Effect of drying techniques on yield, nutritional, minerals of wild banana pulp (*Musa balbisiana* Colla): physicochemical and morphological characterization thereof

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Abstract

Purpose – The study was aimed to compare the effect of three drying techniques viz., spray, freeze and hot air oven (HAO) drying on yield, nutritional parameters, minerals and physicochemical and morphological characterization of wild banana pulp (*Musa balbisiana* Colla).

Design/methodology/approach – Contents of carbohydrate was estimated by Anthrone reagent, protein by Kjeldahl, fat by Soxhlet, dietary fiber and ash by Association of Official Analytical Chemists (AOAC), minerals by Atomic Absorption Spectrophotometry, gross calorific value by Bomb calorimeter, moisture by moisture analyzer, water activity by water activity meter, morphological characterization by Scanning Electron Microscopy (SEM), statistical level of significance at $p < 0.05$ by ANOVA, predictive modeling by simple and multiple linear regression.

Findings – Freeze and HAO drying were standardized with matured (stage 2) and spray drying with ripe bananas (stage 6). Freeze drying showed highest yield (76.69 $\pm$ 0.15%), minerals viz., K (1175.67 $\pm$ 1.41), Fe (2.27 $\pm$ 0.09), Mg (120.33 $\pm$ 0.47), Mn (4.40 $\pm$ 0.28) mg/100 g, protein (7.53 $\pm$ 0.14%), lesser moisture (7.95 $\pm$ 0.01%), water activity (0.17 $\pm$ 0.02a_w), hygroscopicity (6.37 $\pm$ 1.09%), well dispersed particles by SEM. HAO drying exhibited highest dietary fiber (18.95 $\pm$ 0.24%), gross calorific value 357.17 kcal/100 gm, higher solubility (47.22 $\pm$ 0.86%). Spray drying showed highest carbohydrate (85.29 $\pm$ 0.01%), lowest yield (28.26 $\pm$ 0.32%), required 30.5% adjuncts.

Research limitations/implications – Effect of three drying techniques and use of adjuncts were not uniform for ripe and matured bananas.

Practical implications – Commercial utilization of seeded wild banana.

Social implications – Value addition of wild banana in Assam, India

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Compliance with Ethical Standards

Author's contributions: All the data were generated at CSIR-NEIST. NW and TB have contributed equally and conducted the major part of the experiments and written the manuscript. NJB has conducted the rest experiments. JS identified the species. PM, PSB, THA and SPS have helped to conduct the experiments. DB conceptualized the whole project and designed the entire study, verified all the information and edited the final manuscript.

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Originality/value – Freeze drying of mature wild banana pulp (*M. balbisiana*) was found as best technique utilizing lesser energy.

Keywords *Musa balbisiana*, Wild banana, Pulp, Powder, Spray, Oven, Freeze drying, Nutritional, Physicochemical

Paper type Research paper

Nomenclatures

AOAC	Association of Official Analytical Chemists	kcal	kilocalorie
FSSAI	Food Safety and Standards Authority of India	USFDA	Food and Drug Administration, United States
g	gram	WHO	World Health Organization
G	Relative centrifugal force	SEM	Scanning Electron Microscope
		HAO	Hot Air Oven

1. Introduction

Musa balbisiana Colla is a wild under-utilized seeded banana grows in NE to southern India, Andaman and Nicobar Islands to New Guinea in wild habitat and in cultivation (Ranibala *et al.*, 2018; Borborah *et al.*, 2016; IPNI, 2020). Fruits are known as Bhimkol or Athiyakol in Assam and have been consumed as a dietary and nutritional supplement which is rich in nutrients, minerals and exhibited antioxidant, hypo-testicular, antibacterial and antidiabetic activity (Deka *et al.*, 2019; Gopalan *et al.*, 2018; Borborah *et al.*, 2016a; Cabrera-Padilla *et al.*, 2014; Dan and Thaha, 2014; Anyasi *et al.*, 2013). The starch of *M. balbisiana* is highly potential for high temperature processed products (Goula and Adamopoulos, 2008). Several drying techniques viz., rotary dryer with inert bed, spray, vacuum belt, freeze and air drying were employed for preparation of banana powder from banana pulp or from banana and whole milk slurry with characteristic banana odor (Forero *et al.*, 2015; Cabrera-Padilla *et al.*, 2014; Wang *et al.*, 2007; Suzihaque *et al.*, 2015). As per the guidelines of USFDA, WHO and FSSAI, fruits and fruit products can be used as food additive in the category of "other nondairy products" in food and beverage items (WHO, 2020; FSSAI, 2011; USFDA, 2010). The current study was focused to compare the effect of three drying techniques viz., spray, freeze and HAO drying on yield, nutritional parameters, minerals of wild banana pulp (*M. balbisiana*) for the first time along with physicochemical and morphological characterization.

2. Materials and methods

2.1 Raw materials and chemicals

Ripe (stage 6, all yellow and reddish) and mature bananas (stage 2, green with traces of yellow and reddish) of *Musa balbisiana* were collected from local growers in Jorhat, Assam, India and was identified with the help of taxonomic literature. Stages of bananas were recorded as per current market trend (Mendoza and Aguilera, 2004). Maltodextrin (MD) GRM1249-500G and carboxymethylcellulose sodium salt (CMC) MB138-100G were obtained from HiMedia Mumbai and the banana powder production was carried out vide Figure 1.

2.2 Processing of wild banana pulp by spray drying

2.2.1 Feed solution preparation. Ripe bananas were washed, dried, peeled and cut into thin slices. The seeds were removed from the slices prior to blending. The banana pulp was diluted in distilled water in the ratio of 1:4 and homogenized using a Bajaj GX 3 mixer grinder (Bajaj electrical limited, Mumbai) for 30 s with a maximum speed upto 18,000 rpm followed by

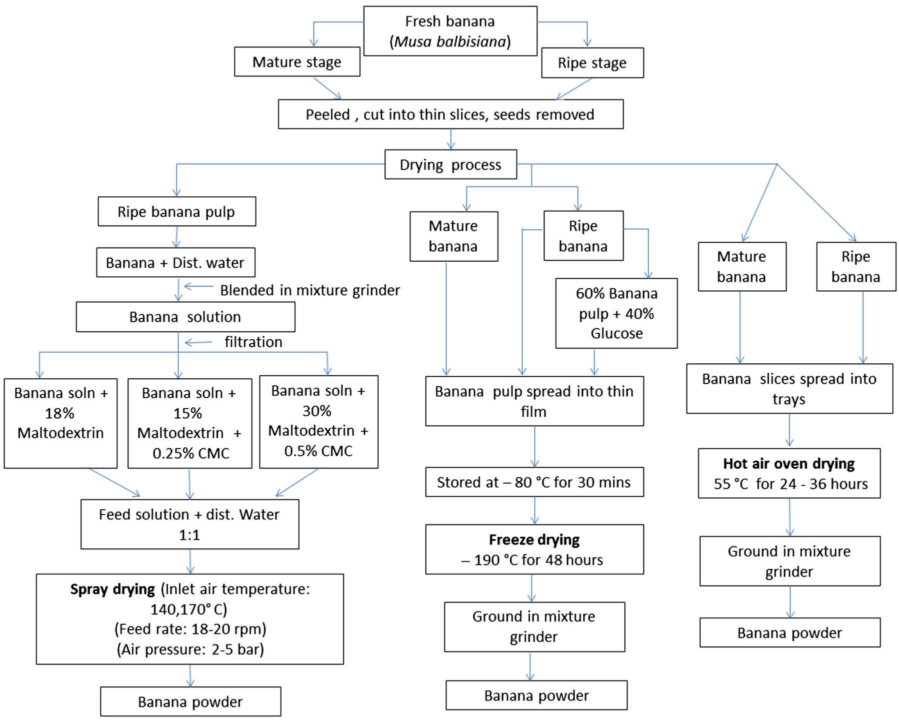

Figure 1.
The comparative flow chart of processing of wild banana pulp by spray, freeze and hot air oven drying

filtration using a sieve (625 micron), these steps were repeated until reaching a total soluble solid content of 28% (w/v) in the homogenized puree. The total soluble solids content of the homogenized puree found by

$$\text{Total soluble solids content} = \frac{(\text{Total weight of banana pulp before filtration, g}) - (\text{Total residue after filtration, g})}{(\text{Total volume of the solution before addition of adjuncts, ml})}$$

Once the total solids in the puree were standardized, Maltodextrin and CMC were added in three different combinations viz. (1) 18% Maltodextrin, (2) 15% Maltodextrin and 0.25% CMC, (3) 30% (w/v) Maltodextrin and 0.5% CMC (Khuenpet *et al.*, 2016) to the banana solution. The banana solution was further diluted with distilled water (1:1) prior to spray drying. Mature banana pulp was not soluble in water and was not successful in obtaining feed solution for spray drying method.

2.2.2 Parameters for spray drying. Laboratory spray dryer (Spraymate, JISL, Mumbai) was used for current study. Inlet air temperatures viz., 140 °C and 170 °C (±1 °C) were used for spray drying of the feed solution. The atomizing pressure was maintained at 8 bar, feed rate at 20 rpm and aspirator rate at 70 m^3/h. The spray drying conditions were optimized for this process following some recent publications (Patil *et al.*, 2013; Goula and Adamopoulos, 2008). Spray dried powders were collected followed by weighing and stored in zip-lock packets in air-tight conditions. The spray-dryer was cleaned with distilled water at the optimized setting 10 min before and after the process.

2.3 *Processing of wild banana pulp by freeze drying*

Both ripe and mature banana were dried using a laboratory-scale freeze dryer (SCANVAC Cool Safe 110-4, Denmark). Ripe bananas were peeled and grated into pulp. The seeds were removed from the pulp. Ripe banana pulp was divided into two parts and to one part of the pulp glucose was added in the ratio 60:40 (60% pulp and 40% glucose). The pulp was spread into thin films in different zip lock bags and stored at −80 °C for 30 min prior to freeze-drying at −190 °C for 48 h. Mature bananas were peeled, cut into thin slices, then stored at −80 °C followed by freeze-drying at same temperature and duration. Mature banana did not require any adjunct. Freeze-dried bananas were then ground into powder using Bajaj GX 3 mixer grinder (Bajaj electrical limited, Mumbai) at 18,000 rpm.

2.4 *Processing of wild banana pulp by hot air oven drying*

Both ripe and mature bananas were peeled and cut into thin slices. The slices were spread into trays after removal of seeds and dried in a hot air oven (Labotech, B.D. Instrumentation (India), Ambala Cantt) at 55 °C for 36 h and checked periodically at an interval of 12 h. This process did not require any adjunct for both ripe and mature banana. The dried banana slices were then ground into powder using Bajaj GX 3 mixer grinder (Bajaj electrical limited, Mumbai) and was carried forward for further processing.

2.5 *Yield percentage employing three drying techniques*

The yield percentage of the banana powder prepared by spray, oven and freeze drying were measured as the percentage of solids obtained from the total solid mass of the feed solution and percentage of mass of powder obtained to the initial mass of the samples taken respectively. Percentage of banana proper and adjunct were also calculated in the produced powder based on the ratio of the adjunct used during processing in applicable cases. Each of the three drying techniques were optimized based on yield percentage, presence of banana proper in the powder by using ripe and mature banana pulp. Both freeze-dried and oven-dried ripe banana powders showed stickiness and difficulty in grinding and were not taken for further analyses and spray drying was successful by using only ripe banana.

2.6 *Study on nutritional parameters employing three drying techniques*

The nutritional parameters of the optimized three differently produced banana powders were characterized according to AOAC methods (Helrich, 1990). Protein content was estimated by the Kjeldahl method (%N × 6.25), fat content was analyzed with soxhlet method, carbohydrate by Anthrone reagent, dietary fiber by AOAC enzymatic-gravimetric method and ashes content was analyzed using gravimetric muffle furnace oven at 600 °C. The mineral content of the banana powders was determined by Atomic Absorption Spectrophotometry (AAS). The gross calorific values were calculated by using Bomb calorimeter (Smit *et al.*, 2004).

2.7 *Study on physicochemical parameters employing freeze and HAO drying*

Moisture analyzer (AnD MX-50, IC-06036900, Wood Dale) was used to estimate moisture content. Water activity was measured by Aqua Lab, SN: S40003153, USA water activity meter. Banana powder samples produced from the different methods were analyzed for their solubility, percentage of insoluble solids, bulk density and hygroscopicity. As the spray drying method required more than 30% adjuncts as encapsulating material during processing, the spray dried powder was discarded to consider for further experiments and subsequent experiments were carried out with the oven and freeze dried powders of matured banana.

2.7.1 Solubility. The solubility of oven and freeze dried banana powders were determined by modified method of Wong and Tan (2017). 2.5 g of banana powder of (−200 mesh size) was mixed in 30 ml of water at 30º C and intermittently stirred for 30 min and centrifuged at

3000 G for 10 min. The solubility percentage was calculated by the weighing the amount of dry solids obtained after evaporation of the supernatant.

$$\text{Solubilty percentage} = \frac{\text{weight of dried solid}}{\text{weight of sample}} \times 100\%$$

2.7.2 Percentage of insoluble solids. Insoluble solid percentage was estimated vide modified Khuenpet *et al.* (2016). 10 g of banana powder was dissolved in 100 ml of distilled water. The above solution was filtered through muslin cloth by using 500 ml suction flask and Buchner funnel having 7.5 cm diameter. The suction flask was attached with IKA MVP10 basic vacuum pump, motor 180 W; IKA® India Private Limited. The filtrate passed through the muslin cloth and the leftover solid that remained stuck to the muslin cloth was dried, weighed and the insoluble solid percentage was calculated. The experiment was carried out at room temperature.

$$\text{Percentage of insoluble solid} = \frac{\text{mass of insoluble solid}}{\text{mass of total solid}} \times 100\%$$

2.7.3 Bulk density. Oven and freeze-dried banana powders were analyzed for bulk density vide Goula and Adamopoulos (2008) with some modifications. 10 g of banana powder was added in a 50 ml measuring cylinder. The experiment was performed by tapping the measuring cylinder until the volume of powder reached a constant level. The bulk densities of both the powders were calculated by measuring the ratio of mass of the powder (g) against the occupied volume (ml).

2.7.4 Hygroscopicity. The banana powders were experimented to estimate the hygroscopicity vide Silva *et al.* (2012) with slight alterations. 1 g sample of each processed powder was stored in desiccators at room temperature along with saturated solutions of sodium chloride (NaCl) with relative humidity of 75% and 0.75a_w water activity. The samples were weighed after a week and the hygroscopicity was calculated by the moisture absorbed per 100 g of dry sample.

2.8 Scanning electron microscopy

Particle size and morpho-physiology of the banana powders processed by freeze and oven drying methods were analyzed using SEM. 0.1 g–0.3 g of samples were added onto surface of double-sided tape attached to stubs followed by a thin gold coated layer under vacuum by Quoram coater (model Q150RS, Germany). Samples were examined at 1500, 2000, 10,000 magnification by Field Emission Scanning Electron Microscope (make ZEISS SIGMA, model 1430 VP, Cambridge, UK).

2.9 Statistical analysis

Experiments were conducted in triplicates ($n = 3$). All the data were expressed as mean ± standard deviations. Statistical analyses were performed by Sigmaplot ver. 14.0 (Systat Software, Inc., San Jose, California, USA). Analysis of variance (ANOVA) was performed in Sigmaplot 14.0 software for yield percentage of mature and ripe banana powder by three different methods, optimization of spray drying using ripe banana adding varying percentage of adjuncts, nutritional parameters, micronutrient contents, physicochemical parameters of the banana powders and process parameters of three drying techniques to determine the level of significance. The data were compared by applying the post-hoc test, Student-Neuman-Keul's method. The detailed results are given in Tables 1–5 respectively. After pairwise multiple comparison test of means, it was found that the test samples of all the different methods were statistically significant at $p < 0.05$.

Simple and multiple linear regression were performed for further analysis of the data using MS Excel (add-ins) 2010 software. The p-values and F ratios less than 0.05 were considered as statistically significant for the analyses. The confidence level of the test was checked for 95.00%.

For simple linear regression modeling, independent and dependent variable were selected as per the process parameters adapted in the study. The informative or successful linear regression model were selected considering >80% correlation coefficient and the rest were discarded from further analysis.

Similarly, multiple linear regression was carried out with the independent variables with p-values < 0.05. The regression equation obtained were further checked with the predicted parameters against observed parameters which were graphically represented.

3. Results and discussions

3.1 Effect of three drying techniques on yield percentage of wild banana pulp

The yield percentages of banana powders from ripe and mature banana processed by the three different methods, i.e. spray, freeze and oven drying were given in Table 1. Presence of banana content in the processed powders was also shown (Figure S1). Based on the yield percentage and presence of banana content each drying method was individually optimized for using either ripe or mature banana. Highest yield of 76.69% was found in mature freeze-dried banana powder followed by ripe freeze-dried banana with 72.36%. However ripe freeze-dried banana powder contained only 43.12% banana content and 56.88% glucose which was used as adjunct during processing. As per WHO recommendations and FSSAI guidelines, only 10% of daily energy intake from sugar is permissible for children, i.e. nearly 50 gm/day and for an adult only 20–30 gm/day (FSSAI, 2020). Hence method of freeze drying was optimized with matured banana which showed highest yield without using any adjunct. Oven drying of matured banana pulp resulted higher yield of 54.88% than 38.08% using ripe banana pulp. Oven drying method did not

Table 1. Effect of drying techniques on yield percentage of wild banana pulp with SD

Name of method	Yield of processed powder (%) Ripe	Mature
Freeze drying	72.36 ± 0.69^{a}	76.69 ± 0.15^{a}
Oven drying	38.08 ± 0.35^{b}	54.88 ± 0.52^{b}
Spray drying	28.26 ± 0.32^{c}	n/d

Note(s): "n/d" means not detected. Mean values within the same column not exhibiting same letter (a, b, c) are significantly different at $p < 0.05$ in one-way ANOVA analysis

Table 2. Effect of drying techniques on nutritional parameters of wild banana pulp with SD

Name of method	Nutritional parameters (%) Carbohydrate	Protein	Fat	Dietary fiber	Ash	Energy
Freeze drying	70.46 ± 0.03^{a}	7.53 ± 0.14^{a}	1.97 ± 0.35^{a}	11.94 ± 0.54^{a}	0.05 ± 0.002^{a}	356.23 ± 0.33^{a}
Oven drying	53.23 ± 0.01^{b}	7.51 ± 0.38^{a}	0.59 ± 0.03^{b}	18.95 ± 0.24^{b}	0.04 ± 0.004^{a}	357.17 ± 0.24^{b}
Spray drying	85.29 ± 0.01^{c}	0.48 ± 0.03^{b}	1.25 ± 0.10^{c}	12.42 ± 0.14^{a}	0.98 ± 0.03^{b}	$356.67 \pm 0.24^{a,b}$

Note(s): Mean values within the same column not exhibiting same letter (a, b, c) are significantly different at $p < 0.05$ in one-way ANOVA analysis

Table 3. Effect of drying techniques on micronutrient contents of wild banana pulp with SD

Name of method	Micronutrient content (mg/100 g)						
	Ca	K	Cu	Mn	Mg	Fe	Na
Freeze drying	1.35 ± 0.04^{a}	1175.67 ± 1.41^{a}	0.21 ± 0.02^{a}	4.40 ± 0.28^{a}	120.33 ± 0.47^{a}	2.27 ± 0.09^{a}	30.33 ± 0.47^{a}
Oven drying	0.63 ± 0.04^{b}	1170.33 ± 0.47^{b}	0.55 ± 0.01^{b}	4.29 ± 0.15^{a}	100.67 ± 0.94^{b}	1.37 ± 0.05^{b}	19.20 ± 0.28^{b}
Spray drying	4.30 ± 0.14^{c}	220.67 ± 0.94^{c}	0.08 ± 0.005^{c}	0.32 ± 0.03^{b}	0.27 ± 0.02^{c}	0.62 ± 0.03^{c}	44.27 ± 0.38^{c}

Note(s): Mean values within the same column not exhibiting same letter (a, b, c) are significantly different at $p < 0.05$ in one-way ANOVA analysis require any adjunct for processing of both ripe and matured banana pulp and based on higher yield oven drying method was optimized with matured banana. Compared to other fresh fruits such as BlackBerry (Ferrari *et al.*, 2011), banana is rich in solids and has low water content (Deka *et al.*, 2019) which resulted difficulty in spray drying and lowered the yield percentage. Spray drying method was successful only with ripe banana pulp by using following combination of adjuncts as encapsulating materials viz., 30% maltodextrin and 0.50% CMC, 18% maltodextrin and 0% CMC and 15% maltodextrin and 0.25% CMC achieving highest yield of 28.26% followed by of 3.48% and 1.74% respectively. Hence spray drying was optimized with ripe banana pulp using 30% maltodextrin and 0.50% CMC with 28.26% yield of ripe banana powder which had poor banana content 52.43% only due to presence of adjuncts (Figure S1, Table S1).

3.2 Effect of three drying techniques on nutritional parameters of wild banana pulp

The nutritional parameters such as protein, carbohydrate, fat, dietary fiber, ash contents and calorific value of the optimized three types of differently processed banana powders in 100 g of sample were given in Table 2. Protein content was almost equal in freeze and oven-dried matured banana powders. Carbohydrate content was highest in ripe banana powder processed by spray drying due to presence of maltodextrin which is a carbohydrate. Oven-dried matured banana powder showed the lowest carbohydrate and fat contents and highest dietary fiber and energy compared to the rest.

3.3 Effect of three drying techniques on mineral contents of wild banana pulp

The mineral content of optimized three types of differently processed banana powders were given in mg/100 g (Table 3). Iron content was highest in freeze-dried banana powder. This study revealed that oven-dried and freeze-dried banana powders exhibited almost similar mineral contents while the spray-dried banana powder varied from the other two due to lesser content of banana (52.43%) in the processed powder. The contents of Magnesium, Manganese, Potassium and Copper were lowest while Calcium and Sodium were highest in spray-dried banana powder among the three. Therefore, the processed banana powders without any adjunct were used for further analysis.

Table 4. Effect of drying techniques on physicochemical properties of wild banana pulp with SD

Parameters	Freeze dried powder	Oven-dried powder
Moisture content (%)	7.95 ± 0.01^{a}	11.37 ± 0.09^{b}
Water activity (a_w)	0.17 ± 0.02^{a}	0.54 ± 0.002^{b}
Hygroscopicity (%)	6.37 ± 1.09^{a}	11.94 ± 1.73^{b}
Bulk density (g/cm^3)	0.99 ± 0.01^{a}	0.96 ± 0.0001^{b}
Solubility (%)	9.86 ± 0.30^{a}	47.22 ± 0.86^{b}
Insoluble solid (%)	81.63 ± 1.21^{a}	38.60 ± 5.23^{b}

Note(s): Mean values within the same column not exhibiting same letter (a, b, c) are significantly different at $p < 0.05$ in one-way ANOVA analysis

Table 5. Technical process parameters of the three drying techniques with SD

Parameters	Spray drying	Freeze drying	Hot air oven drying
Voltage (V)	230 ± 0^{a}	230 ± 0^{b}	220 ± 0^{c}
Power consumption (Watt)	2933.33 ± 94.28^{a}	923.33 ± 32.99^{b}	1333.33 ± 235.70^{c}
Temperature (°C)	140.67 ± 0.94^{a}	-109.33 ± 0.94^{b}	55.67 ± 0.94^{c}
Duration (hours)	12.67 ± 0.94^{a}	48.67 ± 0.94^{b}	37.33 ± 1.89^{c}

Note(s): Mean values within the same row not sharing a common letter (a, b, c) are significantly different at $p < 0.05$ in one-way ANOVA analysis

3.4 Effect of two drying techniques on physico-chemical properties of wild banana pulp

The moisture content and water activity of optimized freeze and oven dried banana powders in 100 g of sample were given in Table 4. Freeze dried banana powder exhibited lesser moisture content, water activity and hygroscopicity than oven dried powder. Freeze dried powder showed higher bulk density and insoluble solids. However, oven dried powder showed higher solubility percentage than the freeze dried powder.

3.5 Process parameters of three drying techniques

Process parameters of spray, freeze and HAO drying techniques viz., requirement of voltage, power consumption, temperature and duration of processing were compared (Table 5). Freeze drying required longest duration 48.67 ± 0.94 h, lowest temperature −109.33 ± 0.94 ℃ and power consumption 923.33 ± 32.99 watts compared to spray and HAO drying.

3.6 Effect of two drying techniques on morphology of wild banana particles

The morphology of optimized freeze and oven dried banana powders were studied under SEM and the micrographs were shown in Figure 2. The particles of freeze-dried banana powders were obovoidal, variable in size, i.e. 13.33–20 × 11.67–16.67 µm, well dispersed and with smooth surface whereas oven dried powders were spheroidal, 8.89–24.44 × 13.33–40 *µm*, with uneven surface and exhibited agglomeration. Morphological characteristics of these two differently dried particles exhibited congruence with the elevated free flowing nature of the freeze-dried banana powder than the oven-dried banana powder.

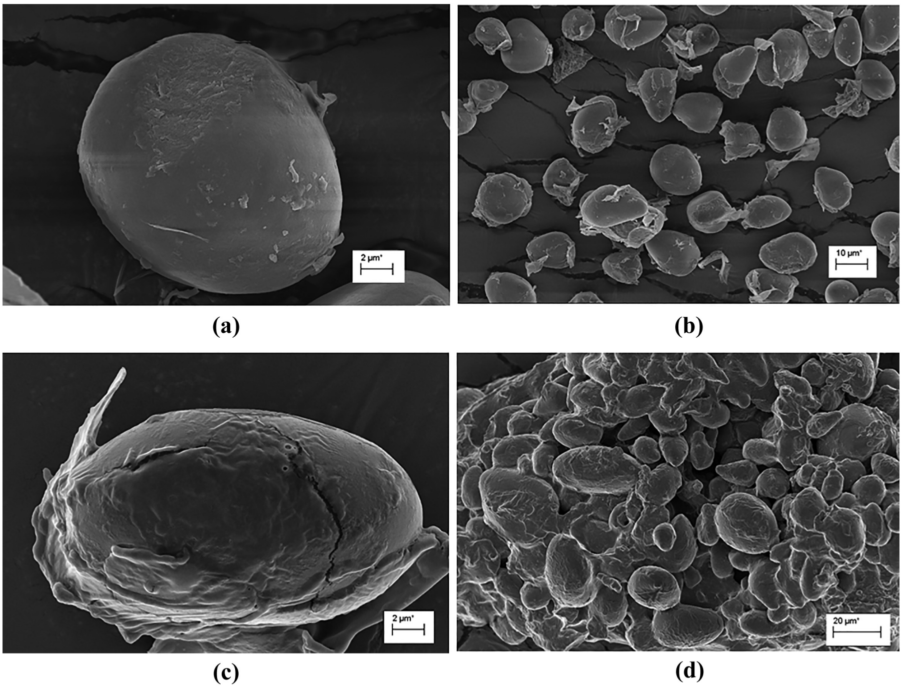

Figure 2. Micrographs of banana particles; Freeze-dried: a 10,000X, b 2000X; Oven dried: c 1000X, d 1500X; Scale bar as shown a, $c = 2\ \mu m$ and $b = 10\ \mu m$, $d = 20\ \mu m$

3.7 Regression analysis

Simple linear regression resulted into equations 1–6 with $R^2 > 0.80$ except equation 1 with 0.78 with predictive models inferring viz., each % increase in yield, protein content would increase by 0.15 mg/100 g (Eqn 1), Calcium (Ca) content by 0.03 mg/100 g (Eqn 2), Manganese (Mn) by 0.09 mg/100 g (Eqn 3), Magnesium content by 2.52 mg/100 g (Eqn 4), Iron (Fe) content by 0.03 mg/100 g (Eqn 5) and Potassium (K) content by 20.40 mg/100 g (Eqn 6) (Table S3).

Based on the results obtained from the other simple linear regression analysis, the models with R^2 value > 80% were selected for further multiple regression analysis which resulted equation 7 of yield in respect to process parameters viz., temperature and voltage inferring that with each % increase in yield, processing temperature would decrease by 0.13 °C and voltage would increase by 1.54 volt. The best predictive models derived from the selected data are given in Table 6 and the comparison between the observed values and the predicted values of the dependent variables (derived from Eqn 7) with respect to the independent variables are represented graphically in Figure 3a and b.

4. Conclusion

The study compared the effect of three different drying techniques for processing ripe (stage 6) and matured (stage 2) wild banana pulp (*Musa balbisiana*) on yield, nutritional parameters, minerals for the first time along with physicochemical and morphological characterization. Freeze and HAO drying were standardized with matured banana and spray drying with ripe banana. Highest yield, minerals, lesser water activity, hygroscopicity, well dispersed processed particles and requirement of lesser energy (923.33 ± 32.99 Watt) during processing showed freeze drying as the best drying technique of mature wild banana pulp of *Musa balbisiana*. However, HAO drying takes shorter time (37.33 ± 1.89 h) to evaporate the water

Table 6. Simple and multiple regression equations

Simple linear regression Dependent (y) vs independent (x) variable	Equation
Protein content vs Yield of banana powder	$y = 0.15x - 2.7537\ R^2 = 0.7781$ (1)
Ca content vs Yield of banana powder	$y = 0.0329x - 1.1754\ R^2 = 0.9815$ (2)
Mn content vs Yield of banana powder	$y = 0.0865x - 1.6036\ R^2 = 0.8067$ (3)
Mg content vs Yield of banana powder	$y = 2.5246x - 60.749\ R^2 = 0.9045$ (4)
Fe content vs Yield of banana powder	$y = 0.0337x - 0.3774\ R^2 = 0.9791$ (5)
K content vs Yield of banana powder	$y = 20.397x - 229.39\ R^2 = 0.8053$ (6)
Multiple linear regression	
Dependent (y) vs Independent (x_1, x_2) variables	*Equation*
Yield of banana powder vs Temperature (x_1) and Voltage (x_2)	$y = -0.13x_1 + 1.54x_2 - 291.62$ (7)

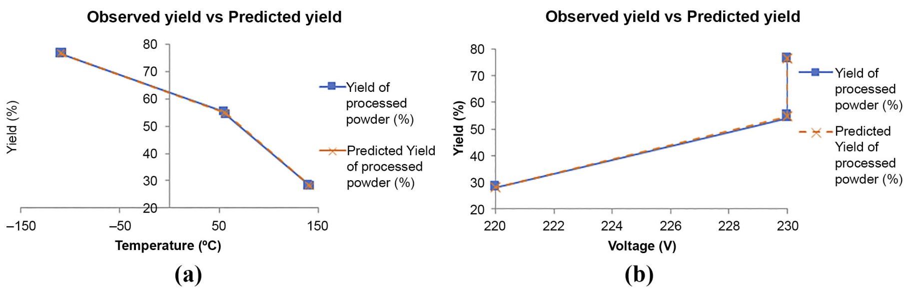

Figure 3. (a) Comparisons of the observed and predicted values of yield of processed banana powder with respect to Temperature. (b) Comparisons of the observed and predicted values of yield of processed banana powder with respect to Voltage

(Sulasmi *et al.*, 2016) and resulted highest energy content, higher percentage of dietary fiber, solubility, lower carbohydrate, fat and insoluble solids (Figure 2; Tables 1–5). Due to low yield and poor banana contents physicochemical properties of spray dried powder was discarded from further analysis.

Various simple and multiple linear regression models were also successfully created using different nutritional parameters against yield and yield against different process parameters which indicated that the nutritional parameters and yield as well as yield and different process parameters are positively correlated with each other. The overall cost of drying of matured banana pulp of *M. balbisiana* was calculated at lab scale for two methods viz, freeze and HAO drying as per standard procedure using current market price comparable with commercial products (Table S2). The estimated cost of drying of matured banana pulp by freeze drying was INR 11.00/g, oven drying was INR 4.50/g which would be reduced if carried out in industrial scale (Table S2). Approximately 60–70% banana production had been market surplus in Assam, India and required value addition to prevent postharvest loss (Abhimanuias, 2019). Processed pulp of wild banana of *M. balbisiana* could be used as natural food additive to enrich nutrients and add flavor in processed and semi-processed food and beverages (Figure S2). HAO drying technique would help the rural entrepreneurs to develop value added products.

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Supplementary material

The supplementary files are available online for this article.

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