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Research Article

Foam-mat drying characteristics of overripe banana pulp using superfine (< 100 μm) fraction of defatted soybean flour as foaming agent

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Abstract

In tropical and subtropical countries, an enormous amount of fruits and vegetables are produced, which are extremely attractive from a commercial point of view, a typical example being the banana. Preservation methods such as drying are of great relevance to increase the shelf life and commercial value of fruit and their derivatives. This investigation aimed to study the drying kinetics of overripe banana fruits at three different drying air temperatures and calculate the effective moisture diffusivities of FMD banana powders, evaluate the effect of concentration levels of defatted soybean flour as foaming agent on the stability and drying kinetics of overripe banana foam-mats. Banana powders were prepared using overripe banana paste incorporating defatted soybean flour (DSF) as foaming agent at a mass concentration of 10%, 15% and 20% (w/w), and drying the resultant foams until a constant moisture content was reached. The maximum foam expansion (87.50%) and foam stability (98.55%) of DSF were found after 5 min whipping. The total drying time required to achieve up to a constant moisture level was 9 hours, 4 hours and 3 hours for 55 °C, 70 °C and 85 °C drying air temperatures, respectively. The fitted logarithmic model was found to be best in almost all cases. The effective moisture diffusivity increased with increasing temperature from 1.65×10^{-6} m^2/s to 9.46×10^{-6} m^2/s, but decreased with the increase in the incorporation rate of DSF. Based on the above parameters, it was resolved that foam mat drying using 10% DSF at 70 °C air-drying temperature was the best combination.

1. Introduction

In tropical and subtropical countries, an enormous amount of fruits and vegetables are produced, which are extremely attractive from a commercial point of view, a typical example being the banana. Banana is one of Cameroonian most consumed indigenous fruits that has widely preferred as excellent source of nutrients, vitamins, minerals and dietary fiber, and appealing look [1, 2]. In addition, banana fruits give excessive production during the season, and are usually consumed (as dessert) in its raw form when it is ripe because of its convenience, ease to eat, sweet taste and aroma, high nutritional value and easy digestibility [3]. However, in association with the seasonal problem, banana fruits, in a mature state, containing high water content, are quite susceptible to degradation. These fruits when exposed to air

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undergo discoloration due to polyphenol oxidase activity [4]. Particularly, ripe bananas are short duration fruit and very perishable and cold storage is not promising because of the development of an unattractive brown colouration on the skin which decreases the quality and the market value [5]. Moreover, overripe banana fruits are discarded in the market due to their low quality and appearance.

Previous works have claimed that the purchase intention for overripe banana fruits is significantly low due to low quality, brown spots and decrease in the firmness of the pulp [6, 7], requiring the adoption of treatments to provide an increase in shelf-life. To enhance its present and future prospects, it is converted into various processed forms after and before ripening. As the process of powder manufacturing from overripe bananas seems to be a good technological option for the reduction of postharvest losses in bananas. Thus, dehydrated overripe bananas could be used potentially as a novel food ingredient or as basis for such developments.

Generally, preservation methods such as drying are of great relevance to increase the shelf life and commercial value of fruit and their derivatives [8]. It is the most important and starting process to preserve different fruits, as it reduces the growth of different enzymes and microbes and increases the product stability. Foam-mat drying (FMD), convective drying, spray drying, sun drying, heated-air drying systems and fluidized bed drying are among the most used methods to produce powdered products, in addition to solving the problem of self-life. Nevertheless, selection of a suitable drying process is very important in cost and final quality of dried products [9]. For example, in heated air-drying systems, overripe sliced bananas dry quite slowly compared to many other fruits [10]. This may be due to the dense physical structure of the fruit, as well as its sugar content and chemical composition (factors that do not facilitate internal moisture movement). Long drying times are required for banana slices and considerable browning and darkening of the banana occur during drying [11]. However, FMD by principle can increase the surface area for drying due to the formation of foams and involves a relatively lower cost compared to other techniques. This helps in making the product more porous, thus allowing rapid moisture removal with a higher drying rate. Indeed, FMD is a technology that involves the incorporation of a foaming agent into liquids or semi liquid with adequate mechanical agitation to form stable and stiff foam, and subsequently dehydrated by air-drying at relatively low temperature and short periods of time [12]. Practically, fruit and vegetable pastes are mixed with different foaming agents in different concentrations with subsequent whipping to form a stable foam and air-drying, and it leads to the production of solid particles or free flowing powders [13]. Soy protein, egg albumin, egg white and guar albumins are the most common foaming agents [14]. The efficiency of FMD method is explained by the fact that bubbles increase the internal surface area, creating a structure less resistant to the transport of water vapor mass, which provides faster drying rate and considerable decrease in temperature and time; as well as improve the sensory, nutritional and functional properties of the product [15-18]. The FMD process is suitable for heat sensitive, volatiles compounds, viscous, and sticky products that cannot be dried using other forms of drying because of the state of the product. More interest has developed for FMD because of the simplicity, cost effectiveness, high-speed drying and improved product quality it provides [19, 13]. According to Febrianto et al. [20], FMD is the simplest form of drying compared to other methods such as freeze-drying, spray drying, as it is less expensive, less complicated, and is less time-consuming. It was proposed to obtain a powder that is simply rehydrated, having organoleptic characteristics, which resembles the crude material [21], and compatible to apply on component with high sugar content foods (such as fruit pulps and juices) that cannot be dried using other forms of drying.

Prediction of drying curves, commonly the moisture content of material at any time after having been subjected to a constant relative humidity and temperature conditions are measured and correlated to the drying conditions [19, 22]. As per our knowledge, the information on the use of defatted soybean flour as foaming agent in the dehydration of overripe banana using FMD method has not been reported. Thus, this investigation aimed to study the drying kinetics of overripe banana fruits at three different drying air temperatures and calculate the

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effective moisture diffusivities of FMD banana powders and evaluate the effect of concentration levels of defatted soybean flour as a foaming agent on the stability and drying kinetics of overripe banana foam-mats. Some physical characteristics (color and particle size) of powders were evaluated as well.

2. Materials and methods

2.1. Procurement of raw material

A basic raw material including banana (*Musa acuminata* Canvendish) fruits and soybean (*Glycine max)* grains was used in the present study. These plant materials were procured from the local market of Ngaoundere (Adamawa Region of Cameroon), and immediately transported in plastic boxes to the laboratory of the Department of Food Sciences and Nutrition, Ngaoundere University. The banana fruits were fresh and matured to the extent where their ripening process had been initiated (stage 5 of ripening: yellow with green tip). They were placed at room temperature of 25 ± 3 °C for fully ripping at maturity stage 7 (overripe banana: appearance of black spots on the surfaces of their peels). The soybean grains were manually separated from inorganic materials, dirt, dust particles, and other foreign materials before. use.

2.2. Sample preparation

The process flow chart for obtaining defatted soybean flour and preparing of foam-mat dried overripe banana powder (OBP) is shown in Fig. 1.

2.2.1. Defatted soybean flour preparation

After the sorting, the soybean grains were soaked for 15 h in tap water in the ratio of 1/3 (w/v). Then, soybean grain batch was pre-cooked at 90 °C in a boiling water bath for 50 min (1/5, w/v) and drained to remove water. In each case, the pre-cooked time was noted when water began boiling. The drained grains were placed within an electric dehydrator to dry for 24 h at 40 ± 3 °C. Soaked soybean grains were decorticated and finely milled in a robot blender mill (MOULINEX model, Paris, France) to pass through a 100 μm mesh sieve. To produce defatted soybean powder, soybeans undergo an extraction process with n-hexane, where soybean oil is carefully removed, resulting in a low fat and protein-rich powder. The defatted soybean flour (DSF) obtained was then dried for 24h at 40 ± 3°C.

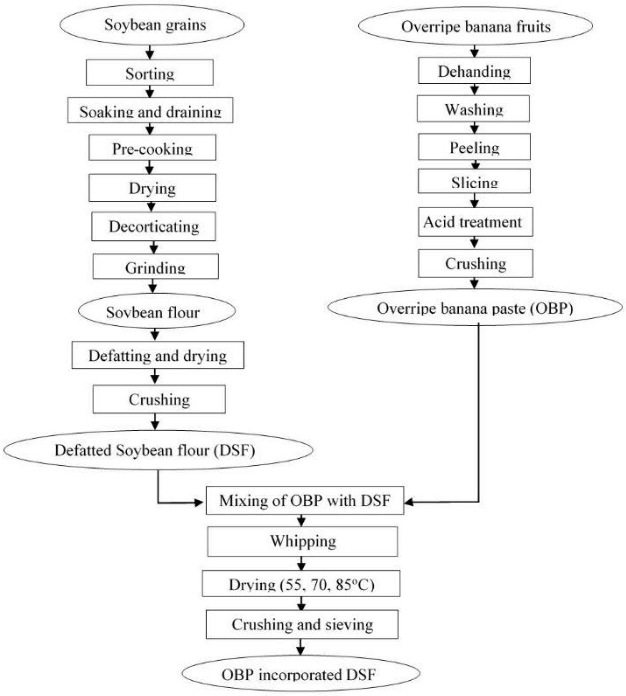

Figure 1. Combined the process flow chart for obtaining defatted soybean flour and preparing of foam-mat dried overripe banana powder (OBP).

According to Judprasong et al. [23], DSF contains total fat less than 1.5 g/100 g compared to 21-22 g/100 g in the full-fat soybean flour. DSF was sieved through a selected test sieve of mesh size 100 μm using a mechanical shaker (ENDECOTTS, MINNOR 1332-06) to obtain the appropriate particle size. Indeed, the stack of sieves was mechanically shaken for 10 min. The flour fraction that passed through the sieve was recovered and put in a polyethylene plastic bag and kept in a refrigerator at 4 °C prior to use as a foaming agent in overripe banana paste.

2.2.2. Obtention of overripe banana paste

The overripe banana fruits were thoroughly cleaned and subjected to washing with running water before being used for the experiment. Then, they were peeled manually by knife. Obtained banana pulps were cut into homogenous small sizes of approximately 0.5 cm, which were immediately immersed into the citric acid solution (3%, w/v) for 10 min to inhibit enzymatic browning and drained to remove a citric acid solution. At the same time, banana pulp slices were blanched at 90 °C for 5 min and crushed with a blender in a rotative manner to finally obtain the desired paste.

2.3. Determination of foaming properties of DSF

The foaming process was optimized in terms of

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maximum foam capacity (foam expansion) and maximum foam stability (minimum drainage volume) according to the used method by Singh et al. [24].

2.3.1. Foam capacity

It is the percentage increase in volume of the defatted soybean protein after foaming with the required amount of the foaming agent and whipping time. Practically, 3 g of DSF was added to 100 mL of distilled water and blended using a hand blender at speed 7 at ambient temperature for 5 min. Foaming quality of foam DSF in terms of foam capacity was determined by volume increase (%) immediately after whipping and was calculated by the equation 1.

$$\text{Foam capacity (\%)} = \left[\frac{V_1 - V_0}{V_0}\right] \times 100 \qquad (1)$$

Where, V_0 is the initial volume of aqueous solution of DSF before whipping (cm^3) and V_1 is the final volume of DSF solution after whipping (cm^3).

2.3.2. Foam stability

50 mL of foam aqueous solution of DSF was immediately transferred into a graduated cylinder tube and kept undisturbed in normal atmosphere for 2 h. Then the decreas of the foam volume was noted at a time interval of 20, 40, 60, and 120 minutes. The reduction of the foam volume was noted to be used as an index for the determination of the stability by using the equation 2.

$$\text{Foam stability (\%)} = \frac{V_1}{V_0} \times 100 \qquad (2)$$

Where, V_1 is the volume of foam after 2 h (cm^3) and V_0 is the initial volume of foam (cm^3).

2.4. Foam-mat drying experiment

For each experiment, DSF (foaming agent) was incorporated in desired different concentrations (10%, 15% and 20%, w/w) in produced banana paste (100 g). Mixing/whipping was done using an electric hand blender (Philips HR-3705/10 300 W Hand mixer) for foam generation by incorporation air in it to increase surface area of banana paste. Each mixture of the foam banana paste was spread uniformly into stainless steel tray (14.85cm×10.5cm×0.5cm). They were dried using tray dryer (Electro technical laboratory) at temperatures of 55 °C, 70 °C and 85 °C. These trays were periodically weighed during the drying process using a digital balance, in order to determine drying rate and other drying parameters (moisture content and diffusivity). At the end of each run, and when the tray weights appeared to be fairly constant with time, the residual or ratio moisture (MR) in banana foam mat was determined by the oven drying method (24 h at 100 °C). Resulting dried mats were then pulverized to be powder and then sieved into fine powder (100 μm diameter. Three overripe banana powders were produced: 10% OBP, 15% OBP and 20% OBP; where means that 10%, 15% and 20% of DSF were incorporated as foaming agent. They were kept in screw cap bottles at 4°C until further use.

Moisture content of foam overripe banana incorporated DSF during the thin-layer drying was expressesed in terms of moisture ratio (MR) according to the equation 3.

$$\text{Moisture ratio (MR)} = \frac{(M - M_e)}{(M_o - M_e)} \qquad (3)$$

Where, M: Moisture content at time t, Kg moisture, M_e: Equilibrium moisture content, Kg moisture and M_O: Initial moisture content, Kg moisture.

Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity (D_{eff}). Thin layered foamed banana pulp in a tray was considered as slab geometry. The equation is expressed as:

$$MR = \frac{8}{\pi^2}\left[\frac{-\pi^2 D_{eff}\, t}{4 L^2}\right] \qquad (4)$$

Equation (5) can be rewritten as:

$$D_{eff} = \frac{\ln MR - \ln \frac{8}{\pi^2}}{\frac{\pi^2 t}{4 L^2}} \qquad (5)$$

The slope (K_o) was calculated by plotting ln (MR) versus time (t) according to equation (6) to determine the effective diffusivity for different temperatures.

$$K_o = \left(\frac{D_{eff}\, \pi^2}{4 L^2}\right) \qquad (6)$$

Where, L: thickness of foam mat (m) and D_{eff}: Effective moisture diffusivity (m^2/s).

2.5. Dried product analyses

2.5.1. Determination of color

Overripe banana powder color was measured using instrumental color readings for LSDSF, which was equipped with a camera instrument control of image software and a D65 circumferential optical sensor. Firstly, each powder sample was filled in the

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transparent Petri dish. Then, the colorimeter based on the CIE$_{L^*a^*b^*}$ color system was previously calibrated with a standard calibration plate having white and black areas and employed for color characterization. Resulted data were expressed in the CIE$_{L^*a^*b^*}$ color system in accordance with the method used by Deli et al. [25]. L* corresponds to the lightness coordinate ranging from no reflection for black (L* = 0) to perfect diffuse reflection for white (L* = 100), a* is the redness coordinate varying from negative values for green to positive values for red and b* is the yellowness coordinate ranging from negative values for blue and positive values for yellow. Resulted values correspond to the average of three measurements performed at different locations of the powder layer.

2.5.2. Particle size analysis

The particle size of produced overripe banana powder was measured using a laser-diffraction particle size distribution analyzer (Mastersizer 2000). The experiments were carried out in a wet cell using ethanol as solvent. Particle size analyses were applied for sample three times and average of them was taken. The chosen size estimator was the particle size in volume and classical granulometric parameters were determined: D_{10}, D_{50}, D_{90} and span; where D_{50} means that 50% of sample particles had diameters inferior to D_X. The width of particle distribution was evaluated through the span, calculated as equation 7.

$$Span = \frac{D90 - D10}{D50} \quad (7)$$

2.6. Statistical analyses

All experiments were carried out in triplicate. Results were expressed as means ± standard deviation. Analysis of variance (ANOVA) was used to determine if there were statistical significant (p≤0.05) differences. Duncan multiple range test was used to determine which of the samples were significantly different. Statgraphics centurion version 16.1 statistical Software was used for this purpose. Sigmaplot 12.5 was used to plot curves. Model parameters were estimated using a nonlinear regression procedure based on the Levenberg-Marquardt algorithm. The fitting quality of the experimental data to all models were evaluated using the coefficient of determination (R^2), the reduced chi-square ($\chi 2$), and the root mean square error (RMSE). These parameters were calculated from the following equations 8 and 9.

$$\chi 2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z} \quad (8)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{1/2} \quad (9)$$

Where, MR_{exp} and MR_{pre} are experimental and predicted dimensionless moisture ratios, respectively; N is the number of observations and z is the number of constants. The best model describing the drying kinetics of samples was chosen as the model with the lowest $\chi 2$ and RMSE values and the highest R^2 value.

3. Results and discussion

3.1. Foaming trials of defatted soybean flour

The obtained foam capacity of defatted soybean flour (DSF) was 87.5%. The foam capacity falls in the range of 65.3-87.8% as reported by Zhang [26] when whey protein concentrates were used and also in the range of 1-90%, when different varieties of soybean were used [27]. On the other hand, the foam capacity of DSF was lower than that of isolated protein (99%) but higher than that of defatted flour (15%) and that of protein concentrate (55%) Al-samh (*Mesembryanthemum forsskalei* Hochst) seeds by Salah et al. [28]. The highest foam capacity of DSF as compared to defatted flour from *Mesembryanthemum forsskalei* Hochst seeds, might be because the precooking process further reduces the amount of anti-nutrients thereby liberating proteins that possess a greater three-dimensional framework. This framework further increases the foam capacity. Indeed, the foam capacity corresponds to the ability of an ingredient to form and stabilize a foam. The foam capacity of an ingredient (protein) is measured as the amount of interfacial area that can be created by whipping the protein. Indeed, during the whipping process, air bubbles were trapped in the foam and the more air present in the foam, the greater the foam expansion or whippability. The higher foam capacity has been attributed to the decreased hydrophobic forces among protein molecules [29]. The rise in the volume of foam may be due to the formation of a solid interfacial film by denaturalizing the protein molecules of the defatted soybean flour during whipping, stability of the interfacial film, surface tension reduction and

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interfacial tension [30]. The interfacial film's ability to entrap and retain more air volume leads to the expansion of foam. Therefore, the more air incorporated during whipping, the more air present in the foam and the greater the foam expansion or whippability.

DSF showed a non-significant (p>0.05) decrease in the stability of the foam. The foam stabilities were 98.55 ± 2.51, 96.88 ± 2.71, 95.43 ± 4.36 and 93.91 ± 2.27, respectively when the foams were left to stand for 20, 40, 60 and 120 min. These results are in accordance with Salah et al. [28], in which the foam stability of isolated soybean proteins were 95%, 91% and 75% when it was left to stand for 60, 90 and 120 min. Foam stability reflects the ability of foam to bind water and is an approach to determine the rate at which the liquid drains from the foam [31]. The foam of flour is due to proteins, which form a continuous cohesive film around the air bubble in the foam [32]. Foam stability is governed by the ability of the film formed around the entrapped air bubbles to remain intact without draining, it follows that stable foams can only be formed by highly surface-active solutes [33]. In foam-mat-drying, foam stability is very important, as the foam should be able to hold its open structure throughout the drying process. The resulting structure is desirable for rapid drying and good product quality [30, 22].

3.2. Drying characteristics

The overripe banana used for the experiment had 82.60±0.57% (wet basis) of moisture content. The variation of the moisture content of foam banana paste (with 10%, 15% and 20% DSF) with drying time at different air temperatures (55, 70 and 85 °C) were presented in Fig. 2. Drying air temperature had significant effect on drying time, which is evident from the fact that drying time reduced with increase in drying air temperature. Moisture reduction per hour was higher at initial stages and then started to decrease with the increasing drying time. The final moisture content of powdered samples (10% OBP, 15% OBP and 20% OBP) was in the range of 9.82 - 17.70% (dry basis). The total drying time required to achieve up to a constant moisture level was 9 hours, 4 hours and 3 hours for 55, 70 and 85 °C as drying air temperatures, respectively. At higher drying

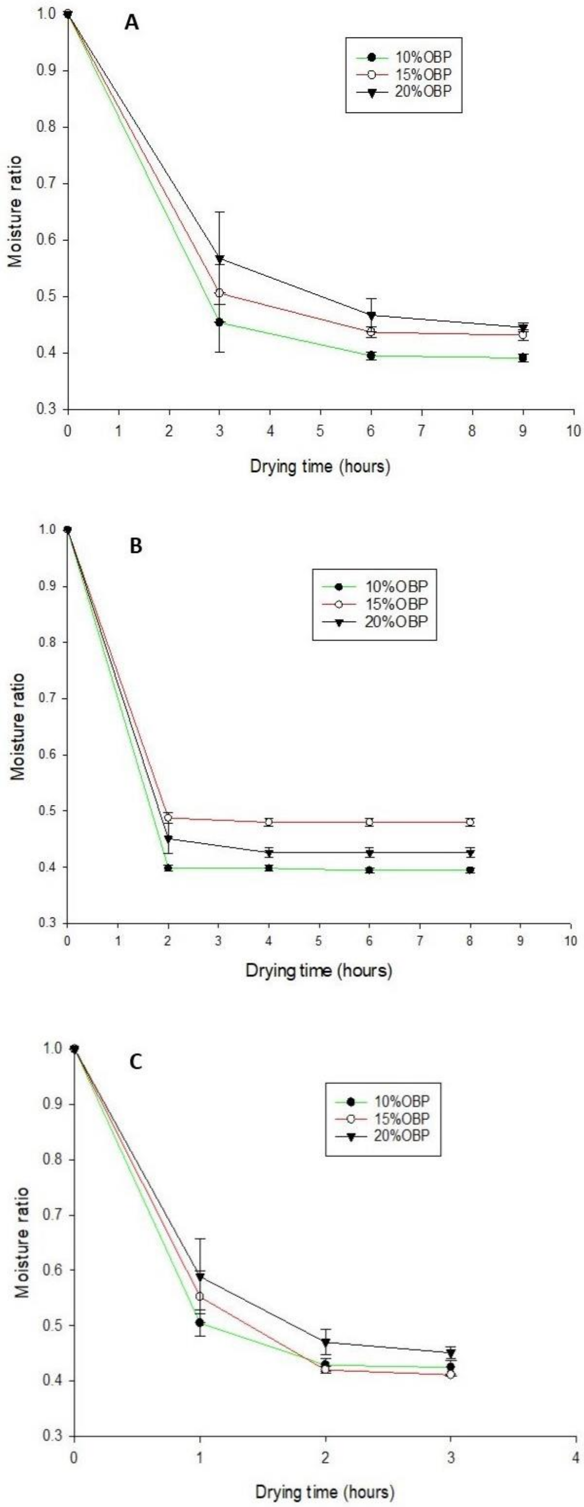

Figure 2. Effect of DSF (%) on drying rate of foam mat dried overripe banana pulp at (A) 55°C, (B) 70°C and (C) 85°C drying air temperatures.

(10 % OBP: overripe banana powder incorporated 10 % (w/w) of defatted soybean flour; 15 % OBP: overripe banana powder incorporated 15% (w/w) of defatted soybean flour; 20 % OBP: overripe banana powder incorporated 20 % (w/w) of defatted soybean flour. Bars differed significantly (p < 0.05) according to Duncan's multiple range test, n=3)

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Table 1. Effective moisture diffusivity and its equation for foam-mat-drying of banana pulp

Temperature (°C)	OBP samples	Equation	D_{eff}	R^2
	10% OBP	y= -0.0493x-12.16	2.16949E06	0.8898
55	15% OBP	y= -0.0483x-12.32	1.85102E06	0.8964
	20% OBP	y= -0.0452 -12.45	1.65028E06	0.9227
	10% OBP	y= -0.0747x-11.67	3.28392E06	0.8509
70	15% OBP	y= -0.0732x-12.00	2.3937E-06	0.8516
	20% OBP	y= -0.0713x-11.82	2.8712E-06	0.850
	10% OBP	y= -0.359x -10.528	9.46754E06	0.9938
85	15% OBP	y= -0.2776x-10.75	8.98445E06	0.9783
	20% OBP	y= -0.2577x-10.96	7.5878E-06	0.9837

10 % OBP: overripe banana powder incorporated 10% (w/w) of defatted soybean flour,
15 % OBP: overripe banana powder incorporated 10% (w/w) of defatted soybean flour,
20 % OBP: overripe banana powder incorporated 10% (w/w) of defatted soybean flour.

temperature i.e 85 °C the drying time was less as compared to lower temperature levels. The results of the current study fall in the range of 5-6.5 hours as reported by Robin et al. [34] for the types of fruit pulps like mango. It was observed that drying occurred primarily in falling rate period and no constant rate period was observed at all drying temperatures. In addition, it can be deduced from Fig. 2 that the concentration of foaming agent has significant effect on drying rate. At 55 °C drying, sample 10% OBP had minimum moisture ratio with respect to time, however in case of drying at 70 and 85 °C, minimum moisture ratios were obtained with 10% OBP and 15% OBP, respectively. From above, it can be resolved that, sample 10% OBP is good due to the effective drying rate. Samples with 15% OBP and 20% OBP had similar drying rate, and being higher concentrations, these could be used in order to valorize overripe bananas, which are usually lost.

3.3. Moisture diffusivity

The effective moisture diffusivity ranged between 1.65×10^{-6} and 9.46×10^{-6} m^2/s for temperature range from 55 to 85 °C (Table 1). These values were higher than that reported by Robin [35] (1.53×10^{-8} and 2.63×10^{-8} m^2/s) for temperature ranging from 65 to 85 °C when foam-mat-drying mango pulps. Moisture diffusivity of overripe banana foam mats increased with increase in drying temperature but decreased with increase in the level of incorporation of DSF. Moisture diffusivity was maximum for 10% OBP at 85 °C along with the highest R^2 values.

3.4. Model fitting

The moisture ratio data of foam-mat-drying of banana pulp at different temperatures using different concentrations of defatted soybean flour were fitted into thin layer drying models. The coefficient of correlation and results of statistical analysis are listed in Table 2. Four criteria for adequacy of the model fit, namely, coefficient of determination (R^2), reduced Chi square (χ^2), mean biased error (MBE) and root mean square error (RMSE) were used. The best model describing the thin layer drying characteristics of banana foam-mat-drying was chosen as the one with the highest R^2 and lowest χ^2, MBE and RMSE. All the models fitted gave R^2 more than 0.9; however, out of these, logarithmic model was the best fitted with R^2 more than 0.99 for 55, 70 and 85 °C. Similar findings were reported for hot air drying of mango pulp [35].

3.4. Physical properties of overripe banana powder

3.4.1. Color Analysis

The values of L*, a*, b* obtained after elaborating the color of composite powder products is shown in Table 3 where the luminance value L* ranges from 63.66 to 71.01. This indicates that the powders have a very high luminance. The a* values are in the range of355.33 to 837.01 and that of b* between 5.01 and 14.01. Hence the color of these powders is between white and yellow. Powders obtained from a drying temperature of 55 °C had no significant difference in the L* whereas the b* decreased with the sample, 10%OBP having the highest b* value. Powders from a drying temperature of 85 °C showed similar trends in the L* and b* values but a slight difference was observed for powders obtained at 70 °C. Powders obtained at 55 °C showed luminance values higher than 85 °C and 70 °C respectively.

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Table 2. Statistical quality analysis of fitted thin layer drying mathematical models to foam-mat-drying of overripe banana pulp

Temperature (°C)	OBP Samples	Model	χ^2	R^2	RMSE
	10% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.002382769	0.99991	0.01939018
55	15% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00272256	0.99969	0.02765632
	20% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00182993	0.99934	0.02040355
	10% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00353003	0.99992	0.02375592
70	15% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00251485	0.99934	0.02352981
	20% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00304745	0.99833	0.02409107
	10% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00506052	0.99991	0.05668136
85	15% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00365693	0.67187	0.05788609
	20% OBP	Logarithmic MR = yo + a*Exp(-b*x)	0.00304668	0.99883	0.05443985

χ^2: reduced Chi square, R^2: coefficient of determination, RMSE: root mean square error, 10%OBP: overripe banana powder incorporated 10 (w/w) of defatted soybean flour, 15% OBP: overripe banana powder incorporated 10% (w/w) of defatted soybean flour, 20% OBP: overri banana powder incorporated 10% (w/w) of defatted soybean flour.

Table 3. Variation of the color attributes of composite powders in relation to the rate of incorporation

Temperature (°C)	OBP Samples	L^*	a^*	b^*
	10% OBP	69.66±0.50^c	773.33±0.11^{ab}	6.66±0.57^b
55	15% OBP	70.01±0.01^c	704.01±0.26^{ab}	6.01±0.01^b
	20% OBP	71.01±0.01^c	837.01±0.22^b	5.00±0.01^a
	10% OBP	63.66±0.50^a	359.66±0.33^a	14.01±0.01^e
70	15% OBP	65.66±2.08^b	746.66±0.18^{ab}	12.01±1.01^d
	20% OBP	64.66±1.15^{ab}	355.33±0.28^a	11.33±1.15^d
	10% OBP	65.66±1.52^b	650.66±0.28^{ab}	11.66±0.57^d
85	15% OBP	70.66±1.15^c	681.66±0.20^{ab}	9.01±0.01^c
	20% OBP	70.66±0.57^c	515.00±0.34^{ab}	9.01±0.01^c

Values are means (±SD) of triplicate samples. Values without superscript are not significantly difference ($p< 0.05$) as assessed by LSD.
The same letter along a colon indicates that there is no significant different between the samples at $p< 0.05$ probability along that row.
DSF: Defatted soybean flour; 10% OBP: powder containing 10% of DSF, 10% OBP: powder containing 15% of DSF, 20% OBP: powder containing 20% of DSF.

The whitish color of powders with 10%, 15% and 20% incorporations, could be due to the low content of fat-soluble pigments removed during lipid extraction and the small particle size of the flour (Table 4), as the reduction of flour particle size increases the brightness [35]. As the whiteness of the flour is an important parameter for the acceptability by the consumers as whitish flours have low a* and a high L* values. Based on color parameters, powder samples can benefit to a wide range of applications in food products without adverse color impartation.

3.4.2. Particle size distribution

Particle size of food ingredients plays a significant role in ingredient functionality as well as in the sensory perception of food and may influence other physicochemical properties such as swelling power and water-binding capacity [36]. As shown in Table 4, all the powder samples had one distinct population of granules. The results revealed that the mean diameters for sample 20%OBP was lower than 15%OBP and 10%OBP for all drying temperatures.

These values are higher than those reported in rice flour obtained through dry (39.98 µm) and semi-wet (54.28 µm) grinding [37] but lower than the values reported in maize (400 µm) and soybean flour (200 µm) by Duarte et al. [38]. The differences observed could be due to the different thermal treatment applied at different time intervals, the chemical composition of the different powders, the grinding system and/or the sieving condition (since this was done manually) and was difficult to maintain constant force and sieving time [25].

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Table 4. Variation in particle size characteristics of overripe banana-soybean composite powders

Temperature (°C)	Samples	Span	D_{50} (µm)	Specific surface (m^2/g)
	10% OBP	1.25±0.01[a]	88.57±2.25[f]	0.16±0.01[b]
55	15% OBP	1.46±0.01[c]	61.13±1.29[d]	0.29±0.01[d]
	20% OBP	1.95±0.01[g]	46.01±0.11[a]	0.42±0.01[g]
	10% OBP	1.53±0.01[d]	83.48±2.62[e]	0.19±0.01[c]
70	15% OBP	1.70±0.01[f]	53.06±0.77[b]	0.37±0.01[f]
	20% OBP	2.09±0.01[h]	45.36±0.21[a]	0.47±0.01[h]
	10% OBP	1.28±0.01[b]	89.98±1.95[f]	0.08±0.01[a]
85	15% OBP	1.63±0.01[e]	57.13±0.55[c]	0.32±0.01[e]
	20% OBP	2.16±0.01[i]	45.03±0.36[a]	0.49±0.01[i]

The same letter along a colon indicates that there is no significant difference between the samples at p< 0.05 probability along that row. DSF: Defatted soybean flour; 10%OBP: powder containing 10% of DSF, 15%OBP: powder containing 15% of DSF, 20% OBP: powder containing 20% of DSF.

Indeed, the foam mat hardness is an indicator of the chemical composition and particles sizes of the powders after milling, the increased protein content in the fine fraction is attributed to the lower seed hardness [39]. The particle size distribution of a powder is also correlated to the type of grinding, the wet process allowing the production of finer particles than the dry process [37]. The different parameters; D_{50}, span and specific surface representing the particle size, particle distribution and contact surface of the particle population were evaluated (Table 5). The D_{10} is characteristic for finer particles, whereas D_{90} characterize the bigger ones [40].

The similarity in span values for each incorporation rate shows that there is no significant difference in scattering shape of the particles of the different powders for the same incorporation rate. However, the span values of these powders less than 3 indicate that these powders have a low range distribution as oppose to the reported data [41], which their particles are homogenous in size.

4. Conclusions

Overripe banana powder samples were prepared using overripe banana paste incorporating defatted soybean flour (DSF) as foaming agents, and the resultant foams were dried in dehydrator (at 55 °C, 70 °C and 85- °C air temperature). The maximum foam expansion of (87.50%) and foam stability of (98.55%) of DSF were recorded. The total drying times required to achieve constant moisture level were 9 hours, 4 hours and 3 hours for 55, 70 and 85 °C drying air temperature, respectively. Defatted soybean flour in a solid form added at 10g/100g showed high aptitude as foam inducer for banana puree. The effective moisture diffusivity ranged from 1.65×10^{-6} and 9.46×10^{-6} m^2/s. Based on the above studied parameters, it was resolved that foam mat drying using 10% defatted soybean flour at 70 °C air-drying temperature was the best combination to get overripe banana powder with the best physical characteristics.

Compliance with ethical standards

Ethical standards are respected in accordance with the declaration of the Department of Food Science and Nutrition.

Authors' contributions

Protocol writing and statistical analyses, S.Z., N.R.M., D.E.B., N.R.; Field work and laboratory analyses, S.Z.; Drafted the manuscript, S.Z., D.M., N.R.M.

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Availability of data and materials

All data will be made available on request according to the journal policy.

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Conflicts of interest

All authors declare no conflict of interest.

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