance with AOAC [11] guidelines. The dehydration ratio was determined by measuring the initial and final masses of moringa leaves, representing the ratio of the weight of the dehydrated sample to the initial weight of fresh leaves. Bulk density values were determined by dividing the mass of the powder by the volume it occupied in the cylinder, following the method described by Goula et al. [12]. Moreover, the total ash and crude fiber contents of moringa leaves were analyzed using a muffle furnace. The crude protein content was determined utilizing the micro Kjeldahl method as described by Steyermark et al. [13], while the ascorbic acid content was evaluated following the procedure outlined by Serban et al. [14]. The carotenoid content was assessed using the colorimetric method as outlined by Ranganna [15].

The Total Soluble Solids (TSS) were determined utilizing a handheld refractometer, with measurements taken within the range of 0 – 45 °Brix (QA Supplies, LLC). The samples were thoroughly mixed, and a small quantity was applied onto the prism of the refractometer, with direct readings obtained by interpreting the scale in meters. The outcomes were expressed in °Brix at a temperature of 20°C, following the guidelines outlined in AOAC [16]. Phenolic compounds were evaluated based on their reaction with an oxidizing agent, phosphomolybdate, in Folin-Ciocalteu reagent under alkaline conditions, resulting in the formation of a blue-colored complex, molybdenum blue, which was quantified colorimetrically at 650nm [17]. The levels of calcium, phosphorous, and potassium were determined using methods recommended by AOAC [11]. The Water Solubility Index (WSI) determined the release of polysaccharides or polysaccharide granules upon the addition of excess water, as outlined by Anderson and Griffin [18]. WSI represented the weight of dry solids in the supernatant from the water absorption index test, expressed as a percentage of the initial weight of the sample. The water activity of moringa leaf powder was measured using a digital water activity meter, with the powder samples placed in contact with the sensor probe, and the resulting water activity values recorded. The color of the dried moringa samples was assessed using a Hunter Lab Colorimeter. The lightness index of color, denoted as L*, a*, and b* scales, were utilized for color determination in the Hunter Lab Colorimeter. The color values L*, a*, and b* indicated lighter (+L) vs. darker (-L), red (+a) vs. green (-a), and yellow (+b) vs. blue (-b) hues, respectively. Color evaluation was conducted for both dried moringa leaves and moringa powder.

The research was carried out utilizing a completely randomized design. Data gathered on diverse characteristics underwent statistical scrutiny employing analysis of variance methods as prescribed by Gomez and Gomez [19]. The appendices furnish the outcomes of the analysis of variance for distinct parameters. The critical difference (CD) was calculated to ascertain the significance or insignificance of variances among treatment means.

3. RESULTS AND DISCUSSION

3.1 Effect of different dryers on the mechanical and physiological attributes of moringa leaf powder

The effects of different dryers on the mechanical and physiological attributes on the moringa leaf powder are presented in Fig. 1. Among the fresh leaf samples, D3 (utilizing fluidized bed drying) displayed the highest drying rate at 9.50 g-water/g dry matter-hour, while D1 (employing tray drying) exhibited the lowest rate at 4.16 g-water/g dry matter-hour. Similarly, for the aged leaf samples, D3 again demonstrated the highest drying rate at 7.81 g-water/g dry matter-hour, with D1 showing the lowest rate at 3.21 g-water/g dry matter-hour. Across all experiments, drying rates consistently decreased, following a typical declining trend during the drying process. This reduction in drying rate towards the end can be attributed to the diminishing availability of moisture as the drying process progresses. These findings are in agreement with those documented by Taheri-Garavand and Meda [20] for savory leaves and Shravya et al. (2019) for guava leaves.

The bulk density of moringa leaf powder exhibited a consistent decline throughout the storage duration. Among the various drying methods, the highest bulk density (0.46 g/cm^3) was observed in D3 (utilizing fluidized bed drying) on day 0 for fresh leaves, with this density decreasing over time. Conversely, the lowest value (0.27 g/cm^3) was recorded in D2 (employing heat pump drying) on day 90 for aged leaves. This reduction in bulk density during storage is attributed to alterations in particle size and an increase in moisture content. Comparable observations were reported by Bandral [21] in amaranthus, radish, and chickpea leaves.

The water absorption index exhibited its highest value on day 0 post-storage and gradually decreased throughout the storage period. Among the drying methods, D1 (Tray drying) maintained the highest water absorption index, with fresh leaves displaying a higher index compared to aged ones. Specifically, the maximum water absorption index (3.82 g) was registered on day 0 for fresh leaves subjected to D1 (Tray drying), while the minimum value (3.12 g) was noted on day 90 for aged leaves subjected to D3 (Fluidized bed drying). This decline in water absorption index is consistent with findings reported by Yousf et al. [22] in rice.

Similarly, the water solubility index demonstrated its highest value on day 0 post-storage and decreased progressively throughout the storage period. Among the drying methods, D1 (Tray drying) maintained the highest water solubility index, with fresh leaves exhibiting a higher index compared to aged ones. Specifically, the maximum water solubility index (3.92%) was observed on day 0 for fresh leaves subjected to D1 (Tray drying), while the minimum value (3.41%) was recorded on day 90 for aged leaves subjected to D3 (Fluidized bed drying). Comparable trends were observed by Looi et al.

[23] in moringa leaf powder and Yousf et al. [22] in rice.

Among the drying methods, D3 (Fluidized bed drying) retained the highest water activity, with aged leaves exhibiting a higher value compared to fresh ones. Specifically, the maximum water activity (0.30) was documented on day 90 for aged leaves subjected to D3 (Fluidized bed drying), while the minimum value (0.23) was observed on day 0 for fresh leaves subjected to D2 (Heat pump drying). Throughout the storage duration, the water activity increased, likely due to moisture absorption during storage in moringa leaf powder, and the uptake of moisture from the environment contributing to this rise in water activity. Similar observations were reported by Bandral et al. [21] in amaranthus, radish, and chickpea leaves.

3.2 Effect of Different Dryers on the Nutritional Quality of Moringa Leaf Powder

The effects of different dryers on the nutritional attributes on the moringa leaf powder are presented in Fig. 2. Among the fresh leaf samples, initial moisture contents averaged 264.96%, 267.65%, and 267.65% (on dry basis) for tray drying, heat pump drying, and fluidized bed drying, respectively. Corresponding averages for old leaf samples were 217.46%, 238.98%, and 214.47% (on dry basis). Following the drying process, final moisture contents decreased to 5.75%, 4.10%, and 4.43% (on dry basis) for tray drying, heat pump drying, and fluidized bed drying, respectively. This reduction in moisture content is attributed to continuous evaporation of moisture into the air during drying. The shortest drying duration was observed at the highest drying air temperature (60 ºC). These findings are consistent with those reported in prior studies on various leafy vegetables and drumstick leaves, such as tray drying by Gernah et al. [24] and curry leaves by Vijayan et al. [25].

Among the fresh leaf samples, D1 (tray drying) demonstrated the highest dehydration ratio at 0.33, while D3 (fluidized bed drying) exhibited the lowest at 0.28. For old leaf samples, D3 again displayed the maximum dehydration ratio at 0.33, with D1 recording the minimum at 0.29. This result is in line with similar findings documented by Kushwaha and Mustafa [26] for fenugreek leaves and Kaur et al. [27] for coriander leaves.

The ash content initially peaked on day 0 of storage and gradually declined over time. Among the different drying methods, tray drying (D1) retained the highest ash content, with aged leaves exhibiting greater ash values compared to fresh ones. Specifically, the highest ash content (14.00%) was observed on day 0 for aged leaves subjected to tray drying (D1), while the lowest value (9.00%) occurred on day 90 for fresh leaves subjected to fluidized bed drying (D3). Throughout the storage period, there was a slight decrease in ash content, likely due to increased moisture content resulting from prolonged storage, a phenomenon similarly observed in carrot and onion slices by Gupta and Shukla [28].

The crude protein content exhibited a consistent decrease throughout the storage period, irrespective of drying methods and leaf type. The highest crude protein content was observed on day 0 after storage, gradually diminishing over time. Among the drying methods, fluidized bed drying (D3) retained the highest crude protein content, with aged leaves displaying higher crude protein content compared to fresh ones. Specifically, the maximum crude protein content (28.53%) was recorded on day 0 for aged leaves subjected to fluidized bed drying (D3), while the minimum value (25.18%) occurred on day 90 for fresh leaves subjected to heat pump drying (D2). The data suggests a decline in crude protein content of moringa leaf powder with the progression of storage, potentially attributed to increased water activity activating certain enzymes due to respiration. This observation is consistent with similar results reported by Khan et al. [29] in soybean.

The crude fiber content exhibited its highest level on day 0 post-storage and decreased during the storage duration. Among the various drying methods, the peak crude fiber content (13.03%) was observed in fluidized bed drying (D3) on day 0 for aged leaves, showing a decline over time. Conversely, the lowest value (10.74%) was recorded in heat pump drying (D2) on day 90 for fresh leaves. This reduction in crude fiber during storage is likely attributable to the degradation of hemicelluloses and other polysaccharides, along with the breakdown of pectic substances facilitated by heat and moisture solubilizers. Similar trends were documented by Sharon and Usha [30] in breadfruit and Singh et al. [31] in pearl millet.

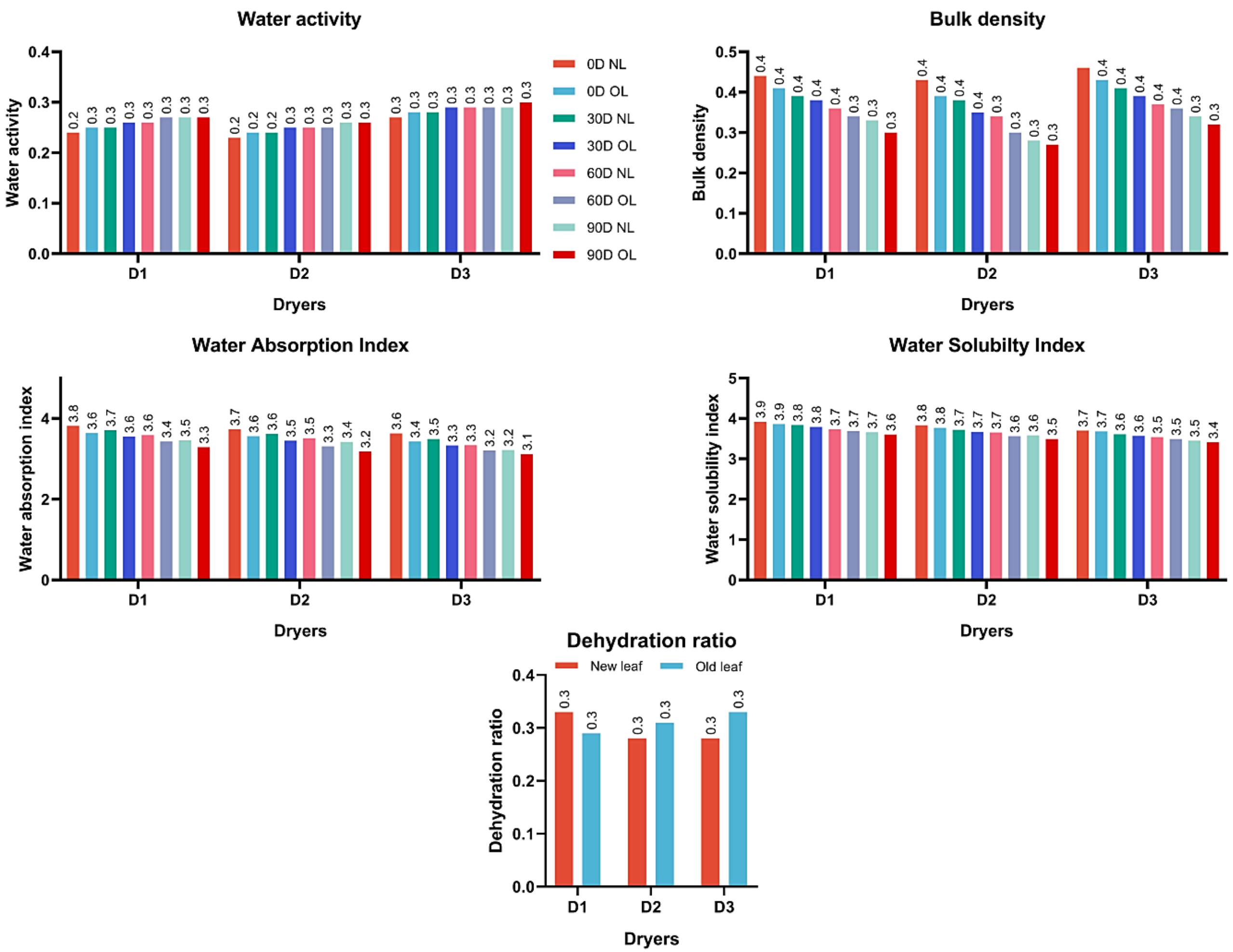

Fig. 1. Effect of different dryers on the physiological attributes of moringa leaf and its powder

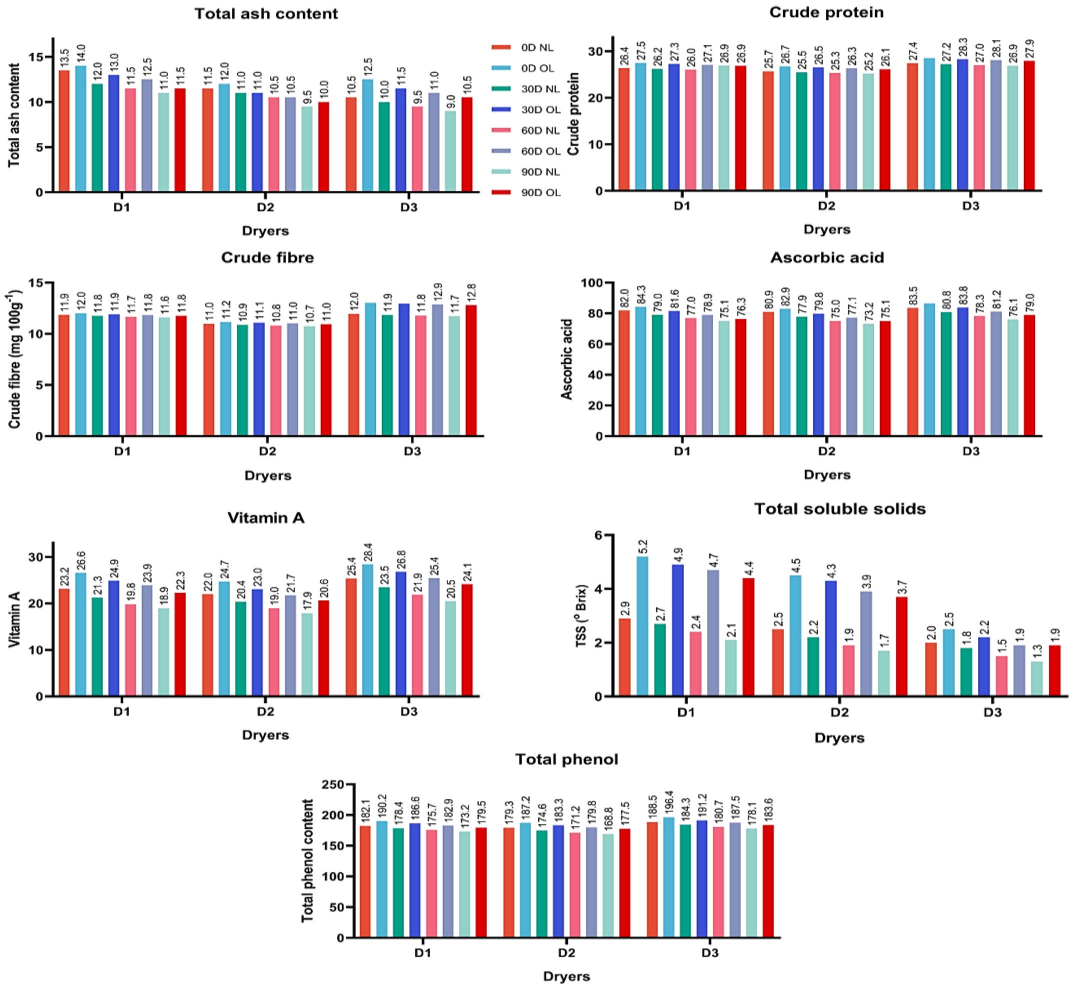

Fig. 2. Effect of different dryers on the nutritional attributes of moringa leaf and its powder

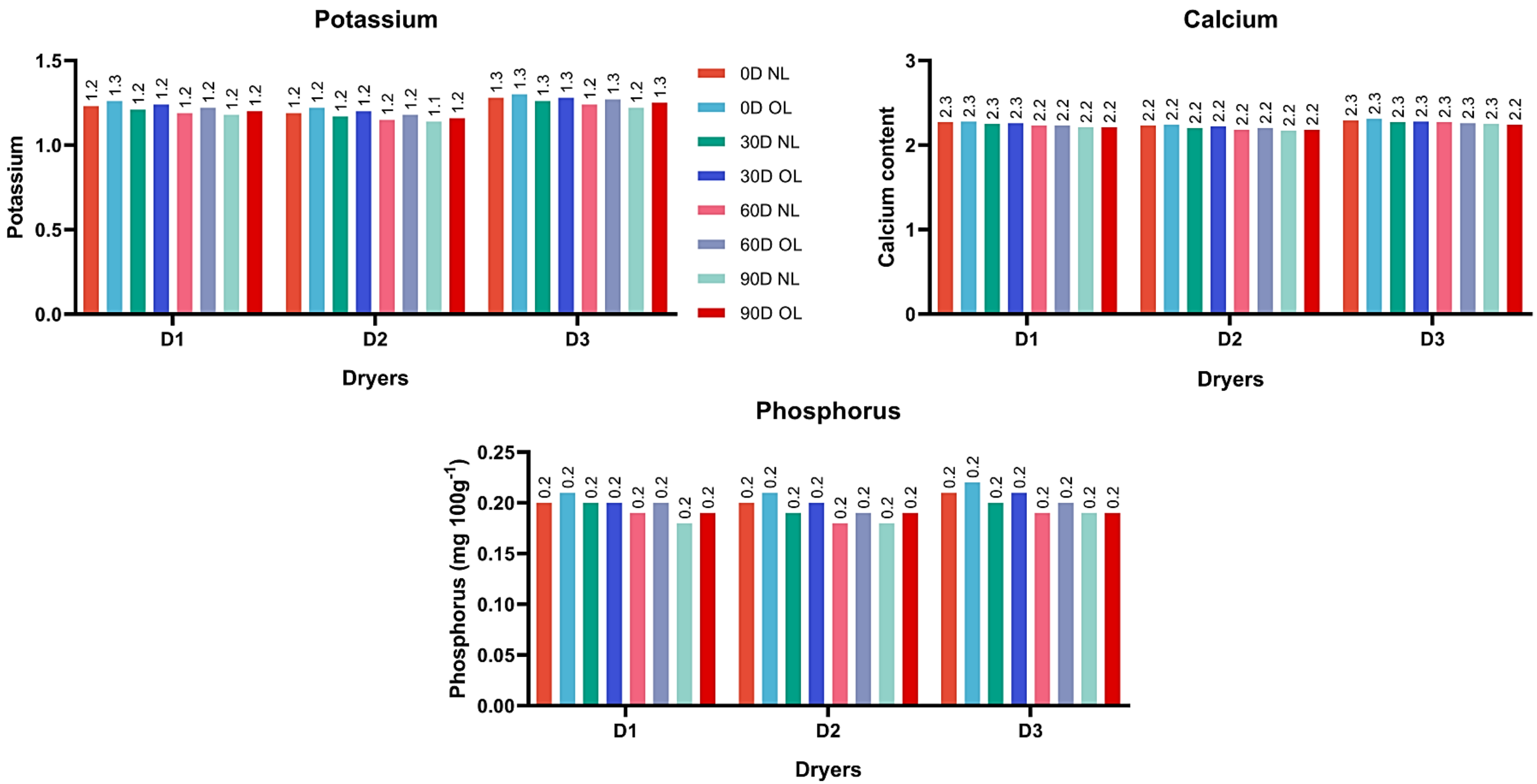

Fig. 3. Effect of different dryers on the micronutrient contents of moringa leaf and its powder

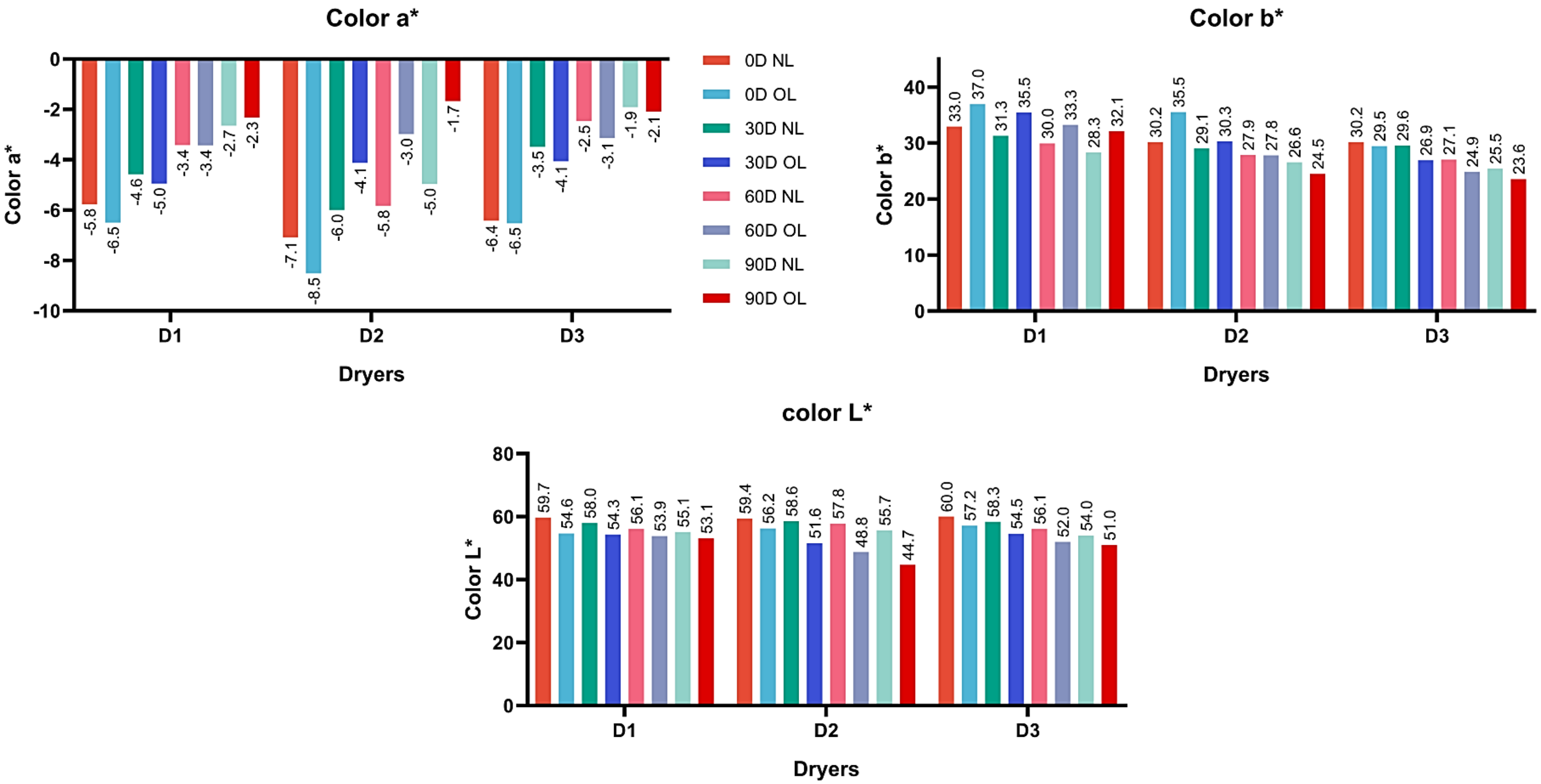

Fig. 4. Effect of different dryers on the color values of moringa leaf and its powder

The ascorbic acid content of moringa leaf powder was not significantly affected by different drying methods but declined over the storage period. The highest ascorbic acid content (86.43 mg/100g) was observed in fluidized bed drying (D3) on day 0 for aged leaves, showing a decrease with storage and reaching a minimum value (73.18 mg/100g) in heat pump drying (D2) on day 90 for fresh leaves. The Fig. 2 illustrates a consistent decline in ascorbic acid content throughout the storage period, likely due to the oxidation of ascorbic acid, leading to the formation of dehydro-ascorbic acid catalyzed by the enzyme ascorbinase during storage. This observation is consistent with similar findings reported by Seevaratnam et al. [32] in green leafy vegetables and Udikala et al. [33] in moringa leaves.

The highest vitamin A content (28.38 mg/100g) was noted in fluidized bed drying (D3) on day 0 for aged leaves, declining with storage to a minimum value (17.89 mg/100g) in heat pump drying (D2) on day 90 for fresh leaves. The decrease in vitamin A content during storage is attributed to thermal treatment, resulting in thermal degradation. This observation aligns with findings by Gupta and Shukla [28] in carrot and onion slices, where thermal degradation led to a reduction in vitamin A content. The decline in vitamin A during storage is likely influenced by oxidative and non-oxidative changes, given its sensitivity to heat. Similar results were reported by Seevaratnam et al. [32] in green leafy vegetables during storage.

The total soluble solids (TSS) content peaked on day 90 post-storage and declined throughout the storage period. Among the drying methods, tray drying (D1) retained the highest TSS content, with aged leaves displaying a greater TSS value compared to fresh ones. Specifically, the maximum TSS content (5.20 °Brix) was recorded on day 0 for aged leaves under tray drying (D1), while the minimum value (1.30 °Brix) was observed under fluidized bed drying (D3) on day 90 for fresh leaves. The decrease in TSS content during storage may be attributed to an increased rate of respiration. Similar findings have been reported by Gil et al. [34] and Pelayo et al. [35] in strawberry fruit.

Among the different drying methods, the highest total phenol content (196.40 mg/100g) was observed in fluidized bed drying (D3) on day 0 for aged leaves, decreasing with storage to a minimum value (168.81 mg/100g) in heat pump drying (D2) on day 90 for fresh leaves. The decline in total phenol content during the storage period is attributed to the oxidation of polyphenols by polyphenol oxidase and increased polymerization of tannins. Similar observations were reported by Mokhtar et al. [36] in pumpkin.

3.3 Effect of Different Dryers on the Micronutrients of Moringa Leaf Powder

The effects of different dryers on the micronutrient levels on the moringa leaf powder are presented in Fig. 3. The potassium content of moringa leaf powder exhibited a consistent decrease throughout the entire storage period. Among the various drying methods, the highest potassium content (1.30g/100g) was observed in fluidized bed drying (D3) on day 0 for aged leaves, decreasing with storage to a minimum value (1.14g/100g) in heat pump drying (D2) on day 90 for fresh leaves. Comparable observations were reported by Verma et al. [37] in guava powder and Mensah et al. [38] in moringa leaves.

Among the drying methods, fluidized bed drying (D3) retained the highest calcium content, with aged leaves displaying a greater calcium value compared to fresh ones. Specifically, the maximum calcium content (2.31 g/100g) was recorded on day 0 for aged leaves under fluidized bed drying (D3), while the minimum value (2.17 g/100g) was observed on day 90 for fresh leaves under heat pump drying (D2). Comparable results were reported by Adsure and Chavan [39] in fenugreek, spinach, and coriander leaves, as well as by Verma et al. [37] in guava powder.

The phosphorus content reached its peak on day 0 post-storage and declined during the storage period. Among the drying methods, fluidized bed drying (D3) retained the highest phosphorus content, with aged leaves exhibiting a higher phosphorus value compared to fresh ones. Specifically, the maximum phosphorus content (0.22 g/100g) was recorded on day 0 for aged leaves under fluidized bed drying (D3), while the minimum value (0.18 g/100g) was observed on day 90 for fresh leaves under heat pump drying (D2). Similar observations were reported by Verma et al. [37] in guava powder and Mensah et al. [38] in moringa leaves.

3.4 Effect of Different Dryers on the Color Values of Moringa Leaf Powder

The effects of different dryers on the color attributes on the moringa leaf powder are presented in Fig. 4. The color of the product plays a crucial role in determining its quality, affecting consumer appeal and market value. Various drying methods had a significant impact on the initial color of the dehydrated product in this study. Furthermore, the color of the dehydrated product decreased with extended storage duration. In fresh leaf samples, the highest L* value (60.04) was observed in fluidized bed drying (D3) on day 0, while the lowest L* value (53.96) was noted in fluidized bed drying (D3) on day 90. The maximum CIE a* color coordinate (-7.08) was found in heat pump drying (D2) on day 0, whereas the minimum (-1.91) was observed in fluidized bed drying (D3) on day 90. Similarly, the maximum CIE b* color coordinate (35.98) was recorded in fluidized bed drying (D3) on day 30, while the minimum (25.45) was observed in fluidized bed drying (D3) on day 90. Moreover, the maximum CIE b* color coordinate (36.97) was noted in tray drying (D1) on day 0, while the minimum (23.55) was observed in fluidized bed drying (D3) on day 90. These findings are consistent with the results reported by other researchers, such as Ali et al. [40] for moringa leaves, Kaur et al. [27] for coriander leaves, and Donkar et al. [41] for moringa leaves. Fig. 1 illustrates the trend of these parameters, elucidating the influence of different dryers on both new and old moringa leaves [42].

4. CONCLUSION

This study extensively examines the effectiveness of different drying methods—namely tray drying, heat pump drying, and fluidized bed drying—in preserving the physical and chemical attributes of moringa leaf powder. Among these techniques, fluidized bed drying emerges as the most efficient in maintaining superior qualities such as vitamin A, ascorbic acid, total phenol, crude fiber, crude protein, calcium, potassium, phosphorus, and color. Notably, aged leaves demonstrate a higher retention of quality characteristics compared to fresh leaves. Regardless of the selected drying method and leaf type, there is a slight reduction in quality parameters observed with the advancement of storage. This thorough investigation provides insights into the nuanced influence of drying methods on the nutritional and chemical composition of moringa leaf powder, highlighting the superior performance of fluidized bed drying in preserving its essential attributes.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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