Effects of Drying Method and Temperature on Sweet Potato Leaf Powder Quality and Its Application in Nutrientdense Snack Cakes

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Abstract

This study aimed to identify a suitable drying condition for sweet potato leaves and evaluate the use of the resulting powder in nutrient-dense rice-based snack cakes. Sweet potato leaves were dried by convection and heat-pump methods at (35, 45, and 55) °C, followed by physicochemical, nutritional, antioxidant, texture, and sensory analyses. Heat-pump drying at 45 °C provided the best overall performance, with 14.55% recovery yield, 7.35% moisture, and the highest β-carotene content (141.83 mg/kg), while maintaining high dietary fiber levels. Increasing sweet potato leaf powder from 30% to 50% improved protein, dietary fiber, β-carotene, total polyphenols, and antioxidant activity. The 5:5 rice flour-to-leaf powder formulation achieved the highest protein (10.22 g/100 g), total dietary fiber (16.71 g/100 g), and overall liking (7.60/9). The present study provided an integrated drying-product formulation approach for valorizing sweet potato leaf by-products into acceptable, nutrient-dense snacks.

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Keywords

Sweet potato leaf; heat-pump drying; snack; sensory; sustainable development.

1 Introduction

Sweet potato (*Ipomoea batatas* – SP) is widely cultivated in Viet Nam and generates a large amount of leafy biomass during harvest and post-harvest handling [1]. In addition to the tuber, SP leaves contain protein, dietary fiber, carotenoids, and phenolic compounds that are relevant to human health and food diversification [2,3]. However, due to high initial moisture, the leaves deteriorate rapidly after harvest, and are often used as low-value animal feed or discarded. Therefore converting the leaves into stable powder is a practical way to extend shelf life and broaden their use in food products such as porridge, bread, and snacks [4,5]. Drying conditions strongly influence moisture removal, color preservation, texture, and the retention of antioxidant compounds [6-8]. Studies on plant powders and dried fruit by-products have shown that moderate drying temperatures can improve the release of phenolics and carotenoids, whereas excessive heat accelerates degradation and quality loss [8, 9]. Based on this background, the present study compared convection drying and heat-pump drying at (35, 45, and 55) °C for SP leaf powder and then applied the selected powder to rice-based snack cakes. The objective was to identify a practical drying condition and to evaluate the effects of powder addition on nutritional quality, texture, and consumer acceptance.

2 Materials and Research Methodology

2.1 Raw Material and Sample Handling

SP leaves, including leaves, young shoots, and tender vine tips, were collected from the former Vinh Long

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Province, Viet Nam. Only fresh, disease free material of approximately 20 cm in length was selected. After harvest, the samples were placed in insulated boxes with ice packs, transported to the laboratory within 4 h, stored at (4 ± 1) °C, and processed within 24 h.

2.2 Preparation of SP Leaf Powder

The leaves were washed with potable water to remove soil and extraneous matter, drained, and loaded onto aluminum trays at 1.0 kg per batch. Drying was performed by convection drying and heat-pump drying at 35 °C, 45 °C, and 55 °C until the moisture content was below 10%. The dried leaves were cooled to room temperature, milled, and sieved through a 150 µm mesh. The powder was packed in laminated polyethylene bags, protected from light, and stored at room temperature for no longer than 24 h before analysis.

2.3 Preparation of Snack Cakes

The powder selected from the drying trial was blended with rice flour at ratios of 7:3, 6:4, and 5:5 (rice flour : SP leaf powder, w/w). The mixture was kneaded with water to form dough, sheeted, pre-dried, cut into small pieces, and deep-fried for 5 s. After frying, the snack cakes were drained, cooled, packed in zip bags, and analyzed on the same day.

2.4 Analytical Methods and Statistical Analysis

Recovery yield was calculated as Equation (1)

$$H\ (\%) = msmd \times 100 \quad (1)$$

where md is the initial mass (g) and ms is the dried mass (g).

Moisture ratio was calculated as Equation (2)

$$M = mH_2Omdry \times 100 \quad (2)$$

where M is the moisture ratio in grams of water per gram of dry matter, mH2O is the mass of water in the material (g), mdry is the mass of dry matter in the material (g)

The analytical methods used for physicochemical evaluation are summarized in Table 1. All measurements were performed in triplicate. Results are reported as mean ± standard deviation. One way analysis of variance followed by Tukey's test was used to detect differences at $p < 0.05$ using IBM SPSS Statistics 26.

Table 1 Analytical Methods Used for Physicochemical Evaluation

Parameter	Method/standard	Brief description and reporting unit
Moisture	TCVN 4415:1987	Oven drying to constant mass; %
Color	NR111 Precision Colorimeter (Shenzhen 3nh Technology Co., Ltd., China)	CIELAB L^*, a^*, b^* values
Carbohydrate	SOP.01-445:2022	Calculated by difference; g/100 g
Total lipid	SOP.01-194:2021	Solvent extraction; g/100 g
Protein	TCVN 10034:2013	Kjeldahl determination; g/100 g
Ash	SOP.01-196:2021	Dry ashing; g/100 g
Total and soluble dietary fiber	AOAC 991.43	Enzymatic-gravimetric method; g/100 g
β-Carotene	QTTN/KT3 241:2019 based on AOAC 2005.07	Spectrophotometric quantification; mg/kg
Energy	TCVN 7088:2015	Calculated energy value; kcal/100 g
Total polyphenol content (TPC)	Folin-Ciocalteu assay	Reported as mg GAE/g dry weight (DW)
DPPH radical-scavenging activity	Standard methanolic DPPH assay	Measured at 550 nm and reported as mg TE/g DW

3 Results and Discussion

3.1 Drying Performance and Color of SP Leaf Powder

Drying time decreased as temperature increased for both methods. Convection drying required 20 h, 8 h, and 6 h at 35 °C, 45 °C, and 55 °C, respectively, whereas heat pump drying required 12 h, 8 h, and 6 h. Moisture content decreased with increasing temperature for both methods (Table 2). Convection drying reduced moisture from (8.44 ± 0.34)% at 35 °C to (5.53 ± 0.10)% at 55 °C, while heat pump drying reduced it from (8.25 ± 0.12)% to (5.24 ± 0.11)%. Recovery yield also declined as temperature increased, indicating greater solids loss or structural shrinkage at severe conditions. At 45 °C, heat-pump drying gave a higher recovery yield than convection drying ((14.55 ± 0.20)% vs. (13.42 ± 0.19)%) while still maintaining moisture below 10%.

Table 2 Moisture Content and Recovery Yield of SP Leaf Powder

	Convection Drying			Heat Pump Drying		
	35 °C	**45 °C**	**55 °C**	**35 °C**	**45 °C**	**55 °C**
Moisture (%)	8.44 ± 0.34^{d}	6.59 ± 0.18^{b}	5.53 ± 0.10^{a}	8.25 ± 0.12^{d}	7.35 ± 0.11^{c}	5.24 ± 0.11^{a}
Recovery yield (%)	14.82 ± 0.14^{cd}	13.42 ± 0.19^{b}	12.50 ± 0.31^{a}	15.45 ± 0.27^{d}	14.55 ± 0.20^{c}	12.76 ± 0.24^{a}

Within the same row, means followed by different letters are significantly different at $p < 0.05$.

The color data likewise favored the heat pump treatment following Figure 1. Lightness (L*) increased with temperature, and heat pump dried samples retained greener tones (negative a* values) and slightly higher yellowness (positive b* values) than convection-dried samples at the same temperature. At 45 °C, the heat-pump powder showed a balanced color profile together with acceptable moisture and yield. Similar temperature dependent drying behavior has been reported for other plant matrices [6-8]. Therefore, heat pump drying at 45 °C was selected for further product development.

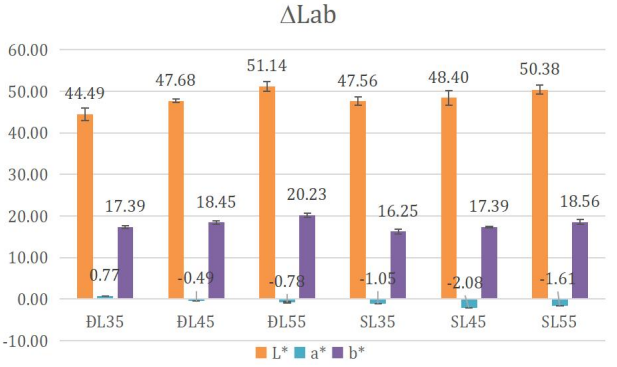


Figure 1 Graph depicting the CIELAB (L*, a*, b*) color values of SP leaf powder

3.2 Nutritional and Antioxidant Properties of SP Leaf Powder

Nutrient retention was strongly affected by drying condition (Table 3). For heat pump drying, soluble dietary fiber was highest at 45 °C (13.49 ± 0.16) g/100 g, while insoluble dietary fiber remained high at (35-45) °C and then declined markedly at 55 °C. β-Carotene also peaked at 45 °C (141.83 ± 0.16) mg/kg, suggesting that this moderate drying condition provided a favorable balance between carotenoid extractability/retention and thermal degradation [8,9].

In contrast, total polyphenol content and DPPH radical-scavenging activity were highest at 35 °C under heat-pump drying, but this condition required longer drying time. The decrease in TPC and DPPH values at 55 °C for both methods indicates thermal and oxidative degradation of heat-sensitive compounds, which agrees with previous reports on dried fruit and plant powders [9]. When drying time, recovery yield, color, dietary fiber retention, and β-carotene stability were considered together, heat-pump drying at 45 °C was considered the most suitable condition among the laboratory-scale treatments investigated in this study. This selection was based on drying performance and product-quality indicators and should not be interpreted as evidence of industrial economic superiority. Industrial feasibility should therefore be verified through pilot- or industrial-scale techno-economic analysis incorporating specific energy consumption, equipment capacity and depreciation, labor and maintenance, production throughput, final powder yield, and unit production cost in comparison with conventional drying.

Table 3 Nutritional Composition and Antioxidant Properties of SP Leaf Powder

	Convection Drying			Heat Pump Drying		
	35 °C	**45 °C**	**55 °C**	**35 °C**	**45 °C**	**55 °C**
Soluble dietary fiber (g/100 g)	9.76 ± 0.16^{b}	11.61 ± 0.09^{c}	6.76 ± 0.18^{a}	13.47 ± 0.27^{d}	13.49 ± 0.16^{d}	6.84 ± 0.12^{a}
Insoluble dietary fiber (g/100 g)	20.53 ± 0.32^{b}	25.23 ± 0.17^{c}	15.51 ± 0.36^{a}	27.94 ± 0.54^{d}	27.99 ± 0.32^{d}	15.67 ± 0.23^{a}
β-Carotene (mg/kg)	90.14 ± 0.08^{b}	131.48 ± 0.25^{e}	74.54 ± 0.27^{a}	115.40 ± 0.16^{c}	141.83 ± 0.16^{f}	119.69 ± 0.25^{d}

TPC (mg GAE/g DW)	1049.51 ± 60.15[a]	1113.70 ± 117.09[a]	991.85 ± 11.97[a]	1800.00 ± 63.05[d]	1487.89 ± 28.06[c]	1033.25 ± 45.95[a]
DPPH (mg TE/g DW)	281.69 ± 13.17[c]	259.91 ± 19.66[c]	84.55 ± 7.14[a]	572.80 ± 3.00[e]	319.22 ± 13.91[d]	119.51 ± 5.87[b]

Within the same row, means followed by different letters are significantly different at $p < 0.05$.

3.3 Quality of Snack Cakes Fortified with SP Leaf Powder

Using the powder produced by heat pump drying at 45 °C, increasing the proportion of SP leaf powder in the snack formulation increased hardness, bioactive compounds, and nutritional value (Tables 4 and Table 5). Hardness increased from (28.66 ± 0.61) mJ at the 7:3 ratio to (52.33 ± 1.27) mJ at the 5:5 ratio, reflecting the higher fiber content and lower expansion of the dough matrix. β-Carotene, TPC, and DPPH values also increased consistently with powder addition, reaching (6.70 ± 0.15) mg/kg, (875.28 ± 3.62) mg GAE/g, and (144.01 ± 0.52) mg TE/g, respectively, in the 5:5 formulation. Similar increases in carotenoids and phenolics after vegetable-powder fortification have been reported in pasta, bread, and cake products [4, 5, 10]. Importantly, the β-carotene values reported here represent retained content in the finished product after the 5-s frying step and should not be interpreted as bioavailability. Further work should first determine β-carotene bioaccessibility using standardized in vitro gastrointestinal digestion and micellarization, followed, where feasible, by cellular uptake or in vivo assessment to establish bioavailability.

Protein, total dietary fiber, soluble dietary fiber, insoluble dietary fiber, and ash increased as the proportion of leaf powder increased, whereas carbohydrate and energy decreased (Table 5). The 5:5 formulation contained (10.22 ± 0.29) g/100 g protein and (16.71 ± 0.31) g/100 g total dietary fiber, compared with 3.50 g/100 g protein and no declared fiber in the market sample. Increasing leaf powder addition slightly darkened the product and shifted the color toward green-yellow tones, but this change did not reduce panel acceptance. Sensory evaluation on a 9-point hedonic scale showed that the 6:4 and 5:5 formulations had the highest overall liking scores (7.35 and 7.60, respectively), whereas the market sample scored 5.40. Because the 5:5 ratio maximized nutritional enrichment and still achieved high consumer acceptance, it was considered the best formulation, while 6:4 may be preferred when a slightly softer texture is desired. Because the snack cakes were analyzed on the day of production, the present study does not establish product shelf-life. Given the relatively high lipid content of the fried formulations, future storage studies should monitor primary and secondary lipid-oxidation indices together with moisture or water activity, β-carotene retention, texture, color, and sensory quality under packaging systems with appropriate oxygen and moisture barriers.

Table 4 Texture, Antioxidant Properties, and Overall Liking of Snack Cakes

	Rice Flour : SP Leaf Powder (w/w)			**Market Sample**
	7:3	**6:4**	**5:5**	**Market**
Hardness (mJ)	28.66 ± 0.61[a]	41.63 ± 0.78[b]	52.33 ± 1.27[c]	52.15 ± 1.41[c]
β-Carotene (mg/kg)	4.09 ± 0.12[a]	5.80 ± 0.12[b]	6.70 ± 0.15[c]	*ND
TPC (mg GAE/g)	490.50 ± 9.02[a]	703.21 ± 9.34[b]	875.28 ± 3.62[c]	-
DPPH (mg TE/g)	82.65 ± 2.57[a]	131.65 ± 0.26[b]	144.01 ± 0.52[c]	-
Overall liking (9-point scale)	6.25	7.35	7.60	5.40

*ND = not detected. Within the same row, means followed by different letters are significantly different at $p < 0.05$.

Table 5 Nutritional Composition of Snack Cakes Compared with the Market Sample

	Rice Flour : SP Leaf Powder (w/w)			Market Sample
	7:3	**6:4**	**5:5**	**Market**
Protein (g/100 g)	6.42 ± 0.03^{b}	7.20 ± 0.19^{c}	10.22 ± 0.29^{d}	3.50^{a}
Carbohydrate (g/100 g)	48.78 ± 0.30^{c}	36.79 ± 0.98^{b}	25.16 ± 0.69^{a}	53.40^{d}
Total lipid (g/100 g)	40.61 ± 0.33^{c}	36.75 ± 0.98^{b}	35.92 ± 0.46^{b}	32.70^{a}
Energy (kcal/100 g)	586.33 ± 3.02^{c}	506.71 ± 13.19^{b}	464.87 ± 4.97^{a}	458.00^{a}
Ash (g/100 g)	2.68 ± 0.17^{a}	2.90 ± 0.12^{a}	5.55 ± 0.21^{b}	8.80^{c}
Total dietary fiber (g/100 g)	11.14 ± 0.76^{a}	14.33 ± 0.76^{b}	16.71 ± 0.3^{c}	-
Soluble dietary fiber (g/100 g)	3.53 ± 0.04^{a}	5.93 ± 0.25^{b}	8.50 ± 0.31^{c}	-
Insoluble dietary fiber (g/100 g)	7.26 ± 0.15^{a}	12.51 ± 0.69^{b}	18.04 ± 0.46^{c}	-
β-Carotene (mg/kg)	4.09 ± 0.12^{a}	5.80 ± 0.12^{b}	6.70 ± 0.15^{c}	*ND

*ND = not detected. Within the same row, means followed by different letters are significantly different at $p < 0.05$.

4 Conclusions

Heat pump drying at 45 °C was the most suitable condition among the laboratory-scale treatments evaluated for producing SP leaf powder because it combined acceptable drying time with good yield, color retention, high dietary fiber, and the highest β-carotene content. Incorporation of this powder into rice based snack cakes improved protein, dietary fiber, β-carotene, and antioxidant properties. The 5:5 formulation gave the highest nutritional value and the highest overall liking, while the 6:4 formulation also performed well. SP leaf powder therefore has good potential as a nutrient-enriching ingredient for rice-based snack products and for the valorization of leafy by products in sustainable food systems. Future work should focus on shelf-life and lipid-oxidation assessment during storage, packaging with appropriate moisture and oxygen barriers, β-carotene bioaccessibility and bioavailability after frying, and pilot- or industrial-scale techno-economic evaluation of heat-pump drying, including energy consumption, equipment capacity, throughput, and unit production cost.

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Ảnh hưởng của phương pháp sấy và nhiệt độ sấy đến chất lượng bột lá khoai lang và khả năng ứng dụng trong sản xuất bánh ăn nhẹ giàu dinh dưỡng

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Tóm tắt Nghiên cứu này nhằm xác định điều kiện sấy phù hợp cho lá khoai lang và đánh giá khả năng ứng dụng bột thu được trong sản xuất bánh snack nền gạo giàu dinh dưỡng. Lá khoai lang được sấy bằng phương pháp đối lưu và bơm nhiệt ở (35, 45 và 55) °C, sau đó được đánh giá các đặc tính lý hóa, dinh dưỡng, chống oxy hóa, cấu trúc và cảm quan. Sấy bơm nhiệt ở 45 °C cho hiệu quả tổng thể tốt nhất, với hiệu suất thu hồi 14,55 %, độ ẩm 7,35 % và hàm lượng β-carotene cao nhất đạt 141,83 mg/kg, đồng thời duy trì hàm lượng chất xơ cao. Việc tăng tỷ lệ bột lá khoai lang từ 30 % lên 50 % giúp cải thiện hàm lượng protein, chất xơ, β-carotene, polyphenol tổng số và hoạt tính chống oxy hóa. Công thức phối trộn bột gạo:bột lá khoai lang 5:5 đạt hàm lượng protein 10,22 g/100 g, tổng chất xơ 16,71 g/100 g và điểm ưa thích chung 7,60/9. Nghiên cứu đề xuất cách tiếp cận tích hợp giữa công nghệ sấy và phát triển sản phẩm nhằm nâng cao giá trị phụ phẩm lá khoai lang thành sản phẩm snack giàu dinh dưỡng và có mức độ chấp nhận cảm quan cao.

Từ khóa Lá khoai lang; sấy bơm nhiệt; bánh ăn nhẹ; cảm quan; phát triển bền vững.