ISSN: 2977-0041

Research article

Journal of Material Sciences and Engineering Technology

Comparative Evaluation of Drying Methods on the Rehydration Kinetics and Quality Attributes of Gnetum africanum Leaves

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Received: March 04, 2026; **Accepted:** March 11, 2026; **Published:** March 18, 2026

ABSTRACT

This study investigated the effects of drying methods on the rehydration characteristics of okazi (Gnetum africanum) leaves. Fresh okazi (Gnetum africanum) leaves were purchased, sliced and dried using shade drying, food dehydrator drying, and freeze-drying methods. Fresh samples served as the control sample. Results from the proximate analysis showed that moisture, protein, fat, fiber, ash and carbohydrates contents ranged from 9.71- 32.68%, 14.98 – 19.92 %, 6.63 - 11.04 %, 31.24 - 35.15%, 5.38 - 6.93 %, 8.92 - 17.27 %, respectively. There were significant ($p < 0.05$) difference in moisture content across all drying methods, with freeze-drying producing the lowest moisture level and the highest concentrations of protein, fat, fiber, ash, and carbohydrate. Vitamin analysis revealed significant increases in beta-carotene after drying, especially in freeze-dried samples, while vitamin C declined in all dried samples, with the greatest loss occurring in the freeze-dried samples. Mineral contents such as calcium, magnesium, and potassium showed significant ($p < 0.05$) difference across all dried samples, with the freeze-dried samples yielding the highest concentrations. Phytochemical evaluation showed enhanced levels of flavonoids, phenols, and saponins after drying, with the freeze-dried samples producing the highest concentrations; however, tannin content increased only under shade drying. Rehydration studies demonstrated that dehydrator-dried and freeze-dried leaves absorbed water more, especially at higher temperatures of 70 - 80◦C. Rehydration progressively improved with increase in temperature and soaking time for all sample demonstrating temperature dependent hydration kinetics. Overall, the results showed that while all drying methods improves nutrient density, freeze-drying provides the most effective method for preserving nutrients and rehydration performance.

Keywords: Gnetum Africanum, Okazi Leaves, Drying Methods, Rehydration Characteristic

Introduction

Fruits and vegetables are characterized by high moisture contents, typically ranging from 80–95%, which predisposes them to rapid physiological deterioration and microbial spoilage after harvest. Consequently, post-harvest preservation techniques are essential to reduce losses and extend shelf life. Drying remains one of the most widely applied and cost-effective preservation methods for plant foods, particularly in developing countries. The process involves simultaneous heat and mass transfer, resulting in moisture removal to levels that inhibit microbial growth and enzymatic activity [1]. Conventional drying methods used for vegetables include sun drying, shade drying, hot-air (oven) drying, and natural air drying, each differing in temperature profile, drying rate, energy input, and impact on product quality. Leafy vegetables are highly perishable due to their delicate tissues and high metabolic activity. In addition to their susceptibility to spoilage, they are prone to nutrient losses during processing if not handled properly. Despite this, leafy vegetables constitute an essential component of human diets and contribute significantly to food and nutrition security. They are recognized for their high nutrient density, supplying essential vitamins (A, C, K, and folate), minerals (iron, calcium, magnesium), dietary fibre, and plant proteins with relatively low caloric content [2]. Epidemiological evidence links increased consumption of leafy greens with reduced risks of cardiovascular diseases, stroke, and certain cancers, largely due to their bioactive phytochemicals such as flavonoids, phenolic compounds, and carotenoids (Upasana and Bhavya, 2024). Indigenous leafy vegetables, in particular, play a critical role in low-income and rural communities by providing accessible micronutrients that help mitigate hidden hunger [3].

Citation: Amonyeze AO, Aremu KO, Ocholi SS, Agwu CH. Comparative Evaluation of Drying Methods on the Rehydration Kinetics and Quality Attributes of Gnetum africanum Leaves. J Mat Sci Eng Technol. 2026. 4(2): 1-13. DOI: doi.org/10.61440/JMSET.2026.v4.107

Gnetum africanum, commonly known as Okazi, Ukazi, or Afang leaf, belongs to the family Gnetaceae and is native to the humid forest zones of West and Central Africa. The plant is widely cultivated and consumed in southeastern Nigeria, especially among the Efik, Ibibio, and Igbo ethnic groups, where it is a key ingredient in traditional soups such as Afang soup [4]. The leaves are characteristically thick, fibrous, and leathery, contributing to their firm texture after cooking. Nutritionally, G. africanum has been reported to contain appreciable amounts of protein, carbohydrates, crude fibre, and essential minerals including calcium, iron, magnesium, sodium, and zinc. It also contains bioactive compounds such as alkaloids, tannins, and saponins, which contribute to its antioxidant and anti-inflammatory properties [4,5]. Traditionally, the leaves are used not only as food but also for therapeutic purposes in managing inflammation, sore throat, and other minor ailments. Due to its high moisture content, fresh G. africanum is highly perishable and susceptible to rapid quality deterioration after harvest. Drying is therefore commonly employed to extend its shelf life and ensure year-round availability. However, the drying method significantly influences structural integrity, cell wall composition, shrinkage behaviour, and porosity of plant tissues, which in turn affect the functional quality of the dried product. One critical quality parameter of dried vegetables is rehydration capacity. Rehydration refers to the ability of dried material to absorb water and regain characteristics similar to the fresh state in terms of texture, appearance, and structural integrity. It is widely used as an indicator of the extent of physical and biochemical damage incurred during drying [6]. Poor drying conditions, such as excessive temperature or prolonged exposure, can cause cellular collapse, case hardening, and irreversible structural damage, leading to reduced water absorption and inferior texture upon reconstitution. In addition to sensory quality, rehydration behaviour affects nutrient retention, as water-soluble vitamins and antioxidants may be lost during soaking or may have degraded during drying [7]. Mathematical modelling approaches, including empirical models such as Peleg's equation, are commonly applied to describe rehydration kinetics and compare the effects of different processing treatments. Although G. africanum is widely consumed after rehydration in soups and traditional dishes, limited scientific information exists regarding how different drying methods influence its rehydration characteristics and functional quality. Given the fibrous structure of Okazi leaves and their culinary reliance on texture after soaking and cooking, understanding the relationship between drying technique and rehydration performance is critical for processors and consumers. The absence of such data constrains the selection of appropriate drying technologies that can preserve structural integrity, optimize water uptake, and maintain nutritional quality. Therefore, this study aims to evaluate the effect of different drying methods on the rehydration properties of Gnetum africanum leaves, with the objective of identifying processing conditions that best preserve their functional and quality attributes.

Materials and Methods

Selection and Procurement of Raw Materials/ Sample Preparation

Fresh leaves of Gnetum africanum (Okazi) were procured from Ahia Ohuru Market in Aba, Abia State, Nigeria. The leaves were selected based on uniform maturity, green coloration, and absence of visible defects, pest infestation, or mechanical damage. Procurement was carried out in the early hours of the day to minimize post-harvest deterioration prior to processing. Upon arrival at the laboratory, the leaves were manually destalked to remove petioles and fibrous stems. The edible portions were sorted to eliminate extraneous materials and damaged leaves, then thoroughly washed under potable running water to remove adhering soil and debris. The washed leaves were drained using a stainless-steel sieve to remove excess surface water.

The cleaned leaves were sliced uniformly using a stainless-steel kitchen knife to ensure consistent thickness and facilitate uniform drying. The sliced samples were subsequently divided into three equal portions (on a weight basis) and subjected to three different drying methods: shade drying, hot-air drying using a food dehydrator, and freeze drying. Each drying treatment was conducted separately under controlled conditions prior to further analysis.

Method of Drying

Three different drying methods were employed: shade drying, hot-air drying using a food dehydrator, and freeze drying. Drying was continued in all cases until samples reached a brittle texture indicative of low residual moisture content suitable for storage and further analysis.

Shade Drying

The sliced Gnetum africanum leaves were uniformly spread in a single thin layer on clean stainless-steel trays to avoid overlap and ensure adequate air circulation. The trays were placed under shade at ambient room conditions (27–32 °C) with relative humidity ranging from 55–68%. The samples were turned manually at regular intervals to promote uniform drying and prevent localized moisture accumulation. Drying was carried out for six (6) days until the leaves became brittle and were considered adequately dried.

Hot-Air Drying (Food Dehydrator)

Samples were evenly arranged in a single layer on the trays of a laboratory-scale food dehydrator. Drying was conducted at a controlled temperature range of 48–52 °C under a relative humidity range of 35–42%. The process lasted approximately 8 hours, and drying was continued until the leaves attained a brittle texture, indicating sufficient moisture removal. Uniform spreading ensured consistent exposure to heated air for effective moisture diffusion.

Freeze Drying

The sliced leaves were pre-frozen at −23 °C for several hours to ensure complete solidification of water within the plant tissues prior to sublimation. The frozen samples were then transferred to a freeze dryer. Freeze drying was performed at a chamber pressure of 0.133 mbar with a condenser temperature of −50 °C for 48 hours. The freeze dryer used was LYO-VAPOR L-300 (BUCHI, Switzerland). Drying was completed when samples were fully dry and crisp, indicating successful removal of moisture through sublimation.

Unit operation for drying okazi leaves under different drying methods

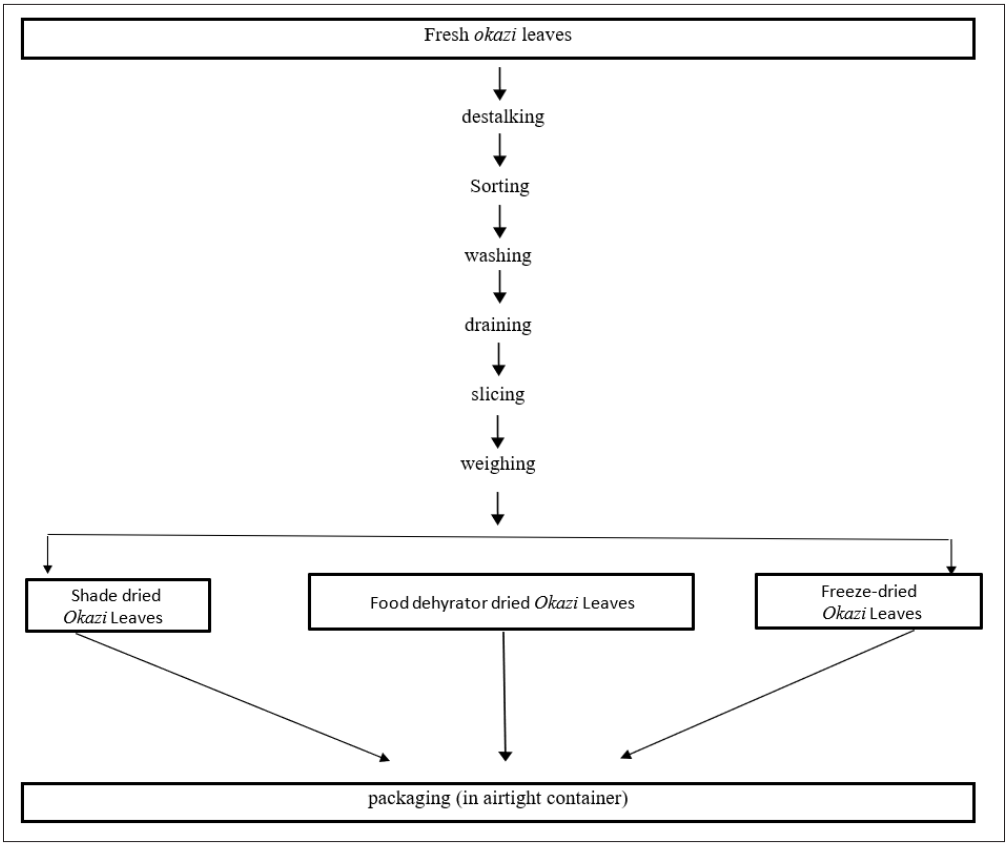

Figure 1: Flowchart for drying Okazi leaves under drying methods
Source: Safarov et al (2023)

Analytical Methods

Proximate Composition Analysis

The proximate composition of the pepper samples was determined using standard analytical procedures described by the Association of Official Analytical Chemists [8].

Moisture Content Determination

Moisture content was determined according to the AOAC (2012) method. Approximately 2 g of each sample was weighed into a pre-dried and weighed moisture dish and dried in a hot-air oven at 100 °C for 24 h until a constant weight was obtained. After drying, the samples were cooled in a desiccator and reweighed. The loss in weight was calculated and expressed as percentage moisture contentand calculated using the formula:

$$\% \text{ Moisture} = \frac{W1 - W2}{W1}$$

Where, W1 = Initial weight of the sample
W2 = Weight after drying

Ash Content Determination

Ash content was determined using the dry ashing method as described by AOAC (2012). Approximately 2 g of each sample was weighed into a pre-weighed porcelain crucible and incinerated in a muffle furnace at 550 °C for 12 h until a light grey or white ash was obtained. The crucibles were then cooled in a desiccator and reweighed. Ash content was calculated as a percentage of the initial sample weight using the formula below:

$$Ash\,content(\%) = (Weight\,of\,ash\,/Weight\,of\,sample) \times 100$$

Where, W1 = Initial weight of the sample, W2 = Weight of the residue after ashing

Crude Protein Content Determination

Crude protein content was determined using the macro-Kjeldahl method (AOAC, 2012). About 2 g of each sample was digested with copper sulfate–sodium sulfate (5:1) in 25 mL concentrated H_2SO_4 until a clear solution formed, cooled, and diluted to 25 mL. A 10 mL aliquot was distilled with 40% NaOH, and released ammonia was collected in 10 mL boric acid and titrated with 0.02 M HCl. Nitrogen content (%N) was calculated and converted to crude protein (%CP) using a factor of 6.2

$$\%N = (Tv \times Na \times 0.014 \times V_1 \times 100) / (G \times V_2)$$

Protein content

$$\%Crude\,Protein = \%N \times 6.25$$

here:

Tv = titre value (mL), Na = normality of HCl, V_1 = total volume of digest (mL), V_2 = volume of aliquot distilled (mL), G = weight of sample (g), and 0.014 = milliequivalent weight of nitrogen

Crude Fat Content Determination

Crude fat content was determined by Soxhlet extraction [8]. About 2 g of pre-dried sample was placed in a Soxhlet thimble and extracted with purified anhydrous ethyl ether for 4 h at 5–6 drops s^{-1} or 16 h at 2–3 drops s^{-1}. The solvent was evaporated,

and the extracted fat was dried at 100 °C for 30 min, cooled in a desiccator, and weighed.

Crude fat content was calculated on a dry weight basis using the following expression

$$\%Fat\left(dry\,weight\,basis\right) = \left(Weight\,of\ \ fat\,extracted\ /Weight\,of\ dried\,sample\right)\times 100$$

Rude Fibre Content Determination

Crude fibre content was determined following AOAC [8]. About 5 g of each sample was defatted with petroleum ether, boiled in dilute H_2SO_4, refluxed, washed, then digested with NaOH and refluxed. The residue was washed, moistened with acetone, incinerated at 550 °C for 3 h, cooled, and weighed. Crude fibre content was calculated using the following expression:

$$\%Crude\,Fibre = \left[\left(W_1 - W_2\right)/W\right]\times 100$$

here:
W = weight of sample (g)
W_1 = weight of crucible + residue before ashing (g)
W_2 = weight of crucible + ash after ashing (g)

Carbohydrate Content Determination

Carbohydrate content was calculated by difference as:

$$\%Carbohydrate = 100 - \left(\%Ash + \%Protein + \%Fat + \%Moisture\right)$$

Extermination of Micronutrients

Determination of Vitamin C

Vitamin C content was determined using the 2,6-dichlorophenolindophenol (DCPIP) titration method (AOAC, 2012). About 2 g of sample was extracted with 100 mL distilled water, stabilized with 25 mL of 20% metaphosphoric acid containing 0.5% oxalic acid, and diluted to 100 mL. A 10 mL aliquot was titrated with standardized DCPIP until a faint pink endpoint persisted for 15 s.

Vitamin C content was calculated using the equation:

$$Vitamin\,C\left(mg/100\,mL\right) = Sample\,volume\left(mL\right)V \times C \times 100$$

Where:
V = volume of DCPIP used (mL)
CCC = concentration of DCPIP (mg/mL)

Determination of Vitamin A

Vitamin A content was determined using the spectrophotometric method described by Okwu (2004). Exactly 10 g of the sample was extracted with 50 mL of EDTA–TCA extracting solution for 1 h and filtered through Whatman No. 1 filter paper into a 50 mL volumetric flask, which was made up to volume with the extracting solution. The absorbance of the extract was measured at 325 nm using a UV–visible spectrophotometer against a reagent blank. Vitamin A content was quantified by comparison with a standard calibration curve and expressed as mg/100 g of sample.

Determination of Calcium

Calcium content was determined by Atomic Absorption Spectrophotometry (AAS) following AOAC and Adedeye and Adewoke [8]. About 2 g of each sample was ashed, digested with 2.5 mL of 0.03 N HCl, boiled, cooled, diluted to 50 mL, and filtered. Calcium was measured at 422.7 nm using AAS and quantified against standard solutions. Results were expressed as mg/100 g of sample.

Determination of Potassium.

Potassium content was determined by flame photometry following AOAC [8]. About 5 g of each sample was ashed at 550 °C, dissolved in 100 mL distilled water with 10 mL HCl, boiled, cooled, and diluted to 500 mL. The solution was filtered, and potassium was quantified using a flame photometer (766–770 nm) calibrated with standard solutions (15 mg K_2O/100 mL). Results were expressed as mg/100 g of sample.

Determination of Magnesium

Magnesium content was determined according to the method described by AOAC using Atomic Absorption Spectrophotometry (AAS). Approximately 1.0 g of the dried and pulverized sample was accurately weighed into a digestion flask. Ten millilitres (10 mL) of concentrated nitric acid (HNO_3) were added, and the mixture was heated gently on a hot plate until initial digestion was achieved. After cooling, 2–3 mL of perchloric acid ($HClO_4$) were added, and heating was continued until a clear digest was obtained. The digest was allowed to cool and then filtered into a 50 mL volumetric flask. The volume was made up to the mark with distilled water.

The mineral extract was analysed using an Atomic Absorption Spectrophotometer. Magnesium was determined at a wavelength of 285.2 nm using an air–acetylene flame. Standard magnesium solutions were prepared from a stock solution to generate a calibration curve. The digested samples were aspirated into the instrument, and absorbance readings were recorded. Magnesium concentration was calculated from the calibration curve and expressed as mg/100 g of sample.

Determination of Phytochemical Composition

Total Phenolic Content (TPC)

Total phenolic content of fresh and oven-dried pepper extracts was determined using a modified Folin–Ciocalteu method (Ashour and Shaaban, 2014). A 0.5 mL aliquot of extract was mixed with 0.5 mL Folin–Ciocalteu reagent and 2 mL of 20 g/L sodium carbonate, incubated for 15 min at room temperature, diluted with 10 mL ultrapure water, and centrifuged at 4,000 × g for 5 min. Absorbance was measured at 725 nm, and total phenolics were expressed as mg gallic acid equivalents (GAE)/100 g dry matter.

Total Flavonoid Content (TFC)

Total flavonoid content of fresh and oven-dried pepper extracts was determined using the aluminium chloride colorimetric assay. A 1 mL aliquot of 1 mg/mL methanolic extract was mixed with 1 mL of 2% aluminium chloride, incubated for 1 h at room temperature, and absorbance measured at 415 nm. Flavonoid

content was expressed as mg quercetin equivalents (QE)/g extract using a quercetin calibration curve.

Determination of carotenoid

Total carotenoids in fresh and oven-dried pepper samples were determined following [9]. Samples were homogenized in methanol, filtered, and carotenoids partitioned into diethyl ether. The extract was evaporated, saponified with ethanolic KOH, re-extracted, washed, and purified using light petroleum and centrifugation. The carotenoid residue was dried and weighed. Results were expressed as mg/100 g dry weight.

Determination of Saponin

Saponin content was determined following Obadoni and Ochuko (2001). About 20 g of sample was extracted with 100 mL of 20% aqueous ethanol at 55 °C for 4 h, filtered, and re-extracted with 200 mL of 20% ethanol. The combined extract was concentrated to 40 mL, partitioned with diethyl ether, and further extracted with 60 mL n-butanol and washed with 5% NaCl. The extract was evaporated, and saponin content was expressed as a percentage of sample weight.

Tannin

The total phenol content of the samples was determined using the method described by Malick and Singh (1980). Each sample (1 g) was taken and ground in 10 mL of 80% methanol using a pestle and mortar. This homogenate was centrifuged at 10,000 rpm for 20 min. Supernatant was saved, and residue was reextracted 5 times with 10 mL of 80 % ethanol. The extract was made up to 50 ml with 80 % methanol. One millilitre (1 ml) was used to determine total phenol content. Then 10 ml of the extract was collected, and 1g polyvinylpolypyrrolidone (PVPP) was added for 30 mins. The solution was centrifuged, and 1 mL of the clear supernatant was added to – Ciocalteu reagent (1 mL) test tube. After 5 min, 1 mL sodium carbonate (7.5 %) solution was added to each tube. After the addition of 7ml of 80 % methanol, the contents of the tubes were mixed thoroughly and incubated at 50 oC for 1 hour. The absorbance was measured at 765 nm against a blank reagent. A standard curve was prepared by using different concentrations of gallic acid.

Tannin content (mg/100g) = Total phenol content of original extract – phenol content of PVPP-treated extract.

Rehydration Procedure

Determination of Initial Moisture Content

The initial moisture content of fresh Gnetum africanum leaves was determined prior to drying. Approximately 10 g of sample was weighed and dried at 100 °C in a hot-air oven until a constant weight was achieved. Moisture content was calculated gravimetrically and expressed on a dry basis (% db).

Rehydration Experiment

Rehydration characteristics of the dried samples were evaluated using a controlled immersion method. For each drying treatment, 1 g (dry weight basis) of dehydrated leaves was weighed and placed into 250 mL glass beakers containing distilled water. The water-to-sample ratio was maintained sufficiently high to prevent concentration effects and ensure unrestricted water absorption.

Rehydration was conducted at three different temperatures: 60 °C, 70 °C, and 80 °C. The temperatures were maintained using a thermostatically controlled water bath to ensure uniform heat distribution throughout the soaking period.

At predetermined time intervals (10, 20, 30, 40, 50, 60, and 70 minutes, and subsequently at 20-minute intervals thereafter), the beakers were removed from the water bath. The samples were withdrawn, gently blotted with absorbent paper to remove excess surface water without exerting pressure on the tissues, and immediately weighed using a digital analytical balance.

Rehydration was continued until equilibrium moisture content was reached, defined as the point at which successive weight measurements showed negligible variation. The increase in sample weight was taken as the amount of water absorbed. Moisture content during rehydration was calculated and expressed on a dry basis (% db).

Modelling of Rehydration Kinetics

To describe the water absorption behaviour of the dried leaves, Peleg's empirical model was applied. Peleg's equation is a widely used non-exponential model for characterizing sorption and rehydration kinetics of food materials. It is expressed as:

$Mt=M0+ K/KI +K2t$ ----------(1)

Linearising equation (1) will give:

$t/ (Mt –M0) = K1 + K2t$ ----------(2)

Were

Mt = the moisture content at time (t) (% d.b.),
M0 = the initial moisture content (% d.b.),
t = rehydration time(min),
K1 = Peleg's rate constant (min% mc db),
K2 = Peleg's capacity (%mc db),
Me = equilibrium moisture content

For model fitting, the curvilinear portion of the hydration data was employed, as Peleg's equation is applicable to the curvilinear segment of the sorption curve. The experimental moisture content data (Mt) were fitted to the linearized form of Peleg's equation using regression analysis.

The goodness-of-fit of the model was evaluated using the coefficient of determination (R^2), which indicates the proportion of variation in moisture content explained by time. Higher R^2 values (closer to 1.0) were considered indicative of better model performance. Statistical significance of the regression parameters (K_1 and K_2) was assessed using the P-value obtained from the regression analysis. The null hypothesis assumed that the regression coefficients had no significant effect. A P-value less than 0.05 ($P < 0.05$) was considered statistically significant. The Peleg model has been widely applied in rehydration studies of food materials due to its suitability for describing water absorption kinetics [10].

Statistical Analysis

Data obtained from the analysis were recorded and subjected to statistical analysis of variance (ANOVA). A complete randomised design (CRD) was used to analyse data obtained from leaves using the SPSS version 23.0 package. Significant differences between the means were estimated using Duncan 's

multiple range tests. Differences were considered significant at $P < 0.05$.

Results and Discussion

Effects of Drying Methods on the Proximate Composition of Okazi (Gnetum africanum) Leaf

Table 1 shows the effects of drying methods on the proximate composition of Okazi (Gnetum africanum) leaf. The moisture contents of the samples ranged from 9.71% in Freeze Dried sample to 32.68% in Fresh sample. Significant ($p < 0.05$) differences were observed in the moisture contents of the samples. The result showed that the Okazi leaf was fresh and rich in moisture at the initial stage before drying. After drying, however, the moisture content of the sample showed that the dried Okazi leaves had expectedly lower moisture values compared to the fresh okazi leaf. Shade drying had the highest moisture retention, followed by dehydrator drying, while the freezedried sample had the highest moisture loss. A similar result was reported in the work of Oni where shade drying of some leafy vegetables (T. occidentalis, B. alba, A. hybridus, T. triangulare, C. biafrae and C. rubens) retained much of the moisture content [11]. Overall, the result showed that the moisture contents of the samples (except the freeze-dried sample) are slightly higher than the 15% standard recommended by the Codex Alimentarius Commission (2009) for high moisture foods. This means that the shade-dried and dehydrator-dried leaf samples would not store for long since high moisture contents increase water activity that enhances microbial growth that causes food spoilage. Thus, the shade-dried and dehydrator-dried samples require cold storage.

The ash content of the samples ranged from 5.38 % in Shade shade-dried sample to 6.93% in the Freeze-dried sample. Statistically, no significant ($p > 0.05$) difference was observed in the ash contents of Fresh and Shade-dried as well as that of Dehydrator dried and Freeze Dried. The ash content of the dehydrator and freeze-dried okazi leaves was higher than the fresh leaves. The higher ash content in the dehydrator and free-dried samples could be attributed to the increase in concentration of nutrients as a result of moisture loss. Freeze-dried okazi leaf retained much of the ash contents compared to other drying methods, and this was consistent with the work of Garba and Oviosa on Vernonia amygdalina leaf which recorded that ash content of dried leaves ranged from 10.38% to 11.20% with freeze dried leaf having the highest value of 11.20% [12]. An increase in the ash content of the okazi leaves on drying may indicate higher mineral elemental composition. This is because ash is an indication of the mineral contents of foods and has been described by Adeola and Ohizua that food products containing high ash contents had an appreciable amount of minerals [9].

The crude fiber contents of the samples showed no variation ($p > 0.05$) among the dried samples Shade Dried, Dehydrator Dried and Freeze Dried. However, Dehydrator Dried sample had the highest (34.63%) fiber content while the Fresh sample had the lowest (31.24%) fiber content. This shows that drying increases the concentration of crude fiber in the leaf. A similar result of an increase in crude fiber on drying was reported by Alassane for different leaf vegetables (Cerathoteca sesamoides, Leptadenia hastata, Ocimum gratissimum and Portulaca oleracea). According to the British Nutrition Foundation (2023), a food item is considered a source of fiber if it has at least 3g fiber per 100g, but is considered a high fiber food when it has more than 6g per 100g [13]. This shows that the okazi leaf samples are rich sources of dietary fiber. Dietary fiber is the indigestible component of plant material that lowers serum cholesterol, obesity and enhances intestinal health, normalises bowel movements, prevents constipation and helps control blood sugar [14].

The fat content of the samples ranged from 6.63% in the fresh sample to 11.04% in the freeze-dried sample. Statistically significant ($p < 0.05$) differences were observed in the fat contents of the samples. The result showed that drying increases the concentration of fat in the leaf, with the freeze-dried leaf having the highest fat content (11.04%) followed by the dehydrator-dried sample (9.90%), while the shade-dried sample had the lowest concentration of fat (8.25%) after drying. This is in contrast with the reports of Garba and Oviosa where an increase in fat content of Vernonia amygdalina (bitter leaf) was observed to be highest in shade-dried leaf (2.64%) compared to other drying methods which ranged from 1.84% to 2.53% [12]. Fat is an essential component of tissues and a veritable source for fat-soluble vitamins (A, D, E and K) and is also able to supply thrice the amount of energy required by the body [15]. This means that the dried okazi leaf samples would supply appreciable amounts of fat-soluble vitamins.

The crude protein contents of the samples ranged from 14.98% in the fresh sample to 19.92% in the freeze-dried sample. Significant (<0.05) differences were observed in the crude protein contents of the okazi leaf samples. The result showed that drying increases the concentration of protein, with freeze-drying having the highest protein concentration of 19.92% and shade-drying having the lowest protein concentration of 16.89%. This is in contrast to the study by Oni, who reported a decrease in the concentration of protein on drying of leaves from the range of 24.09% to 32.87% in fresh leaves to as low as 2.83% to 19.29% in dried leaves of some common Nigerian vegetables [11]. The differences in the concentration of protein in the dried okazi leaf samples could be due to differences in the percentage moisture loss, as the protein content increased with higher moisture loss. According to the Codex Alimentarius Commission (2009), a solid or liquid food is said to contain high protein when the protein content is greater than 5% per 100g of the food. Thus, all the okazi leaf samples are rich in proteins, especially the dried samples and therefore can be used basically for supplementation, as a relatively high amount of protein is required for functional foods and nutraceuticals The total carbohydrate content of the okazi leaf samples ranged from 8.92 % in the fresh sample to 17.27 % in the freeze-dried sample. Statistically significant ($p < 0.05$) difference was observed in the carbohydrate contents of the samples. The result showed that the carbohydrate content of the okazi leaf increased on drying, with the free-dried sample having the highest concentration of total carbohydrate and shade drying having the least concentration of carbohydrate. This was in agreement with the work of Shonte who reported an increase in the carbohydrate content of Spinach leaves from 2.4% to 22.1% after drying [16]. Carbohydrates are the most abundant biological molecules and play important roles as sources of energy to the body, brain, heart, nervous system, digestive function and immune system [17]. The results of this study indicate that dried okazi leaf has the potential to supply good amounts of carbohydrates that can provide accessible fuel

(energy) for physical performance and the regulation of nerve tissues [4].

Table 1: Effects of Drying Methods on the Proximate Composition of Okazi (Gnetum Africanum) Leaf

Sample	Moisture (%)	Crude protein (%)	Fat (%)	Crude fiber (%)	Ash (%)	Carbohydrate (%)
FR	32.68d ± 0.19	14.98a ± 0.06	6.63a ± 0.01	31.24a ± 0.61	5.57a ± 0.13	8.92a ± 0.98
SD	22.78c ± 0.24	16.89b ± 0.32	8.25b ± 0.43	34.18b ± 0.49	5.38a ± 0.28	12.54b ± 0.34
DD	16.45b ± 0.25	17.93c ± 0.11	9.90c ± 0.03	34.63b ± 0.48	6.35b ± 0.39	14.75c ± 0.42
FD	9.71a ± 0.08	19.92d ± 0.23	11.04d ± 0.28	35.15b ± 0.95	6.93b ± 0.06	17.27d ± 0.89

Values are means ± standard deviation of replicate determination. Means with different superscripts in the same column are significantly ($p< 0.05$) different.

Keys: FR = fresh okazi leaf, SD = shade-dried okazi leaf, DD = dehydrator-dried okazi leaf; FD = freezedried okazi leaf.

Effects of Drying Methods on the Micronutrient Composition of Okazi (Gnetum Africanum) Leaf

Table 2 shows the effects of drying methods on the micronutrient composition of okazi (Gnetum africanum) leaf. The beta-carotene contents ranged from 62.46 µg/100g in Fresh sample to 699.50 µg/100g in Freeze Dried sample. Statistically significant ($p < 0.05$) difference was observed in the beta-carotene contents of the samples. The result showed that the drying method increases the concentration of beta-carotene (provitamin A), with the freeze-dried sample having the highest beta-carotene content. Variation in the concentration of beta-carotene could be attributed to differences in moisture loss in the respective samples. It could also be attributed to the differences in fat contents of the samples since vitamin A and its derivatives (beta-carotene) are fat-soluble vitamins and therefore, the freeze-dried okazi leaf, which had the highest fat content, also had the highest concentration of beta-carotene. In contrast to this finding Mohammadi reported a decrease in the beta-carotene (provitamin A) levels from 3.03mg/gram in fresh carrot to 2.98mg/gram in freeze dried carrots after drying [18]. Beta-carotene and its derivatives have multiple functions: it is important for growth and development, for the maintenance of the immune system and good vision.

On the other hand, the vitamin C contents of the sample ranged from 82.35 mg/100g in Dehydrator Dried sample to 113.39 mg/100g in Fresh sample. A significant ($p < 0.05$) difference was observed in the vitamin C contents of the okazi leaves. The result showed reductions in vitamin C concentration during drying, with freeze-dried okazi leaf having the highest vitamin C loss, while shade-dried leaf had the highest vitamin C retention. The decrease in the vitamin C content of the okazi leaf could be attributed to the fact that vitamin C is water-soluble and is lost through leaching in water. Following this narrative, the freeze-dried okazi leaf had the highest moisture loss and consequently the least concentration of vitamin C. The result is in line with the findings of Vargas who reported a reduction in the vitamin C contents of spinach after drying, with the freeze-dried sample having the highest loss in vitamin C(5.35mg/g) [19]. In support of the increased beta-carotene and decreased vitamin C contents following the drying process, Godoy noted that water-soluble vitamins (B-group and C) are more unstable than fat-soluble vitamins (K, A, D and E) during food processing and storage. Functionally, vitamin C is an important physiological antioxidant and has been shown to regenerate other antioxidants within the body, including alpha-tocopherol (vitamin E) [20].

The calcium contents of the samples were highest (1520.52 mg/100g) in Freeze Dried sample but lowest (791.22 mg/100g) in Fresh sample. On the other hand, the potassium content ranged from 1067.58 mg/100g in Fresh sample to 2853.89 mg/100g in Freeze dried sample, while the magnesium content similarly ranged from 335.09 in Fresh sample to 996.27 mg/100g in Freeze dried sample. Significant ($p < 0.05$) differences were observed in the calcium, potassium and magnesium contents of the samples. The result showed that the concentrations of calcium, magnesium and potassium increased during the drying process, with the freeze-dried sample having the highest concentrations of calcium, potassium and magnesium. The result is in line with the statement made by Adriana and Crosby (2015) that the bioavailability of some minerals may be increased by dehydration processes. In comparison to related literature, the study is similar to that reported by Isaac (2023) where drying increased the calcium (from 72.59 to 298.19 mg/100g), magnesium (from 41.16 to 176.04 mg/100g) and potassium (from 6.92 to 176.01 mg/100g) contents of some leafy vegetables, with freeze-drying containing the highest concentration of the minerals. The increase in the calcium, potassium and magnesium content of okazi leaf is important in ensuring adequate intake of the minerals. Calcium forms an integral part of bone structure, providing a rigid frame that holds the body upright and serves as attachment points for muscles, making motion possible (Whitney and Rolfes, 2016). On the other hand, magnesium is required for energy production, oxidative phosphorylation, and glycolysis and also contributes to the structural development of bone while specific roles of potassium in the body include nerve function, blood pressure regulation, electrolyte regulation and muscle control.

Effects of Drying Methods on the Phytochemical Contents of Okazi (Gnetum Africanum) Leaf

Table 3 shows the effects of drying methods on the phytochemical contents of okazi (Gnetum africanum) leaf. Phytochemicals (phytonutrients) are biologically active compounds that are known to be beneficial to human health and disease prevention.

The flavonoid content ranged from 171.54 mg/100g in Fresh sample to 558.4mg/100g in Freeze dried sample. Likewise, the phenolic content was highest (2417.32 mg/100g) in Freeze dried sample and lowest in Fresh sample, while the saponin content ranged from 196.82 mg/100g in Fresh sample to 1204.21mg/100g in Freeze dried sample. Statistically significant ($p < 0.05$) differences were observed in the flavonoid, phenols and saponin contents of the samples. These results showed

that drying increased the flavonoid, phenol and saponin contents of okazi leaf, with the freeze-dried sample having the highest concentrations of the aforementioned phytochemicals. In contrast, Oni reported a decrease in the saponin contents of some indigenous leafy vegetables like T [11]. occidentalis that its saponin content went from 5.76 in fresh leaf to 4.46mg/100g after freeze drying and T. triangulare that went from 4.00 in fresh leaf to 3.83mg/100g after being subjected to freeze drying. Functionally, flavonoids, saponins and phenols have been reported to possess significant antioxidant, anticancer, antitumor, hepatoprotective, anti-inflammatory and anti-diabetes activity on human health [21]. Thus, significant losses are of great disadvantage and vice versa. Therefore, to get the benefits of these phytochemicals, drying, particularly freeze-drying of okazi leaf, is advised.

Table 2: Effects of Drying Methods on the Micronutrient Composition of Okazi (Gnetum Africanum) Leaf

Sample	Calcium (mg/100g)	Potassium (mg/100g)	Magnesium (mg/100g)	Beta-carotene (µg/100g)	Vitamin C (mg/100g)
FR	791.2a ± 2.68	106.58a ± 0.62	335.09a ± 0.01	62.46a ± 0.01	113.39c ± 3.69
SD	859.19b ± 7.88	178.72b ± 0.01	607.75b ± 1.70	66.13b ± 0.01	90.77b ± 0.41
DD	145.43c ± 7.94	269.88c ± 1.01	946.07c ± 0.26	646.79c ± 0.00	82.35a ± 002
FD	152.52d ± 5.17	285.89d ± 2.07	996.27d ± 0.03	699.50d ± 0.01	87.00ab ± 164

On the other hand, the tannin contents of the samples ranged significantly ($p<0.05$) from 4.84 mg/100g in Dehydrator dried to 133.79 mg/100g in Shade dried sample. This result showed that shade drying increased the concentration of tannin; while freeze-drying and drying by using a food dehydrator all decreased the tannin contents of the samples. The differences in the tannin content could be attributed to the amount of heat and, or air pressure involved in the different drying methods since shade-drying which tend to involve little heat or air pressure was able to increase the concentration of tannin in in the leaf while the use of dehydrator significantly reduced the tannin content due to too much hot air involved in the dehydration process. In comparison to related literature, the effect of the drying process on the tannin content of okazi leaf is in line with the findings of Oni, who reported a decrease in the tannin contents of some leafy vegetables like T [11]. occidentalis that went from 4.54 to 4.46mg/100g and T. triangulare that went from 4.36 to 4.31mg/100g after drying. According to Nyamai, all forms of tannins may participate in the management of glucose levels in the blood by stimulating the receptor cells to utilise carbohydrates [22]. Tannins, in the form of proanthocyanidins, may also have a beneficial effect on vascular health.

Table 4: Effects of Drying Methods on the Phytochemical Contents of Okazi (Gnetum Africanum) Leaf

Sample	Flavonoids (mg)	Phenols (mg)	Tannin (mg)	Saponin (mg)
FR	171.54a ± 11.74	671.74a ± 13.0	90.34c ± 3.28	196.82a ± 9.68
SD	248.80b ± 0.01	972.80b ± 22.66	133.79d ± 1.45	420.28b ± 13.92
DD	361.00c ± 7.79	1961.05c ± 22.66	43.84a ± 3.27	962.31c ± 51.91
FD	558.84d ± 3.87	2417.32d ± 0.02	52.77b ± 3.25	1204.21d ± 6.50

Values are means ± standard deviation of duplicate determination. Means with different superscripts in the same column are significantly ($p< 0.05$) different.

Keys: FR = fresh okazi leaf, SD = shade-dried okazi leaf, DD = dehydrator-dried okazi leaf; FD = freeze-dried okazi leaf.

Rehydration Characteristics of Dehydrated Okazi leaves

Plate 1: Plates 1–3: Rehydrated Dehydrator-Dried, Shade-Dried, and Freeze-Dried Gnetum Africanum leaves.

Rehydration Curve of the Samples at 60oC

The rehydration curve of Okazi leaf at 60 °C, as shown in Figure 1 showed rapid moisture uptake within the first 5 minutes across all drying methods, rising to approximately 320 - 350 dry basis, indicating rapid water absorption due to initial surface hydration. Freeze-dried leaves demonstrated the fastest water uptake at this stage because freeze-drying preserves cellular microstructure and increases porosity, allowing water to penetrate quickly. This agrees with Kaleta who observed that freeze-dried beets demonstrated rapid early rehydration compared to convective or Shade-dried samples due to the porous microstructure formed during sublimation [23]. Shade-dried leaves followed closely, as the mild drying conditions resulted in minimal structural collapse and maintained moderate capillarity. This observation is in agreement to the findings by Okpala and Ekechi on the rehydration characteristics of dehydrated West African pepper leaves where it was concluded that for West African pepper leaves, Sun-drying resulted in dehydrated products with superior rehydration characteristics compared to Shade-Drying because low-temperature Shade-drying was shown to reduce the porosity and permeability of dried tissue, resulting in slower water uptake during the early rehydration period [24]. Food-dehydrated leaves absorbed moisture more slowly at first, most likely due to high-temperature drying, which caused tissue shrinkage and structural damage, reducing pore space and limiting early water entry. This agrees with studies on convective-dried vegetables where hot-air drying at moderate temperatures causes intermediate levels of structural damage [25].

Between 5 and 30 minutes, moisture gain stabilized at 350 -370 percent dry basis, with shade-dried samples slightly outperforming freeze-dried leaves due to partially preserved tissue elasticity, allowing for better internal hydration. Finally, after 30 to 90 minutes, there was a more gradual increase, reaching around 380 - 400 percent dry basis, with food-dehydrated leaves having the highest final moisture content. This suggests that, while initial absorption was hampered, prolonged soaking caused damaged cell walls to soften and swell, allowing for deeper hydration. Freeze-dried samples had slightly lower final moisture due to limited swelling potential despite their high porosity, whereas shade-dried leaves struck a balance between structural retention and hydration efficiency. This is consistent with the trend observed by Okpala and Ekechi which suggests that although freeze-drying provides excellent porosity, its fragile structure can recollapse during extended soaking, which limits deep hydration [24]. Overall, freeze drying promoted rapid rehydration, shade drying provided the best quality compromise, and food dehydration allowed for maximum moisture recovery during prolonged soaking.

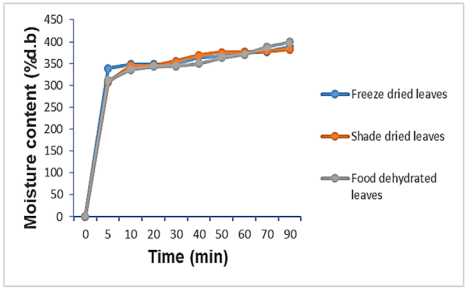

Figure 1: Moisture absorption characteristics of dried okazi leaves during rehydration at 60 0C

Rehydration curves of the samples at 70 °C

Figure 2 depicts the rehydration curve of okazi leaf at 70 °C, demonstrating a rapid increase in moisture content for all drying methods within the first 5 minutes, indicating rapid initial water uptake. At this point, freeze-dried, shade-dried, and food-dehydrated samples had all reached around 330-350 per cent dry basis, indicating effective surface hydration due to increased water diffusivity at higher temperatures. Consistent with research, the freeze-dried samples exhibited excellent initial rehydration due to their highly porous microstructure and preserved capillary channels, which facilitate swift water penetration [26]. However, the food-dehydrated leaves recorded the highest initial moisture uptake, likely because the elevated rehydration temperature enhanced tissue swelling and softened cell wall rigidity caused by thermal drying, allowing water to penetrate more easily [27]. In contrast, freeze-dried samples, while highly porous, rehydrated slightly lower at first because higher temperatures may have caused partial collapse of fragile dried structures, reducing capillary action. Shade-dried samples showed moderate initial rehydration, which is consistent with their partially preserved structural integrity.

Between 5 and 40 minutes, all samples demonstrated a steady but slower moisture gain, with values gradually increasing to 350-380 percent dry basis. The shade-dried samples trailed slightly behind the others due to moderate tissue compaction, whereas the freeze-dried leaves continued to absorb water gradually via diffusion into remaining internal pores. Eventually, from 40 to 100 minutes, food-dehydrated samples reached the highest final moisture content (approximately 390400 percent dry basis), demonstrating that prolonged soaking at higher temperatures enhances hydration of heat-damaged tissue networks. Despite their rapid rehydration, freeze-dried leaves had slightly lower moisture absorption at later stages, which could be attributed to capillary channel saturation and limited cell wall swelling potential. Shade-dried leaves retained consistent rehydration while remaining slightly lower than both methods. Overall, increasing the rehydration temperature from 60 °C to 70 °C improved total moisture recovery, especially in food-dehydrated samples, owing to increased softening and swelling of compacted cell structures. This suggests that freeze drying is best for rapid rehydration, whereas food dehydration benefits from higher temperatures and longer soak times, making it appropriate for traditional cooking methods [28].

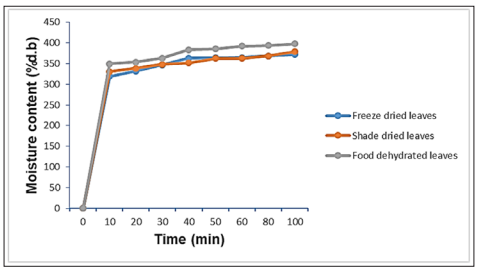

Figure 2: Moisture absorption characteristics of dried okazi leaves during rehydration at 70 °C

Rehydration curves of the samples at 80 °C

Figure.3 depicts the rehydration characteristics of the different dried leaf samples at 80 °C, and the results show clear differences in moisture uptake patterns between the three drying methods. Across all samples, moisture content increased rapidly within

the first 5 minutes of rehydration. This dramatic increase is due to the high temperature of the rehydration medium, which increases the mobility of water molecules, reduces viscosity, and accelerates diffusion into dried plant tissues. At higher temperatures, surface cells swell rapidly and capillary pores open, allowing water to penetrate at a much faster rate than at lower temperatures.

Food-dehydrated leaves had the highest rehydration capacity, reaching 430-460 percent (dry basis) by 90 minutes. This superior performance is due to structural changes caused by hot-air dehydration. Rapid moisture removal during drying causes internal vapour pressure to build up, expanding the leaf matrix and forming numerous interconnected pores. These pores function as capillary channels, effectively transporting water during rehydration. The gradual upward trend after the first 10 minutes indicates continued diffusion of water into deeper tissue layers until equilibrium moisture content is reached.

Freeze-dried leaves also demonstrated high rehydration values, ranging from 380 to 420 percent (dry basis). Freeze-drying removes water via sublimation, preserving cellular integrity and creating a highly porous, sponge-like structure [29]. This minimal structural collapse facilitates rapid and uniform water uptake. However, the final moisture content remained slightly lower than that of food-dehydrated samples, possibly due to the partial collapse of delicate pores when exposed to hot water, reducing the leaf's maximum water-holding capacity over extended rehydration [28].

In contrast, shade-dried leaves recorded the lowest rehydration values, stabilizing at 300-350 percent (dry basis). The slow drying rate associated with shade drying promotes significant cell wall shrinkage, tissue compaction, and decreased functional capillary pathways. This leads to reduced porosity and restricted water diffusion during rehydration. The early rise in the curve indicates that the most accessible water-binding sites are quickly filled, whereas deeper penetration is limited by the compact structure formed during shade drying. The overall pattern of all three samples, with a steep initial rise followed by a slower approach to equilibrium, reflects the typical rehydration behavior of dried plant materials. The rapid early uptake is driven by capillary action and surface hydration, whereas the slower later phase is caused by water diffusion into the interior and the establishment of equilibrium between the plant matrix and the surrounding water. The findings clearly demonstrated that the drying method has a significant impact on the rehydration performance of leafy materials, primarily through its effects on tissue porosity, cell wall integrity, and structural collapse.

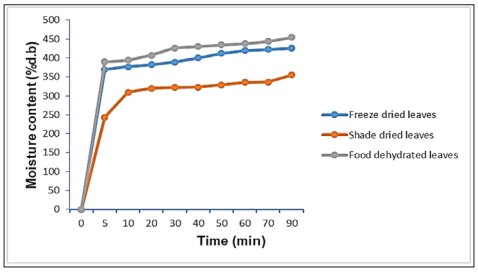

Figure 3: Moisture absorption characterisitics of dried okazi leaves during rehydration at 800C

Peleg's constant K2 and the equilibrium moisture content

Peleg's equation was used to fit the experimental data within the curvilinear segments of the curves. The result of the linear regression models fitted to the data at hydration temperatures of 60-800C is presented in Table 6. The result obtained for the Peleg's constant K2 is presented in Table 6. K2, the Capacity constant defines the equilibrium moisture content, a property that does not vary with temperature [30]. Peleg's constant K2 is related to maximum water absorption capacity so, the lower the K2, the higher the water absorption capacity.

Across all temperatures, the shade-dried samples showed the highest K2 values (0.257–0.281), while the food-dehydrated samples generally showed the lowest values, especially at 80 °C (0.218). From the study, temperature had a consistent effect across all drying methods. At 80 °C, the K2 values were lower than at 60 °C and 70 °C, meaning the leaves absorbed more water and were closer to their equilibrium moisture. This behaviour agrees with the general expectation that higher rehydration temperatures soften plant tissues faster and accelerate diffusion, resulting in lower K2 values [25]. The trend confirms that Okazi leaves, like many other green leafy vegetables, respond strongly to thermal softening during rehydration.

Furthermore, this trend aligns with Kaleta who observed that higher K2 values of 5.61 ×10-1 corresponded to poorer final rehydration in dried beet cubes, especially in tissues that experienced shrinkage or tougher cell walls during drying [23]. In contrast, materials that remained more porous after drying such as hot-air-dried or mechanically dehydrated products typically developed lower K2 values and therefore achieved higher equilibrium moisture contents [28]. A similar observation was made by Okpala and Ekechi in their study on West African pepper leaves, where the authors reported that structural disruptions from convective drying improved water uptake, reflected in lower Peleg K2 values of 2.20 ×102 [30].

The coefficients of determination, R2 values, varied from 0.995 – 0.999 with $P < 0.000$ (probability of null hypothesis of the slope of the slope = 0; indicating a good fit to the experimental data). This suggests that Peleg's equation is suitable for describing the water absorption characteristics of Shade, Food dehydrated and freeze dried leaves at investigated hydration temperatures which is 60-800C. This is consistent with previous studies showing that the Peleg model performs reliably for describing the non-linear water uptake behaviour of leafy vegetables, grains, and root crops [28].

The linear regression model results indicated that hydration rate of Okazi leaves was significantly affected by drying method and rehydration temperature. All regression models were highly significant ($p < 0.05$) with remarkably strong fits (R^2 = 0.995–0.999), confirming that moisture gain during rehydration progresses linearly over the measured period. The estimated slope (K_2) values suggest that increasing hydration temperature generally improved rehydration kinetics, particularly in shade-dried samples, which exhibited the highest rate at 80 °C ($K_2 = 2.81\times10^{-1}$). Freeze-dried samples rehydrated fastest at 70 °C ($K_2 = 2.62\times10^{-1}$), describing their superior structural integrity, while food dehydrated leaves showed best performance at 80 °C ($K_2 = 2.18\times10^{-1}$).

These findings imply that freeze-drying combined with hydration at 70–80 °C has optimal rehydration characteristics, whereas excessive mechanical dehydration may slightly limit water diffusion due to cell wall collapse.

Table 3: Summary of Linear Regression Models Fitted t/ (Mt – M0) Versus t for Okazi Leaves Hydrated at 60-800C

Treatment	Temperature (0C)	Estimated slope K2 (% mc db)	P	R2
Shade	60	2.57×10^{-1}	0.000	0.999
	70	2.59×10^{-1}	0.000	0.999
	80	2.81×10^{-1}	0.000	0.997
Food Dehydrated	60	2.47×10^{-1}	0.000	0.995
	70	2.45×10^{-1}	0.000	0.999
	80	2.18×10^{-1}	0.000	0.999
Freeze	60	2.56×10^{-1}	0.000	0.998
	70	2.62×10^{-1}	0.000	0.999
	80	2.31×10^{-1}	0.000	0.999

Peleg's Rate Constant K1

From the results obtained for each treatment Peleg's constant K1 values demonstrated that both drying method and rehydration temperature significantly influenced the rehydration kinetics of Okazi leaves. A lower K_1 and higher $1/K_1$ value indicate faster water absorption. Freeze-dried samples showed the best rehydration performance, particularly at 80 °C ($1/K_1 = 1.978$), suggesting minimal cell wall damage and effective restoration of hydration properties. Shade-dried leaves also rehydrated well at 80 °C (2.294), likely due to less thermal degradation during drying. In contrast, food dehydrated samples exhibited poor hydration at 60 °C ($1/K_1 = 1.103$), possibly due to structural collapse caused by high drying temperature. Overall, freeze-drying followed by hydration at 80 °C provided the best rehydration, while food dehydrated samples recovered more slowly, highlighting the importance of gentle drying methods for leafy vegetable.

The Peleg's rate constant K1 is a crucial indicator of the initial rate of water absorption during rehydration, with lower values corresponding to faster initial uptake. Fooddehydrated leaves at 80 °C had the lowest value (0.435), indicating the fastest initial water absorption. Shade-dried leaves exhibited higher values, with the highest being 0.789 at 80 °C, suggesting slower initial water penetration. Freeze-dried leaves showed intermediate values (0.505–0.629), reflecting moderate rehydration rates. These trends are consistent with literature reports which state that higher rehydration temperatures generally reduce, facilitating faster initial water uptake in various plant-based foods [23].

The differences in between drying methods likely reflect structural changes induced by the drying process. Higher-temperature food dehydration may create micro-pores or weaken cell walls, enhancing water diffusion, whereas freeze-drying preserves original tissue integrity, limiting immediate water penetration despite maintaining overall rehydration capacity.

The reciprocal of the Peleg rate constant 1/k1 provides a direct measure of the initial water absorption rate, with higher values indicating faster uptake. In this study, food-dehydrated leaves at 80 °C exhibited the highest 1/k1 (~2.294), confirming their rapid initial rehydration. Shade-dried leaves had lower 1/k1 values (1.334–2.033), while freeze-dried samples displayed intermediate values (1.588–1.978).

The trend of increasing 1/k1 with higher rehydration temperatures was observed across all drying methods. For example, in shade-dried leaves, 1/k1 increased from 2.033 at 60 °C to 2.294 at 80 °C, indicating that higher temperature enhances the initial water absorption rate. This pattern aligns with findings from Zhang et al., (2024) and Górnicki, who reported faster initial rehydration at higher temperatures due to enhanced diffusion and reduced tissue resistance [23].

Table 4: Peleg's K1 values for Okazi Leaves Hydrated at 60-700C

Treatment	Temperature (0C)	K1	1/ K1
Shade	60	4.91×10^{-1}	2.033
	70	7.49×10^{-1}	1.334
	80	7.89×10^{-1}	2.294
Food Dehydrated	60	9.06×10^{-1}	1.103
	70	6.54×10^{-1}	1.526
	80	4.35×10^{-1}	1.266
Freeze	60	5.51×10^{-1}	1.813
	70	6.29×10^{-1}	1.588
	80	5.05×10^{-1}	1.978

Conclusion

Green leafy vegetables are under-utilized despite high nutrient density. From the results gotten in this study, it demonstrated that different drying methods influence the nutritional, micronutrient, phytochemical, and rehydration properties of okazi leaves. Freeze-drying consistently produced the most desirable outcome, yielding the lowest moisture content and the highest concentrations of protein, fat, carbohydrate, vitamins (beta-carotene), minerals, and phytochemicals. Dehydrator drying also enhanced nutrient concentration but was less effective than freeze-drying. Shade drying retained more vitamin C and increased tannin levels but provided lower overall nutrient concentration. The rehydration characteristics showed that dehydrator dried and freeze-dried samples rehydrated rapidly, especially at high temperatures, making them more suitable for processing applications. These results show the importance of selecting an appropriate drying method to preserve okazi leaf quality. Freeze-drying is therefore recommended for optimal nutrient retention, while dehydrator drying serves as a practical alternative when freeze-drying is unavailable.

Recommendation

From the results gotten in this study, it is recommended that:

- Freeze-drying should be adopted as the preferred method for processing okazi leaves, especially in commercial and industrial applications where maximum nutrient and phytochemical retention is required.

- Food dehydrator drying may be used as a cost-effective and accessible alternative for small-scale processors, as it retains significant nutrient levels and provides excellent rehydration performance.
- Shade drying should be applied only when modern drying technologies are unavailable, as it preserves vitamin C but results in lower overall nutrient concentration and higher residual moisture.
- Rehydration of dehydrated Okazi leaves at 800C is recommended. At this temperature, the leaves reconstituted faster within few minutes of immersion.

Acknowledgments

The authors sincerely acknowledge the Department of Food Science and Technology, University of Nigeria, Nsukka, for providing the laboratory facilities necessary for this study.

References

1. Sontakke MS, Salve P. Solar drying technologies: a review. International Refereed Journal of Engineering and Science. 2015. 4: 29-35.
2. Ejoh RE, Wireko-Manu FD, Page D, Renard CMG. Traditional green leafy vegetables as underutilized sources of micronutrients in a rural farming community in southwest Nigeria I: estimation of vitamin C, carotenoids and mineral contents. South African Journal of Clinical Nutrition. 2021. 34: 40-45.
3. Osafo R. Nutrient composition and health benefits of underutilized green leafy vegetables in Ghana: a review. European Journal of Nutrition and Food Safety. 2021. 13: 43-62.
4. Okerulu IO, Onyema CT. Comparative assessment of phytochemicals, proximate and elemental composition of Gnetum africanum (Okazi) leaves. American Journal of Analytical Chemistry. 2015. 6: 604-609.
5. Amonyeze AO, Aremu KO, Onwuchekwa AI, Chukwuebuka NO, Ojotule O, et al. Okazi (Gnetum africanuum) manually operated leaf slicer: design, fabrication and performance evaluation. African Journal of Food Science and Technology. 2022. 13: 021.
6. Wang B, Li Y, Wang Z, Wen L, He Y. Dehydration-rehydration mechanism of vegetables at the cell-wall and cell-membrane levels and future research challenges. Critical Reviews in Food Science and Nutrition. 2023. 64: 11179-11195.
7. Nasim K. Effect of biopolymer dip-coating pretreatments on physicochemical characteristics, drying, and rehydration kinetics of pears. Foods. 2024. 12: 2466.
8. AOAC. Official methods of analysis (18th ed.). Association of Official Analytical Chemists. 2012.
9. Adeola AA, Ohizua ER. Physical, chemical, and sensory properties of biscuits prepared from flour blends of unripe cooking banana, pigeon pea, and sweet potato. Food Science Nutrition. 2018. 6: 532-540.
10. Sarma U, Bhavya TR. Dietary phytonutrients in common green leafy vegetables and the significant role of processing techniques on spinach: a review. Food Production Processing and Nutrition. 2024. 6: 10.
11. Oni MO, Ogungbite OC, Akindele AK. The effect of different drying methods on some common Nigerian edible botanicals. International Journal of Advanced Research in Botany. 2015. 1: 15-22.
12. Garba Z, Oviosa S. The effect of different drying methods on the elemental and nutritional composition of Vernonia amygdalina (bitter leaf). Journal of Taibah University for Science. 2019. 13: 396-401.
13. Alassane CT, Abdoulaye T, Fabrice ZA, Claude KAL, Souleymane M, et al. Effect of three drying modes on nutritive and antinutritive properties of leafy vegetables consumed in northern Côte d'Ivoire. EAS Journal of Nutrition and Food Science. 2022. 4: 102-111.
14. Okwunodulu IN, Nwaorienta C, Okwunodulu FU, Onuorah CC, Ndife J, et al. Impact of different packaging materials on some physicochemical and acceptability of moimoi prepared from cowpea (Vigna unguiculata). Acta Scientific Nutritional Health. 2019. 3: 60-71.
15. Wardlaw GM. Perspectives in nutrition. 2024.
16. Shonte TT, Duodu KG, de Kock HL. Effect of drying methods on chemical composition and antioxidant activity of underutilized stinging nettle leaves. Heliyon. 2020. 6: 10-11.
17. Ojinnaka MC, Odimegwu EN, Chidiebere FE. Comparative study on the nutrient and antinutrient composition of the seeds and leaves of Uziza (Piper guineense). Journal of Environmental Science Toxicology and Food Technology. 2016. 10: 42-48.
18. Mohammadi X, Deng Y, Matinfar G, Singh A, Mandal R, et al. Impact of three different dehydration methods on nutritional values and sensory quality of dried broccoli, oranges, and carrots. Foods. 2020. 9: 1464.
19. Vargas L, Kapoor R, Nemzer B, Feng H. Application of different drying methods for evaluation of phytochemical content and physical properties of broccoli, kale, and spinach. Food Science and Technology. 2022. 155: 112892.
20. Pehlivan FE. Vitamin C: an antioxidant agent. 2019.
21. Xiao J, Capanoglu E, Jassbi AR, Miron A. Advance on the flavonoid C-glycosides and health benefits. Critical Reviews in Food Science and Nutrition. 2015. 56: 29-45.
22. Nyamai DW, Arika W, Ogola PE, Njagi ENM, Ngugi MP. Medicinally important phytochemicals: an untapped research avenue. Research and Reviews Journal of Pharmacognosy and Phytochemistry. 2016. 4: 35-49.
23. Kaleta A, Górnicki K, Obranović M, Kosiorek K. Suitable model for rehydration of dried red beets: effect of solid-to-liquid ratio on rehydration characteristics. Applied Sciences. 2024. 14: 6132.
24. Okpala LC, Ekechi CA. Rehydration characteristics of dehydrated West African pepper (Piper guineense) leaves. Food Science & Nutrition. 2014. 2: 664-668.
25. Kuna-Broniowska I, Blicharz-Kania A, Andrejko D, Kubik-Komar A, Kobus Z, et al. Modelling water absorption in micronized lentil seeds with the use of Peleg's equation. Sustainability. 2020. 12: 261.
26. Li J, Chen R, Chen T, Zuo J, Ma J, et al. Quality characteristics and microstructural analysis of dried garlic slices prepared by different drying methods. Drying Technology. 2023. 41: 1184-1198.
27. Dutta P, Gogoi SD, Saikia S. Effect of temperature and pretreatments on dehydration and rehydration characteristics of Naga chili. Journal of Food Science and Technology. 2023. 60: 1361-1370.
28. Nayi P, Kumar N, Kachchadiya S, Chen HH, Singh P, et al. Rehydration modeling and characterization of dehydrated sweet corn. Food Science & Nutrition. 2023. 11: 3224-3234.

29. Adeyeye SAO, Ashaolu TJ, Babu AS. Food drying: a review. Agricultural Reviews. 2022. 2023: 8877953
30. Peleg M. An empirical model for the description of moisture sorption curves. Journal of Food Science. 1988. 53: 1216-1217.