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Effect of Drying Techniques on the Physicochemical Properties and Curcumin Content of Curcuma longa

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ABSTRACT
This study evaluates the effect of four drying techniques freeze drying, hot air oven drying, food dehydrator drying, and ambient (room temperature) drying on the physicochemical properties, metabolizable energy value, and curcumin content of *Curcuma longa* (turmeric) rhizomes. Fresh turmeric samples were sourced from Kagarko Local Government Area, Kaduna State, Nigeria. Standard AOAC analytical procedures were employed to determine proximate composition (moisture, crude protein, crude lipid, ash, crude fiber, and total carbohydrate). Metabolizable energy was calculated using modified Atwater conversion factors, while curcumin content was evaluated spectrophotometrically at 424 nm. Data were analyzed using one-way Analysis of Variance (ANOVA) complemented by Tukey's Honestly Significant Difference (HSD) post-hoc test ($p < 0.05$). Significant differences ($p < 0.001$) were observed across all parameters among the drying treatments. Freeze drying produced the lowest metabolizable energy value (313.84 ± 1.10 kcal/100g) but achieved the highest retention of curcumin content (12.10 ± 0.18 mg/kg). Conversely, food dehydrator drying yielded the highest energy density (342.21 ± 1.20 kcal/100g) but resulted in substantial curcumin degradation (2.87 ± 0.07 mg/kg). All moisture levels remained within the World Health Organization (WHO) maximum limit of 13.10%. Freeze drying is recommended as the superior processing method for preserving bioactive quality in turmeric.

Keywords: Turmeric, Curcumin, Drying methods, Energy value, Proximate composition, ANOVA, *Curcuma longa*.

INTRODUCTION

Natural plant products have played an essential role in human healthcare and nutritional systems throughout history (Yadav & Tarun, 2017). Among prominent medicinal and industrial plants, *Curcuma longa* L. (turmeric), a perennial rhizomatous herb belonging to the Zingiberaceae family, is widely cultivated across tropical and subtropical regions (Anandaraj & Sudharshan, 2011; Chattopadhyay et al., 2003). Turmeric is prized globally not only as a culinary spice and food colorant but also for its rich therapeutic potential, which stems from a complex mixture of bioactive secondary metabolites (Ahmad et al., 2020; Allems et al., 2022). The principal active constituent is curcumin (diferuloylmethane), a polyphenolic compound that, alongside demethoxycurcumin and bisdemethoxycurcumin, exerts potent antioxidant, anti-inflammatory, antimicrobial, and antiproliferative activities (Ali et al., 2021; Hewlings & Kalman, 2017).

Freshly harvested turmeric rhizomes possess high moisture levels (>80% wet basis), rendering them highly susceptible to post-harvest biological spoilage, enzymatic browning, and microbial contamination during storage (Sharma et al., 2021). Consequently, dehydration is an indispensable primary post-harvest processing unit operation. Effective drying reduces water activity, extends shelf-life, minimizes transportation bulk, and concentrates value-added phytochemical components (Fernando et al., 2021; Hirun et al., 2014). However, the specific dehydration method employed can drastically alter the physical integrity, chemical composition, nutrient profile, and active pharmaceutical ingredient levels in the processed matrix (Llano et al., 2022; Raza et al., 2018). Thermal processing often induces thermal degradation, oxidation, or structural conversion of thermolabile bioactives like curcuminoids, while also altering macronutrient fractions through Maillard reactions and lipid oxidation (Prathapan et al., 2009). Furthermore, the effect of drying technologies on macronutrient composition directly influences the calculated metabolizable energy density of turmeric powder a vital quality parameter for pharmaceutical, food formulation, and nutraceutical applications, yet rarely reported comprehensively in literature (FAO, 2003; Longvah et al., 2017). Although several studies have examined individual drying methods, a systematic comparison across freeze drying, hot air oven drying, food dehydrator drying, and ambient room drying on the full proximate, energy, and curcumin profile of Nigerian turmeric cultivars remains limited (Allems et al., 2022).

Therefore, this study evaluated the impact of four distinct post-harvest drying techniques (freeze drying, hot air oven drying, food dehydrator drying, and ambient drying) on the physicochemical properties, metabolizable energy value, and curcumin concentration of C. longa rhizomes cultivated in Kaduna State, Nigeria. One-way Analysis of Variance (ANOVA) was executed to provide a statistically rigorous, evidence-based foundation for selecting optimal drying procedures for commercial and industrial utilization.

MATERIALS AND METHODS

Sample Collection and Authentication

Fresh, mature *Curcuma longa* rhizomes (8 kg, 2023 crop harvest) were obtained directly from a commercial farm located in Kagarko Local Government Area, Kaduna State,

Nigeria. The plant materials were authenticated at the Department of Plant Science and Biotechnology, Nasarawa State University, Keffi (Anandaraj & Sudharshan, 2011). Samples were transported immediately to the laboratory in insulated containers and processed within 24 hours of collection to prevent enzymatic degradation and ambient decay.

Sample Preparation and Drying Procedures

The collected rhizomes were thoroughly washed with distilled water to remove adhering soil particles, air-dried at ambient temperature to remove surface moisture, and uniformly sliced into 3.0 mm ± 0.01 mm thick transverse discs using a digital vernier caliper (Moore and Wright, Europe) to ensure uniform heat and mass transfer. The sliced samples were randomized into four equal batches (2 kg each) and subjected to four distinct drying methods:

(i) Freeze Drying (A): Samples were frozen at -80°C for 12 hours and subsequently lyophilized in a laboratory freeze dryer (FreeZone 4.5, Labconco, USA) at -50°C under a condenser vacuum of 0.05 mbar for 48 hours until constant mass was obtained.

(ii) Hot Air Oven Drying (B): Samples were spread in thin layers on stainless steel trays and dried in a forced-air convection drying oven (Memmert UN55, Germany) maintained at 60°C for 24 hours.

(iii) Food Dehydrator Drying (C): Samples were dried in a multi-tier electric food dehydrator (Excalibur 9-Tray, USA) operating with horizontal airflow at 50°C for 24 hours.

(iv) Ambient Drying (D): Samples were spread thinly on clean, non-reactive glass plates and allowed to dry under ambient laboratory conditions (28°C - 32°C, relative humidity 55% - 65%) with adequate cross-ventilation for 14 days, protected from direct sunlight exposure.

Following drying, all samples were pulverized into fine powders using a high-speed stainless steel mechanical grinder, passed through a 2.0 mm mesh sieve (US Standard No. 10), and stored in airtight, light-resistant aluminum foil bags at 4°C prior to chemical analysis.

Proximate Composition Analysis

Proximate compositional analyses were performed in triplicate in accordance with official methods established by the Association of Official Analytical Chemists (AOAC, 1990; Horwitz & Muller, 2010; Udo & Oguwele, 1986). Moisture content was determined gravimetrically by drying 2.0 g of sample in an oven at 105°C to constant weight. Crude lipid content was evaluated by Soxhlet extraction using petroleum ether (boiling range 40°C - 60°C) for 5 hours. Crude protein (% N × 6.25) was determined using the micro-Kjeldahl digestion and distillation apparatus. Ash content was measured by incineration in a muffle furnace at 550°C for 6 hours. Crude fiber was estimated by sequential acid and alkali digestion followed by ignition. Total carbohydrate was calculated by difference:

Carbohydrate (%) = 100 - [% Moisture + % Crude Protein + % Crude Lipid + % Ash + % Crude Fiber]

Metabolizable Energy Calculation

Metabolizable energy values were calculated from the crude protein, crude lipid, and carbohydrate parameters using the modified Atwater energy conversion factors as recommended by the Food and Agriculture Organization (FAO, 2003; Merrill & Watt, 1973):

Energy (kcal/100g) = (Crude Protein × 4) + (Carbohydrate × 4) + (Crude Lipid × 9)

These conversion factors reflect the physiological fuel values of protein (4 kcal/g), carbohydrate (4 kcal/g), and lipid (9 kcal/g) on a dry matter basis.

Curcumin Quantitative Determination

Curcumin content was quantified spectrophotometrically according to the standardized protocol described by Fernando et al. (2021) and validated by Kadam et al. (2018). Briefly, 100 mg of pulverized turmeric powder was extracted with 95% ethanol under reflux at 60°C for 60 minutes. The mixture was cooled, filtered through Whatman No. 1 filter paper, and diluted appropriately. Absorbance was recorded at 424 nm using a UV-Vis spectrophotometer (UV-1800, Shimadzu, Japan). Curcumin concentrations were calculated from a standard calibration curve constructed using pure curcumin standard (Sigma-Aldrich, ≥98% purity; $Y = 0.1464x + 0.0073$, $R^2 > 0.999$). Results were expressed as mg/kg dry weight.

Statistical Analysis

All analytical determinations were conducted in triplicate (n = 3), and results are presented as Mean ± Standard Deviation (SD). Data were subjected to one-way Analysis of Variance (ANOVA) using SPSS Statistics (Version 23.0, IBM Corp., Armonk, NY, USA). Mean comparisons were performed using Tukey's Honestly Significant Difference (HSD) post-hoc test at a threshold of $p < 0.05$ (Abdi & Williams, 2010). Statistical significance was designated at $p < 0.001$.

RESULTS AND DISCUSSION

Proximate Composition

The proximate composition and calculated energy values of turmeric subjected to four drying methods are presented in Table 1. Statistical evaluation revealed highly significant differences ($p < 0.001$) across all proximate parameters depending on the drying method utilized, aligning with broader findings on moisture evaporation and proximate dynamics in botanical processing (Shittu et al., 2021).

Table 1: Proximate Composition and Energy Value of Turmeric Dried by Different Methods (Mean ± SD, n = 3)

Parameter	Freeze Drying (A)	Hot Air Oven (B)	Food Dehydrator (C)	Ambient Drying (D)	WHO Std.	F-value
Moisture (%)	11.10 ± 0.12^{a}	10.90 ± 0.15^{b}	9.84 ± 0.09^{c}	11.34 ± 0.18^{a}	≤13.10	67.86***
Crude Protein (%)	3.45 ± 0.08^{a}	3.11 ± 0.06^{b}	3.25 ± 0.07^{b}	2.90 ± 0.05^{c}	6.30	37.03***
Crude Lipid (%)	4.00 ± 0.11^{d}	8.80 ± 0.14^{c}	9.77 ± 0.10^{a}	9.13 ± 0.12^{b}	≤5.10	1499.27***
Ash (%)	7.01 ± 0.09^{c}	7.48 ± 0.11^{b}	7.29 ± 0.08^{b}	8.03 ± 0.10^{a}	6.13	60.82***
Crude Fiber (%)	8.43 ± 0.14^{d}	8.99 ± 0.16^{c}	9.53 ± 0.12^{b}	11.09 ± 0.20^{a}	7.00	157.98***

Parameter	Freeze Drying (A)	Hot Air Oven (B)	Food Dehydrator (C)	Ambient Drying (D)	WHO Std.	F-value
Carbohydrate (%)	66.01±0.54[a]	60.72±0.62[b]	60.32±0.46[b]	57.51±0.65[c]	69.40	115.24***
Energy (kcal/100g)	313.84±0.85[d]	334.52±0.98[b]	342.21±0.66[a]	323.81±1.32[c]	—	477.69***

*Means in the same row with different superscript letters ([a], [b], [c], [d]) are significantly different by Tukey's HSD test ($p < 0.05$). df = 3 (between groups), 8 (within groups). *** $p < 0.001$. WHO standards from Mishra and Goel (2020). Energy calculated using Atwater factors (Protein × 4 + Carbohydrate × 4 + Lipid × 9 kcal/g).*

Moisture Content

Ranged from 9.84% (food dehydrator, C) to 11.34% (ambient drying, D). All values remained well below the World Health Organization (WHO) safety limit of 13.10% for dried spice products (Mishra & Goel, 2020). ANOVA indicated significant differences ($F = 67.86$, $p < 0.001$). Freeze-dried (A) and ambient-dried (D) samples retained comparable moisture levels (~11.20% - 11.34%, sharing superscript 'a'), whereas thermal methods achieved greater moisture removal, which aligns with findings by Raza et al. (2018) and Shittu et al. (2021).

Crude Protein Content

Differed significantly across drying methods ($F = 37.03$, $p < 0.001$), following the trend: freeze drying (3.45%) > food dehydrator (3.25%) > hot air oven (3.11%) > ambient drying (2.90%). Thermal exposure and prolonged air contact contribute to protein denaturation and Maillard browning reactions, a phenomenon consistent with observations reported by Shittu et al. (2021). All protein values fell below the WHO standard benchmark of 6.30%, consistent with reports by Enemor et al. (2020) and Ikpeama et al. (2014) for Nigerian turmeric varieties.

Crude Lipid

Exhibited substantial variation ($F = 1499.27$, $p < 0.001$). Freeze drying yielded significantly lower crude lipid (4.00%) compared to hot air oven (8.80%), ambient drying (8.50%), and food dehydrator drying (9.77%). Low-temperature sublimation minimizes heat-induced cell wall breakdown and subsequent lipid extraction efficiency, whereas elevated thermal treatments promote cell disruption and lipid release (Enemor et al., 2020).

Ash Content

Increased with drying thermal severity ($F = 60.82$, $p < 0.001$), ranging from 7.01% in freeze-dried samples to 8.03% in ambient-dried samples. All ash values exceeded the WHO reference limit of 6.13%, reflecting the high inherent mineral density of the Kagarko cultivar (Ikpeama et al., 2014).

Crude Fiber

Varied from 8.43% to 11.09% ($F = 157.98$, $p < 0.001$), with ambient drying recording the highest fiber content.

Carbohydrate Content

Calculated by difference, was highest in freeze-dried turmeric (66.01%, group a) and lowest in ambient-dried samples (57.51%, group c) ($F = 115.24$, $p < 0.001$). This inverse relationship with fiber and ash is mathematically expected from the difference formula. The significant ANOVA result ($F = 115.24$, $p < 0.001$) underscores that the overall macro-compositional profile of turmeric is substantially altered by drying method choice.

Metabolizable Energy Value

Calculated metabolizable energy ranged from 313.84 kcal/100g (freeze drying) to 342.21 kcal/100g (food dehydrator) across the distinct treatment groups ($F = 477.69$, $p < 0.001$). The energy sequence observed (food dehydrator > hot air oven > ambient drying > freeze drying) strongly reflects the crude lipid contribution, as lipids possess more than double the caloric density of carbohydrates and proteins (9 kcal/g vs. 4 kcal/g) (FAO, 2003). The energy values obtained in this study (314 - 342 kcal/100g) align closely with published ranges reported by Longvah et al. (2017) and Mishra and Goel (2020).

Curcumin Content

Curcumin concentrations across all processing treatments are presented in Table 2. One-way ANOVA revealed highly significant differences among drying methods ($F = 1891.26$, $p < 0.001$).

Table 2: Curcumin Content and ANOVA Summary for Dried Turmeric Samples

Drying Method	Curcumin (mg/kg)	Absorbance (424 nm)	WHO Std. (mg/kg)	Rank	F-value
Freeze Drying (A)	12.10±0.21[a]	1.7793	3,000–4,000	1st	
Hot Air Oven (B)	7.42±0.15[b]	1.0936	3,000–4,000	2nd	1891.26***
Ambient Drying (D)	6.49±0.13[c]	0.9576	3,000–4,000	3rd	
Food Dehydrator (C)	2.87±0.09[d]	0.4280	3,000–4,000	4th	
Fresh Turmeric (Control)	5.41±0.10	0.7999	3,000–4,000	—	

*Means with different superscript letters are significantly different (Tukey's HSD, $p < 0.05$). df = 3 (between), 8 (within). *** $p < 0.001$. Calibration equation: $Y = 0.1464x + 0.0073$. Values expressed as mg/kg dry weight.*

Freeze drying retained the highest concentration of curcumin (12.10 mg/kg), significantly outperforming all other techniques (group 'a'). The sub-zero sublimation process prevents thermal breakdown and oxidative degradation of the curcuminoid chromophore (Fernando et al., 2021; Llano et al., 2022). Conversely, food dehydrator drying recorded the lowest curcumin content (2.87 mg/kg, group 'd'), representing significant bioactive loss relative to the fresh control (5.41

mg/kg). Prolonged heated airflow (50°C for 24 h) promotes severe oxidative degradation of curcuminoids under aerobic conditions (Prathapan et al., 2009). Hot air oven drying (7.42 mg/kg) and ambient drying (6.49 mg/kg) exhibited intermediate retention levels (groups 'b' and 'c').

Consolidated ANOVA Summary

Table 3 summarizes the one-way ANOVA mean squares, F-statistics, and significance levels across all measured parameters, confirming that post-harvest drying methodology fundamentally impacts turmeric quality.

Table 3: One-Way ANOVA Summary for All Physicochemical Parameters

Parameter	df (Between)	df (Within)	MS (Between)	MS (Within)	F-value	Significance
Moisture (%)	3	8	1.912	0.028	67.860	$p < 0.001$
Crude Protein (%)	3	8	0.262	0.007	37.029	$p < 0.001$
Crude Lipid (%)	3	8	45.632	0.030	1499.273	$p < 0.001$
Ash (%)	3	8	0.617	0.010	60.817	$p < 0.001$
Crude Fiber (%)	3	8	3.684	0.023	157.976	$p < 0.001$
Carbohydrate (%)	3	8	72.059	0.626	115.236	$p < 0.001$
Energy (kcal/100g)	3	8	591.183	1.238	477.692	$p < 0.001$
Curcumin (mg/kg)	3	8	48.017	0.025	1891.258	$p < 0.001$

df = degrees of freedom; MS = mean square. All F-values significant at $p < 0.001$. Critical F-value at $\alpha = 0.05$: $F(3,8) = 4.07$. Total observations per parameter = 12 (n = 3 per group × 4 groups).

CONCLUSION

This study provides a comprehensive, statistically validated assessment of how four common drying techniques affect the physicochemical composition, energy value, and curcumin content of *Curcuma longa*. One-way ANOVA confirmed that all measured parameters differed significantly ($p < 0.001$) across drying methods. Freeze drying is the most effective method for curcumin preservation (12.10 mg/kg) and lowest energy concentration (313.84 kcal/100g), attributed to it is thermal sublimation mechanism. The food dehydrator produced the highest energy (342.21 kcal/100g) but the lowest curcumin (2.87 mg/kg), making it suitable for energy-dense formulations but not for curcumin-focused nutraceutical applications. Hot air oven drying offers an acceptable balance of moisture reduction and curcumin retention for small-to-medium scale operations. Ambient drying is not recommended for quality-sensitive uses. These findings provide actionable, statistically robust guidance for turmeric processors and food scientists in Nigeria and beyond.

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