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Comparative Evaluation of Drying Methods on the Quality Characteristics of *Musa paradisiaca* Floret Powder

Shubham Upadhyay[1], *Ruchi* Verma[1]*, *Lavika* Tomar[1], *Gulshan* Mishra[2], *Srashti* Sharma[1] and *Shiwanand* Pandey[3]

[1]Department of Food Processing and Technology, School of Vocational Studies and Applied Sciences, Gautam Buddha University
[2]Department of Biotechnology, School of Biotechnology, Gautam Buddha University
[3]School of Advanced Agriculture Sciences and Technology (SAAST), Chhatrapati Shahu Ji Maharaj University, Kalyanpur, Kanpur-208024

*Corresponding authors: ruchiverma0715@gmail.com

Abstract: The present study investigated the effect of different drying methods on the quality characteristics of banana floret powder (BFF). Banana blossom florets were selected due to their richness in dietary fiber, phenolic compounds, flavonoids, and antioxidants, which are associated with potential health benefits, including the management of diabetes, PCOS, and cancer. Fresh banana florets were pre-treated with 1% potassium metabisulphite (KMS) solution and subjected to tray drying (TD), fluidized bed drying (FBD), and freeze drying (FD). The drying methods were compared based on their effects on the physicochemical, nutritional, functional, mineral, and color properties of BFF. Among the drying techniques, FD exhibited superior quality retention with the lowest moisture content (3.50%) and significantly higher ash (10.2%), fat (3.2%), protein (12.6%), and fiber (20.6%) contents, indicating better nutrient preservation. Functional properties were also significantly improved in FD samples, demonstrating enhanced techno-functional characteristics suitable for value-added food applications. Mineral analysis revealed greater retention of iron, manganese, zinc, calcium, and magnesium in FD samples compared to TD and FBD. Furthermore, FD showed significantly higher L* and C* values, indicating better color preservation. Overall, freeze drying was identified as the most effective drying method for producing nutritionally superior and functionally stable banana floret powder, followed by fluidized bed drying.

Keywords: Banana blossom floret, Moisture, Mineral, Drying, Color

1. Introduction

Banana (Musa spp.) is one of the most important fruit crops cultivated worldwide and is extensively grown in tropical and subtropical regions. India is among the leading producers of bananas and generates a large quantity of agricultural by-products during cultivation and processing. The scientific name of the banana is *Musa paradisiaca*, the fruit of the *Musa* family [1,2]. It is traditionally consumed as a vegetable in many Asian countries including India, Sri Lanka, Thailand, and the Philippines [3]. Banana blossom florets are rich in dietary fiber, proteins, vitamins, minerals, phenolic compounds, flavonoids, and antioxidants. These bioactive compounds contribute to various health-promoting properties such as antioxidant, antimicrobial, antidiabetic, and cardio-protective effects. Banana fruit is rich in minerals such as calcium and iron, as well as magnesium, sodium, potassium, and phosphorus. Banana contains more lutein than provitamin. A pigments, α-carotene and β-carotene [4]. Banana blossom is generally used for ill health like heart attack, diarrhea, asthma, and stomach pain it could also be used to cure bronchitis, dysentery, weight loss, anaemia, constipation, ulcers, menstruation, diabetes, cancer, etc [5]. Blossom is reported to cure asthma, stomach and throat ulcers, itching of the eyes, and blood flow problems. It keeps the uterus healthy, reduces bleeding during the menstrual cycle, acts as a lactating agent, reduces anxiety, and increases good mood. Drying is a critical preservation technique that significantly affects the nutritional, functional, and physicochemical properties of food products. Different drying methods vary in their drying mechanisms, energy requirements, processing costs, and ability to retain heat-sensitive bioactive compounds. Therefore, a comparative evaluation of different drying techniques is essential to identify the most suitable method for producing high-quality banana floret powder with maximum retention of nutrients and bioactive compounds. Previous studies have reported that freeze drying provides superior retention of color, phenolic compounds, antioxidants, and sensory quality in various fruits and vegetables; however, it is associated with high operational costs and longer processing times. In contrast, hot-air and tray drying methods are economically feasible and widely adopted at industrial scale, but they may result in greater degradation of heat-sensitive nutrients and bioactive compounds. Several researchers have demonstrated the influence of drying techniques on the quality attributes of plant-based materials such as mango, pumpkin, moringa leaves, beetroot, and banana products, highlighting the need for crop-specific optimization of drying conditions. In several studies, food products like probiotic drinks were developed by fermenting flowers and leaves using *Lactobacillus paracasei* [6], the banana inflorescences were also used to formulate beverages and biscuits.

Therefore, the present study aimed to evaluate and compare the effects of different drying methods on the physicochemical, nutritional, antioxidant, and functional properties of banana floret powder and to identify the most suitable drying technique for the development of nutritionally enriched functional food ingredients.

2. MATERIALS AND METHODS

2.1 Collection of Raw Material

Banana blossom were harvested from the Meerut Agriculture University (SVPUAT) and inspected for damage manually before processing. The experiment was conducted in Food Processing and Technology laboratory of Gautam Buddha University, Greater Noida.

2.2 Sample Preparation

Manually removed the non-edible portion and outer bracts and separated carefully. Then the florets were steeped in 1 % KMS solution for 1 hr at ambient temperature to inhibit the enzymatic browning and help to preserve the color. After pretreatment, the excess amount of water was drained and the samples were divided into three equal portions for different drying treatments [7].

2.2.1 Drying Methods

Pretreated banana florets were subjected to three different drying methods viz Tray Drying (TD), Fluidized Bed Drying (FBD), and Freeze Drying (FD). For tray drying, the florets were uniformly spread on stainless steel trays and dried at 55°C. In FBD the samples were dried under controlled temperature and airflow conditions using a fluidized bed dryer, which provided rapid and uniform heat transfer for efficient moisture removal. For FD, the samples were pre-frozen at −40°C for 24 h and then dried under vacuum conditions in a freeze dryer where moisture was removed by sublimation. The drying processes were continued until safe moisture content suitable for storage was obtained [7,8,9]. The dried samples obtained were ground by a grinder to obtain fine powder and were sieved through a standard mesh sieve (80 BSS) to ensure uniform particle size and stored in airtight container for further analysis as shown in Fig. 1.

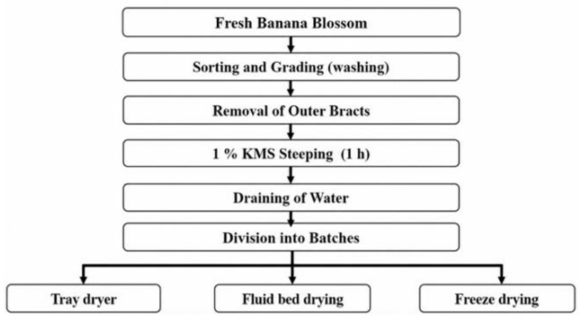

Fig. 1. Processing of Banana Floret Powder

2.3 Physicochemical Analysis

Moisture, ash and fat content of the sample were evaluated by using standard method. Crude fibre and protein were analyzed used by using automatic extraction unit (Kelpus pelican) whereas pH determined using digital pH meter (Biogen Scientific, India) [10,11,12].

2.4 Functional Properties

Functional properties, including water absorption capacity and oil absorption capacity, were evaluated using standard analytical methods. Briefly, 1 g of sample was dispersed in 30 ml of distilled water, heated at 50°C for 30 min, and centrifuged (Biogen Scientific, India) at 4500 rpm for 15 min. Swelling power (SP) and solubility index (SI) were calculated at different temperatures (60, 70, 80 and 90^0 C) following the standard analytical procedure.

2.5 Bulk and Tapped density

BD was determined by measuring the volume occupied by 50 g of the sample in a graduated cylinder where as tapped density was measured after mechanically tapping the cylinder until a constant volume was obtained [13].

2.6 Flow properties

It was calculated using Carr's Index (CI) and Hausner Ratio (HR) were used to assess flowability [6]. CI values below 15% and HR values <1.25 indicate good flowability.

$$CI (\%) = [(Tapped – Bulk) / Tapped] \times 100$$
$$HR = Tapped / Bulk$$

2.7 Color Analysis

Color characteristics of samples were measured by using hunter color lab colorimetery (Hunter Associates Laboratory Inc., Reston, VA, USA) were expressed in terms of L* (lightness), a* (redness), b* (yellowness), C* (chroma) and h° (hue) [14].

2.8 Elemental Analysis

A 0.25 g aliquot of each dried sample underwent acid digestion with 6 mL of nitric acid (HNO_3) and 1 mL of hydrogen peroxide (H_2O_2) in a microwave digestion apparatus. The digested samples were diluted to 50 mL with deionised water and subsequently diluted 1:10 before analysis. Elemental concentrations were determined using Inductively Coupled Plasma Optical Emission Spectroscopy (Thermo Scientific iCAP 7000 Series), and results were expressed in mg/kg [2].

2.9 Statistical Analysis

All experiments were performed in triplicate and results were expressed as mean ± standard deviation. Statistical analysis was carried out using one-way analysis of variance (ANOVA) using SPSS software to determined significant differences among drying methods at $p < 0.05$ level of significance.

3. Result and Discussion

3.1 Effect on Physicochemical Properties

The variations in physicochemical properties as depicted in Table 1 and may be associated with differences in drying temperature, heat transfer efficiency, oxygen exposure, and duration of dehydration, which influence nutrient retention and structural stability of the powder.

Moisture content ranged from 8.6±0.10% to 4.6±0.10%, with the lowest value observed in FD BFF may be due to sublimation drying preserves the porous cellular matrix, which may retain some bound water molecules within the structure [15]. FBD BFF observed lower moisture than TD BFF may be attributed to rapid and uniform heat transfer during fluidization, resulting moisture removal efficiency [16]. Lower moisture content is beneficial for improving shelf stability and minimizing microbial spoilage. Similar findings were reported by [15,16] in banana blossom powder.

Ash content increased from 9.7±0.10% in TD BFF to 10.2±0.10% in FD BFF. The higher ash content observed in FD powder may be due to superior preservation of mineral constituents under low-temperature drying conditions that will help to inhibit thermal degradation and oxidation reactions [17]. Similar observations were reported by [18], indicating improved mineral retention in freeze-dried products.

Table 1. Effect on physicochemical properties

Parameter (s)	Samples		
	TD BFF	**FBD BFF**	**FD BFF**
Moisture (%)	8.6± 0.10[c]	6.63± 0.10[b]	3.6± 0.10[a]
Ash (%)	9.7± 0.10[a]	9.9±0.10[b]	10.2± 0.10[c]
Fat (%)	2.8± 0.10[a]	3± 0.57[b]	3.2± 0.10[b]
Protein (%)	11.1± 0.12[a]	11.9± 0.10[b]	12.6± 0.10[c]
Fibre (%)	18.6± 0.10[a]	19.3± 0.10[b]	20.6± 0.10[c]
pH	5.76± 0.57[a]	5.93± 0.57[b]	6.06± 0.57[c]
Acidity (%)	0.43± 0.01[c]	0.38± 0.10[b]	0.32± 0.10[a]

Values expressed are ±SD (n=3)
Different superscripts differ significantly ($p \leq 0.05$).
TD BFF: Tray Dried Banana Floret Flour
FBD BFF: Fluidized Bed Dried Banana Floret Flour
FD BFF: Freeze Dried Banana Floret Flour

Fat content increased significantly from 2.8±0.10% in TD BFF to 3.2±0.10% in FD BFF. The higher fat retention in FD BFF may be attributed to minimal lipid oxidation under low-temperature and vacuum drying conditions [19]. Similar trend were followed by [17], who reported fat content of 3.4% in FD plant powders compared to 2.6% in TD dried samples due to reduced oxidative deterioration.

Protein content was highest in FD BFF (12.6±0.10%) followed by FBD (11.9±0.10%) and TD BFF (11.1±0.10%). The improved protein retention in FD BFF may be associated with reduced protein denaturation and minimise the Maillard reactions under low-temperature conditions [20], but thermal drying may decrease measurable protein content due to structural degradation and modify the heat-induced protein. Similar findings were reported by [21], who observed protein content of 13.1% in freeze-dried banana blossom powder and 10.8% in hot-air dried samples due to better preservation of nitrogenous compounds in during freeze drying.

Fibre content ranged from 18.6±0.10% in TD BFF to 20.6±0.10% in FD BFF. The higher fibre content observed in FD powder may be due to better preservation of structural polysaccharides and cell wall components [22]. Thermal treatments may partially degrade pectin, hemicellulose, and other fibre fractions, resulting in lower fibre retention

The pH values increased from 5.76±0.57 in TD samples to 6.06±0.57 in FD samples. The lower pH observed in TD BFF may be associated with thermal degradation of carbohydrates and formation of acidic compounds during prolonged heating [23]. FD minimises oxidative and biochemical reactions, and similar findings were reported by and observed 6.12 value in FD vegetable powders and 5.68 in hot-air dried samples due to reduced acid formation during low-temperature drying [23].

Acidity showed an inverse trend, decreasing from 0.43±0.01% in TD BFF to 0.32±0.10% in FD BFF. Higher acidity may result from thermal degradation of carbohydrates and production of organic acids during prolonged drying, while lower acidity in FD BFF indicates better preservation of the original biochemical composition due to minimal thermal stress [22]. Similar observations were reported by [18], who documented acidity values of 0.31% in FD powders and 0.46% in thermally dried vegetable powders.

The present study showed that the FD demonstrated superior retention of nutritional constituents such as protein, fibre, fat, and minerals because of minimal thermal degradation and oxidation. FBD exhibited the lowest moisture content, suggesting better storage stability and shelf-life characteristics. TD resulted in comparatively lower nutrient retention due to prolonged exposure to heat and oxidative conditions. Present study showed that FD may be considered the most suitable drying technique for preserving the physicochemical quality of BFF, whereas FBD may be advantageous for achieving lower moisture content and improved storage stability.

3.2 Effect on Functional Properties

Functional properties are important quality parameters because they determine the suitability of powders in various food formulations, such as bakery, dairy, beverage, and emulsified products. In Table 2 presented the variations that may be associated with differences in drying temperature,
structural modification, protein denaturation, and retention of hydrophilic and hydrophobic compounds during drying.

WAC ranged from 2.15±0.05 g/g in TD BFF to 2.85±0.50 g/g in FD BFF. The significantly higher WAC in FD BFF may be attributed to the formation of a porous and sponge-like structure during sublimation drying, which increases water-binding sites and improves hydration characteristics [25]. In contrast, thermal drying methods may cause shrinkage and structural collapse, thereby reducing water-binding ability due to compact cellular arrangement and reduced availability of hydrophilic groups. Similar findings were reported by [25] who observed higher WAC in FD vegetable powders (2.74 g/g) and gac fruit powder (2.02 g/g) as compared to hot thermally dried powder due to better porosity and preservation of hydrophilic groups and also indicated the superior hydration properties under low temperature.

Table 2. Effect on functional properties

Parameter (s)	Samples		
	TD BFF	**FBD BFF**	**FD BFF**
WAC (g/g)	2.15± 0.05[a]	2.45± 0.05[b]	2.85± 0.50[c]
OAC (g/g)	1.65± 0.50[a]	1.85± 0.50[b]	2.05± 0.50[c]
EA (%)	49.00± 1.00[a]	53.00± 1.00[b]	59.00± 1.00[c]
ES (%)	45.50± 0.50[a]	48.50± 0.50[b]	52.50± 0.50[c]
FC (%)	19.00± 1.00[a]	22.50± 0.50[b]	29.00± 1.00[c]
FS (%)	16.50± 0.50[a]	19.50± 5.0[b]	24.50± 0.50[c]

Values expressed are ±SD (n=3)
Different superscripts differ significantly ($p \leq 0.05$).
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OAC increased significantly from 1.65±0.50 g/g in TD BFF to 2.05±0.50 g/g in FD BFF may be due to better preservation of hydrophobic amino acid residues and porous structures that facilitate oil entrapment and flavour retention [19,21]. Lower OAC in TD BFF may result from protein denaturation and destruction of non-polar binding regions caused by prolonged heat exposure and oxidative deterioration [3]. Similar observations were reported by [21], who reported OAC values of 2.12 g/g for FD vegetable powder and 1.71 g/g for hot-air dried samples, indicating improved oil retention in low-temperature dried products.

Emulsion activity increased from 49.00±1.00% in TD BFF to 59.00±1.00% in FD BFF, whereas emulsion stability increased from 45.50±0.50% to 52.50±0.50%, respectively. Similar findings were reported by [3,26] who observed higher EA of 61.20% in FD dried plant powders followed by reduced ES from 54.10% to 44.30% due to protein denaturation and aggregation during heating. The improved emulsion properties in FD BFF may be attributed to better preservation of surface-active proteins and polysaccharides responsible for emulsion formation and stabilization [26]. FD minimises protein denaturation and aggregation, thereby maintaining protein solubility and interfacial activity, while thermal drying may decrease emulsifying properties because protein unfolding reduces their ability to stabilise oil–water interfaces [3].

FC and FS also followed the order FD BFF > FBD BFF > TD BFF. FC increased from 19.00±1.00% in TD BFF to 29.00±1.00% in FD BFF, while FS increased from 16.50±0.50% to 24.50±0.50%, respectively. Similar observation were reported by [15] FC of 28.40% in minimally processed flour samples and 18.60% in heat-treated samples may cause protein coagulation and reduced surface activity, thereby lowering foaming characteristics. Furthermore, [27] observed foaming stability values of 25.10% in freeze-dried flour samples compared to 17.80% in thermally dried powders due to better preservation of protein flexibility and solubility, which facilitate rapid adsorption at the air–water interface and formation of stable foam structures.

In present study demonstrated the enhanced hydration, emulsification, oil absorption, and foaming characteristics noted in FD may be attributed to minimal thermal degradation and improved preservation. FBD showed intermediate performance because of shorter drying duration and efficient heat transfer, whereas TD exhibited comparatively lower functional quality due to structural damage.

3.3 Effect on SI and SP

The variations among drying methods may be associated with differences in microstructural integrity, porosity, starch gelatinization behaviour, and preservation of hydrophilic constituents during dehydration as represented in Table 3. These functional characteristics are important indicators of reconstitution ability and applicability of powders in food systems.

SI of all BFF increased progressively with increase in temperature due to enhanced molecular mobility and weakening of intermolecular hydrogen bonding at elevated temperatures, resulting in increased dissolution of soluble solids [19]. At 50°C, SI values ranged from 10.50±0.50% in TD BFF to 15.50±0.50% in FD BFF, whereas at 90°C, values increased to 18.50±0.50%, 23.50±0.50%, and 30.50±0.50% for TD, FBD, and FD samples, respectively. Similar findings were reported by [27] who observed SI of 31.6% in FD vegetable powder compared to 20.4% in hot-air dried samples due to higher porosity and reduced structural collapse during low-temperature drying. Likewise, [24] reported improved solubility behaviour in freeze-dried fruit powders because of better preservation of hydrophilic compounds and cellular structure. Similar observations were documented by [19], who reported that solubility of plant-based powders increased from 15.1% at 50°C to 30.2% at 90°C because of enhanced starch gelatinization and molecular dispersion at higher temperatures.

Table 3. Effect on SI and SP

Parameter (s)	Samples		
	TD BFF	**FBD BFF**	**FD BFF**
Solubility Index (%)			
50 °C	10.50± 0.50	12.50± 0.50	15.50± 0.50
60 °C	12.50± 0.50	14.50± 0.50	18.50± 0.50
70 °C	14.50± 0.50	17.50± 0.50	22.50± 0.50
80 °C	16.50± 0.50	20.50± 0.50	26.50± 0.50
90 °C	18.50± 0.50	23.50± 0.50	30.50± 0.50
Swelling Power (g/g)			
50 °C	4.55± 0.05	5.25± 0.05	6.10± 0.10
60 °C	5.55± 0.05	5.55± 0.05	6.60± 0.10
70 °C	5.55± 0.05	5.95± 0.05	7.10± 0.10
80 °C	5.55± 0.05	6.45± 0.05	7.70± 0.10
90 °C	6.05± 0.05	7.10± 0.10	8.60± 0.10

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Different superscripts differ significantly ($p \leq 0.05$).
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SP also increased significantly with increase in temperature for all drying methods. At 50°C, SP ranged from 4.55±0.05% in TD BFF to 6.10±0.10% in FD BFF, while at 90°C, values increased to 6.05±0.05%, 7.10±0.10%, and 8.60±0.10% for TD, FBD, and FD BFF, respectively. The significantly higher SP observed in FD BFF may be due to preservation of porous microstructure and amorphous starch regions, which facilitate greater water uptake and granule expansion during heating disruption of crystalline regions and increased hydration of amylopectin chains [28,29].

FD minimizes structural collapse and maintains capillary spaces that improve hydration behavior. In contrast, prolonged thermal drying may induce starch retrogradation and rigid compact structures, thereby limiting swelling capacity [30]. Similar findings were reported by [29], who observed SP values of 8.7% in FD powders and 5.8% in hot-air dried samples due to better preservation of starch granule structure and water absorption properties.

3.4 Effect on flowability properties

The flowability of all BFF showed significant differences ($p < 0.05$) among the drying methods as presented in Table 4. Parameters such as bulk density, tapped density, Carr's index, Hausner's ratio, and angle of repose are important indicators of powder handling behaviour, flow characteristics, packaging efficiency, and storage stability.

BD values ranged from 0.42±0.01 g/cc in FD BFF to 0.52±0.01 g/cc in TD samples. The significantly lower BD observed in FD may be due to the formation of highly porous and expanded structures during sublimation drying, which increases inter-particle void spaces and reduces particle compactness. In contrast, tray drying may result in structural shrinkage and particle compaction because of prolonged thermal exposure, thereby increasing BD. Similar trend followed by [32] who reported that thermal drying produced denser powder particles because of structural collapse during moisture removal.

TD followed a similar trend, decreasing significantly from 0.65±0.01 g/cc in TD BFF to 0.55±0.01 g/cc in FD BFF. Thermal drying methods generally produce compact particles with reduced void spaces, leading to higher tapped density values. Similar observations were reported by [28], who observed tapped density values of 0.54 g/cc in FD plant powder compared to 0.69 g/cc in thermally dried samples due to differences in particle compactness porosity and irregular particle structures generated during FD.

CI values ranged from 15.75±0.23% in FD BFF to 20.00±0.35% in TD BFF. Present study lower CI observed in FD BFF samples indicates improved flowability and reduced cohesiveness of powders resulting from porous and lightweight structures where as higher CI observed in TD BFF may be due to increased cohesiveness caused by compact particle arrangement and moisture-associated adhesion. Similar findings were reported by [32], who documented a CI of 16.2% in FD powders and 21.8% in hot-air dried powders.

Table 4. Effect on flow properties

Parameter (s)	Sample		
	TD BFF	FB BFF	FD BFF
Bulk Density (g/cc)	0.52± 0.01^{c}	0.48± 0.01^{b}	0.42± 0.01^{a}
Tapped Density (g/cc)	0.65± 0.01^{c}	0.60± 0.01^{b}	0.55± 0.01^{a}
Carr's Index (%)	20.00± 0.35^{c}	18.28± 0.31^{b}	15.75± 0.23^{a}
Hausner's Ratio	1.24± 0.00^{c}	1.22± 0.00^{b}	1.17± 0.01^{a}
Angle of Repose (°)	38.16± 0.35^{c}	35.16± 0.35^{b}	32.16± 0.35^{a}

Values expressed are ±SD (n=3)
Different superscripts differ significantly ($p \leq 0.05$).
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FD BFF: Freeze Dried Banana Floret Flour

HR decreased significantly from 1.24±0.00 in TD BFF to 1.17±0.01 in FD BFF. Lower Hausner's ratio values are indicative of better powder flow properties and reduced cohesiveness. Similar observations were reported by [33], who reported HR values of 1.15 for FD powders and 1.28 for hot-air dried powders due to improved particle separation and lower cohesiveness and increased particle porosity, which reduce inter-particle attraction forces.

The angle of repose decreased significantly from 38.16±0.35° in TD BFF to 32.16±0.35° in FD BFF. Lower angle of repose values indicate superior flowability and reduced friction between particles. Similar findings were reported by [34], who observed angle of repose values of 31.4° in freeze-dried powders and 39.2° in thermally dried samples may be due to lower bulk density, increased porosity, and smoother particle morphology resulting from reduced compactness and cohesiveness where as TD may produce irregular and dense particles that increase frictional resistance and hinder powder flow.

3.5 Effect on Mineral Composition

Essential minerals such as iron, manganese, copper, zinc, calcium, and magnesium were found in appreciable amounts in all samples; however, FD BFF exhibited comparatively higher mineral retention than FBD and TD BFF as showed in Table 5. The variations in mineral content may be attributed to differences in thermal exposure, oxidation reactions, and structural preservation during dehydration.

Iron content increased from 7.20 mg/100 g in TD BFF to 9.00 mg/100 g in FD BFF. The higher iron retention observed in FD BFF may be associated with

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minimal thermal degradation and reduced oxidative losses under low-temperature drying conditions [35]. Similar findings were reported by [35], who observed iron content of 9.4 mg/100 g in FD vegetable powders compared to 7.1 mg/100 g in hot-air dried samples due to superior mineral preservation under freeze drying where as TD methods may cause degradation of iron-associated complexes because of prolonged heat exposure and oxidation.

The higher manganese retention in FD BFF may be due to reduced destruction of mineral-binding compounds during low-temperature dehydration While TD may promote oxidative reactions and structural breakdown that reduce mineral stability [36].

Table 5. Effect on mineral contents

Parameter (s) (mg/100)	Samples		
	TD BFF	**FBD BFF**	**FD BFF**
Iron	7.20	8.13	9.00
Manganese	2.96	3.46	3.96
Copper	1.00	1.26	1.50
Zinc	3.50	3.80	4.16
Calcium	112.50	118.30	125.60
Magnesium	95.30	102.80	110.50

TD BFF: Tray Dried Banana Floret Flour
FBD BFF: Fluidized Bed Dried Banana Floret Flour
FD BFF: Freeze Dried Banana Floret Flour

Calcium content was highest in FD BFF (125.60 mg/100 g), followed by FBD (118.30 mg/100 g) and TD BFF (112.50 mg/100 g). Similar findings were reported by [37], who observed calcium values of 128.4 mg/100 g in freeze-dried vegetable powders compared to 114.2 mg/100 g in hot-air dried samples due to superior nutrient preservation in low-temperature drying and minimal structural degradation and improved preservation of mineral-associated cellular components.

Copper content increased from 1.00 mg/100 g in TD BFF to 1.50 mg/100 g in FD BFF. The improved copper retention in FD BFF may be associated with preservation of cellular integrity and minimal nutrient leaching during dehydration [19], while TD conditions may accelerate oxidation and degradation of trace mineral complexes, thereby lowering copper content.

Zinc content followed a similar trend, increasing from 3.50 mg/100 g in TD BFF to 4.16 mg/100 g in FD BFF. Similar observations were reported by [38], who reported zinc content of 4.3 mg/100 g in FD powders and 3.4 mg/100 g in thermally dried samples because of reduced thermal damage during dehydration.

The higher magnesium retention in FD BFF may be associated with reduced oxidation and preservation of mineral-containing biomolecules during sublimation drying [39]. Thermal drying may induce structural breakdown and oxidative reactions that decrease mineral retention. Similar observations were documented by [39], who reported magnesium content of 112.6 mg/100 g in freeze-dried due to lower thermal degradation under freeze drying conditions. In present study showed that the freeze drying may be considered the most suitable drying technique for preserving the mineral composition and nutritional quality of banana blossom floret powder.

3.6 Effect on Color Properties

The L* value (lightness) increased significantly from 48.2±0.26 in TD BFF to 52.51±0.18 in FBD and 58.64±0.18 in FD BFF as presented in Table 6. The higher L* value observed in FD BFF indicates better retention of natural colour and lower browning intensity may be due to low-temperature drying conditions that minimize Maillard reactions and enzymatic browning [7]. In contrast, TD caused darker powder formation because prolonged heat exposure accelerates pigment degradation and browning reactions [31]. Similar findings were reported by [7,31]. [40] reported significantly higher L* values in freeze-dried of banana blossom (56.84) compared to hot-air dried samples (47.92).

a* value (redness) decreased significantly from 6.77±0.09 in TD BFF to 5.81±0.07 in FBD and 4.84±0.08 in FD BFF. The higher a* value in TD BFF may be attributed to thermal browning reactions leading to the formation of reddish-brown pigments during drying. Similar observations were reported by [1] in plant leaf powder, where hot-air dried samples exhibited higher a* values than freeze-dried samples because of increased non-enzymatic browning. Similarly, [40] studied a* values ranged from 7.20 in tray-dried to 4.95 in freeze-dried, while b* values increased from 17.80 to 24.10 with FD in banana blossom powder.

Present study showed higher b* value in FD BFF may be due to better retention of carotenoids and flavonoid pigments under low-temperature drying conditions while TD may accelerate oxidation and degradation of yellow pigments, thereby reducing yellowness. Similar findings were reported by [39] in red pepper powder, where freeze-dried samples retained higher yellowness values compared to thermally dried samples.

Table 6. Effect on color quest

Parameter (s)	Sample		
	TD BFF	**FBD BFF**	**FD BFF**
L*	48.26± 0.26[a]	52.51± 0.18[b]	58.64± 0.18[c]
a*	6.77± 0.09[a]	5.81± 0.07[b]	4.84± 0.08[c]
b*	18.53± 0.12[a]	20.44± 0.09[b]	23.83± 0.12[c]
c*	19.72± 0.08[a]	21.25± 0.11[b]	24.31± 0.10[c]
h°	69.93± 0.37[a]	74.13± 0.13[b]	78.50± 0.23[c]

Values expressed are ±SD (n=3)
Different superscripts differ significantly ($p \leq 0.05$).
TD BFF: Tray Dried Banana Floret Flour
FBD BFF: Fluidized Bed Dried Banana Floret Flour
FD BFF: Freeze Dried Banana Floret Flour

Chroma (c*), which represents colour intensity and saturation, ranged from 19.7267±0.08 in TD BFF to 21.2533±0.11 in FBD and 24.3167±0.10 in FD BFF. Chroma value which is significantly higher observed in FD BFF which indicates greater colour vividness and pigment preservation due to reduced thermal degradation and structural collapse during freeze drying [19]. Present study revealed higher chroma in FD BFF (23.80) compared followed by FBD and FD BFF (19.64) that indicating improved colour intensity and pigment retention in freeze-dried powder.

The hue angle (h°) increased significantly from 69.93±0.37 in TD followed by FBD 74.1367±0.13 and 78.5000±0.23 in FD BFF. Higher h°values indicate better retention of yellow colour tones and lower browning intensity and reduced thermal degradation during drying [37]. Similar results were reported by [19] in banana powder, where freeze-dried samples exhibited higher hue angle values than tray-dried samples. The researchers found h° values of 77.20 in freeze-dried powder and 68.45 in tray-dried powder, which closely supports the present findings where FD BFF showed higher h° values (78.5000±0.23) compared to TD BFF (69.9367±0.37). In present study showed the higher L*, b*, c*, and h° values along with lower a* values observed in FD samples indicate better preservation of natural pigments and reduced browning reactions. Fluidized bed drying showed intermediate colour quality, whereas tray drying resulted in greater colour deterioration because of prolonged heat exposure.

3.7 Effect on FTIR

The FTIR BFF through TD, FBD, and FD exhibited characteristic peaks at 2922.55, 1605.84, and 1032.91 cm^{-1}, revealed C–H stretching of lipids and cellulose, amide/carboxyl group vibrations of proteins and phenolic compounds, and C–O stretching of carbohydrates and polysaccharides, respectively as presented in Fig. 2. A broad absorption band observed between 3200–3400 cm^{-1} corresponded to O–H stretching vibrations associated with hydroxyl groups and bound water molecules.

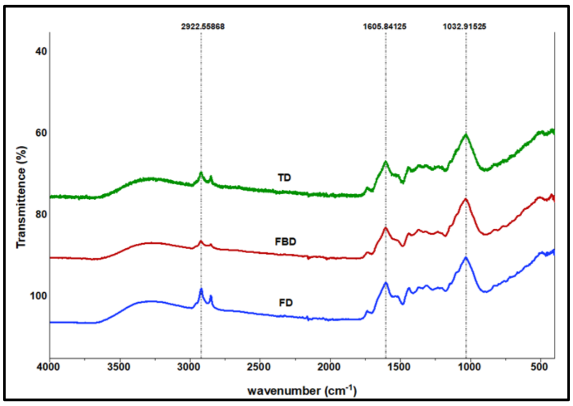

Fig. 2. FTIR spectra of BFF

Among the drying methods, FD samples showed sharper and more intense peaks compared to TD and FBD, which represent the better preservation of functional groups, bioactive compounds, proteins, and carbohydrate structures due to low-temperature dehydration. The peak intensity near 1032.91 cm^{-1} was particularly higher in FD, suggesting improved retention of polysaccharides and fiber components. In contrast, TD BFF exhibited comparatively reduced peak intensity and slight band flattening, which may be attributed to thermal degradation, oxidation, and structural modifications caused by prolonged heat exposure. FBD samples showed intermediate spectral characteristics between TD and FD, indicating moderate retention of biomolecules. Present findings suggest that FD minimized structural damage and preserved the biochemical integrity of banana blossom powder more effectively than conventional drying methods. Similar observations were reported by [4], who found stronger FTIR absorption bands in freeze-dried banana blossom powder than hot-air dried samples. Likewise, [7] reported that high-temperature drying leads to reduction in functional group intensity due to degradation of food biomolecules and cellular structures.

Conclusion

The present study demonstrated that drying methods significantly influenced the physicochemical and nutritional properties of banana floret powder. Among the evaluated techniques, freeze drying exhibited superior performance by producing powder with the lowest moisture content and the highest retention of protein, fiber, fat, ash, and pH values. In contrast, tray drying resulted in comparatively lower retention of nutrients and higher acidity. Fluidized bed drying showed intermediate performance between freeze drying and tray drying. The findings indicate that freeze drying is the most suitable technique for preserving the nutritional quality and functional attributes of banana floret powder. Therefore, freeze-dried banana floret powder has considerable potential for application as a functional food ingredient and nutraceutical supplement owing to its enhanced nutritional profile and storage stability. Freeze drying is recommended as the most suitable method for producing high-quality banana floret powder with enhanced nutritional retention and functional properties.

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