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Effects of Foam-Mat Oven Drying Towards the Physicochemical Properties of Banana (*Musa paradisiaca*) Peel Powder

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The high demand for bananas indirectly contributes to the increase in banana waste nowadays. In fact, the undervalued banana peel has the potential to be transformed into functional food, as it has been traditionally consumed as food and medicine to treat various kinds of ailments. This study aimed to produce foam-mat oven-dried (FMOD) banana peel powder using egg white as a foaming agent and carboxymethylcellulose as a foam stabiliser. A few parameters, including whipping time and concentration of foaming agent and stabiliser, were evaluated using the Box-Behnken Design combined with the Response Surface Methodology. The foam expansion (367%), density (0.611 g/cm^2), and stability (21.43%) were optimised at 20%, 0.625%, and 5 minutes of foaming agent, foam stabiliser, and whipping time, respectively. The FMOD technique gave non-hygroscopicity (1.19%) and non-caking banana peel powder (3.12%) due to its low moisture content, fair flowability (35.99%), poor wettability (27 min 32 sec) and water solubility index (14.79%). The proximate analysis of protein, crude fibre, moisture, ash, and carbohydrate was found to be 1.45%, 10.62%, 14.35%, 24.99%, and 51.41%, respectively. This study meets the policy of sustainable development goals by curbing the disposal of banana peel waste for the benefit of different industries such as health, nutraceuticals, and pharmaceuticals, besides improving the national economy.

Keywords: Foam-mat oven drying; banana peels; foam properties; hygroscopicity; flowability

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Banana is the fruit of an herbaceous plant of the genus *Musa*. *Musa* species thrive in a variety of environments and are one of the most popular tropical fruits traded commercially. Although mature bananas are eaten raw, a considerable number of bananas are industrially processed into banana flour, chips, and other processed foods, resulting in a significant amount of banana by-product. The deposition may include stalks, inflorescences, pseudostems, peels, and leaves. Typically, banana peels represent approximately 35–50% of the total fruit mass [1], but there is no further treatment given to banana peels that are discarded into the environment.

Every year, over 36 million tonnes of banana peels are generated, resulting in serious environmental problems and economic losses [1]. Several tonnes of banana peel trash are created every day in home waste and fruit markets and disposed of in landfills without benefiting from it. But now, the conversion of banana peels into useful items will assist the agriculture business financially [2]. Several studies have shown that banana peel, which has been used as food and medicine, has the potential to be transformed into useful food products. The findings appear to further justify the suggested use of banana peel in several food industries, notably in terms of the numerous bioactive chemical components in the peel and their related biological activities [2].

Generally, banana peels have been found to contain bioactive compounds such as flavonoids, tannins, phlobatannis, alkaloids, glycosides, anthocyanins, and terpenoids, which are associated with various biological and pharmacological functions such as antibacterial, antihypertensive, antidiabetic, and anti-inflammatory [3]. Rebello [4] discovered that banana peel extract is a great source of total phenolics (29 mg/g as GAE), responsible for the higher antioxidant activity than the pulp [5]. According to Someya [6], the gallocatechin content of banana peel is also five times higher than that of the pulp. Therefore, banana peel is chosen for this study due to its widespread disposal as a by-product in the food

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industry in Malaysia. However, banana peels contain the enzyme polyphenol oxidase, which will interact with oxygen, turning the banana peel and fruit brown. In addition, banana peels have a high moisture content of about 85%, making them susceptible to micro-organisms and enzymatic processes. Thus, it is necessary to reduce the moisture content to maintain the quality of the banana peels.

To address this issue, drying is used to preserve the banana peels. Among the drying methods, foam-mat oven-dried (FMOD) is preferred over spray drying because it is ideal for high-sugar foods, thermally sensitive foods, and viscous substances with sticky behaviour [7]. In foam mat drying, the physical structure of raw food material is altered by breaking down the cell walls and the inclusion of gas (air), forming a stable, porous honeycomb sheet or mat. This will reduce the time required for the sample to dry. Interestingly, the product after foam mat dried will retain its original qualities when being reconstituted.

Nevertheless, studies on the influence of the FMOD method on the physicochemical properties of banana peel powder are lacking and less reported. The addition of foaming agents and stabilisers that could help improve the foam mat's stability could also be a factor affecting the foam mat drying process. Therefore, this study aimed to optimise the whipping time and the concentration of foaming agent and stabiliser in producing a stable foam by using Box-Behnken Design (BBD) combined with Response Surface Methodology (RSM) and to investigate the effects of foam-mat oven drying on the physicochemical properties of banana peel powder. The determination of foam properties, including foam stability, foam density, and foam expansion, was conducted.

EXPERIMENTAL

Chemicals and Materials

The "Berangan" banana ripening scale at stage 6 (pale yellow) was purchased from a fruit shop at Simpang Pertang, Negeri Sembilan. Meanwhile, the fresh CP Hygienic eggs in size B were purchased from the supermarket. The chemicals of ammonium sulphate (Qrec, New Zealand), concentrated sulphuric acid, Kjeldahl catalyst tablet, sodium hydroxide (50%), boric acid (2%), hydrochloric acid, methyl red, ethanol, methanol (99.9%), and carboxymethyl cellulose were obtained from the laboratory of Food Technology, UiTM Campus Kuala Pilah.

Preparation of Banana Peel Foam

The banana peel foam was prepared according to Karim and Wai [8] with modifications. The banana pulp was separated from the peel and washed before being sliced into smaller pieces. Distilled water was then added in a 1:1 ratio and blended to obtain a paste. Next, banana peel foam was prepared by whipping the banana peel paste, egg albumin as foaming agent (5 to 20% w/w), and carboxymethyl cellulose (CMC) as a foam stabiliser (0.25 to 1% w/w) [9, 10] using a hand mixer, fixing the batch volume at 100 mL. The whipping process was carried out at room temperature (27°C) for 5 to 20 minutes.

Optimisation of Foam Properties

A randomised block with three-level BBD was used, and their coded and actual levels are presented in Table 1. A total of 17 experiments with various combinations of independent factors (X_1, X_2, and X_3) were conducted to determine the optimal condition for foam formation. The stable foam properties in terms of foam density, foam expansion, and foam stability were evaluated as response variables at the end of each run. The foam was then spread evenly on aluminium foil before being oven-dried for 6 hours at 80°C. The dried layer was scrapped and pulverised using a grinder, then sieved into powder and stored in a plastic bag before further analysis.

Foam Expansion

Foam expansion indicates the amount of air incorporated into the whipped mixture. A combination of banana peel and distilled water was ground into a paste and weighed (V_1). After that, the paste was added with EW and CMC, whipped until it became foam, and weighed (V_2). Foam expansion was calculated using the differences in the weight of the peel before and after foaming according to Equation 1 [11]:

$$\text{Foam expansion (\%)} = \frac{V_2 - V_1}{V_1} \times 100 \quad (1)$$

Where, V_1 is initial volume of material (mL) and V_2 is final volume of material (mL).

Table 1. Actual and coded factors and the level for each independent variable.

Variables	**Factor level**		
	-1	**0**	**1**
Egg albumin (X_1, %)	5.00	12.50	20.00
Carboxymethyl cellulose (X_2, %)	0.25	0.625	1.00
Whipping time (X_3, minutes)	5.00	12.50	20.00

Foam Density

The banana peel foam was poured into a 50-mL measuring cylinder without trapping the air voids and breaking down the foam structure, according to Karim and Wai [8]. The weight (g) and volume (mL) of the foam were recorded. Foam density was then calculated using Equation 2:

$$\text{Foam density (\%)} = \frac{\text{Weight of the foam (g)}}{\text{Volume of the foam (mL)}} x\ 100 \qquad (2)$$

Foam stability

A measure of foam stability is the change in foam volume. The banana peel foam was transferred into a 50-mL measuring cylinder and kept at room temperature without any disturbance. The reduction in volume of foam was measured after two hours, and the foam stability index was determined by using Equation 3.

Physical Analysis of Foam-Mat Oven Dry (FMOD) Banana Peel Powder

Hygroscopicity Determination

The hygroscopicity was measured based on a technique by Shuen [12], where the powder was placed in a glass desiccator pre-filled with saturated ammonium sulphate solution to create a relative humidity of 81%. Then, the samples were weighed after a week. The hygroscopicity was determined using the following formula, Equation 4.

Degree of Caking Determination

Utilizing the A15a methodology described by the GEA Niro Research Laboratory [13], approximately 5 g of powder was sieved through a 35 mesh size (500 micron) sieve. The remaining powder on the sieve was weighed to determine the degree of caking. The degree of caking was calculated using the formula, Equation 5.

Angle of Repose Determination

The angle of repose was used to calculate the flowability of the sample. As described by Guo *et al.* [14], the filter funnel was set up at 2 cm above the base, and 5g of powder was poured from the top of the filter funnel. Then, the height and diameter of the small mountain formed were measured. The value was calculated using the formula:

$$\text{Angle of repose, } \tan\theta = \frac{\text{Height (cm)}}{\text{Radius (cm)}} \qquad (6)$$

Water Solubility Index Determination

The water solubility index (WSI) was evaluated following the method described by [15], and 1 g of powder was mixed with 10 mL of distilled water before incubating in a water bath with a shaker at 37°C for 30 min. Then, the solution was centrifuged at 4,400 rpm for 10 minutes, and the supernatant will be dried in a convection oven at 105°C for 5 hours. The WSI was calculated using Equation 7.

$$\text{Water solubility index (\%)} = \frac{\text{Weight of dried powder (g)}}{\text{Weight of original powder (g)}} \text{ x } 100 \qquad (7)$$

Wettability Determination

The wettability was determined using the Shuen [12] method, where the time taken, in s, was measured for 1 g of powder to get fully wet in 10 mL of distilled water.

Proximate Analysis

Samples were analysed for moisture, crude protein, crude fibre, and ash content in accordance with the methods described by AOAC [16]. The total carbohydrate was calculated by the difference.

Moisture Determination

The moisture content of the powder was assessed using an MB45 halogen moisture analyser (Ohaus Corporation). The empty sample pan was placed inside the analyser, and the reading was set to zero. Approximately 5 g food sample was then placed evenly in the sample pan. The cover was closed, and the sample was dried at 105°C for 5 minutes to attain a constant weight.

Ash Determination

The ash content of banana peel powder was evaluated using the dry ashing method. At first, 5 g of the banana peel powder was weighed and put into the porcelain dish. The powder was burned gently over a Bunsen burner until smoke no longer evolved when heated strongly. Then, the dish was placed in a muffle furnace and heated at 550°C for 3 hours until whitish or greyish ash was obtained. Lastly, the dish was removed from the muffle furnace and cooled in a desiccator. The dish was weighed again after attaining room temperature (assume this to be the constant weight). Ash percentage was calculated using the formula:

$$\text{Ash (\%)} = \frac{\text{weight of ash (g)}}{\text{weight of sample (g)}} \text{ x } 100 \qquad (8)$$

$$\text{Foam stability (\%)} = \frac{\text{Volume of foam after two hours (mL)}}{\text{Initial volume of banana peel foam (mL)}} x\ 100 \qquad (3)$$

$$\text{Hygroscopicity (\%)} = \frac{\text{Final weight of sample (g)} - \text{Initial weight of the sample (g)}}{\text{Initial weight of the sample (g)}} \text{ x } 100 \qquad (4)$$

$$\text{Degree of caking (\%)} = \frac{\text{sample retained in the sieve (g)}}{\text{Sample used (g)}} \text{ x } 100 \qquad (5)$$

Crude Protein Determination

The protein content of the powder was determined using the Kjeldahl method. The digestion tubes were placed in the digestion tube holder. About 1 g of powder was weighed and placed into the digestion tube, while another 2 pills of the catalyst mixture (5 g potassium sulphate + 5 mg selenium) and 20 mL of concentrated sulphuric acid were added. The suction module with the fitted gaskets was placed on the digestion tube holder. The water supply was turned on to the condenser, and the scrubber unit was switched on. Then, the digestion unit was switched on, and the energy regulator was set at position 10. The samples were allowed for digestion until they were complete. The samples should be clear, with no charred material remaining. After that, the samples were removed from the digestion block and allowed to cool to room temperature. The power system of the distillation unit was switched on and warmed up at least 2 minutes before the first run. About 70 mL of 2% boric acid and 3 drops of screened methyl red as an indicator were filled into the conical flask. The distillation apparatus was set up with the delivery tube dipping below the solution. The sample tube was then put in place to make sure it was seated securely. Next, 50 mL of distilled water and 80 mL of 32% NaOH were also added to the digestion tube by pressing the NaOH button until the desired volume was reached. The steam switch was turned on to start the distillation process. Then, 200 mL of the distillate was collected and titrated against 0.1 M HCl, and the volume of HCl used for the sample and blank was recorded. The crude protein was calculated using the formula, Equation 9.

Crude Fibre

The crude fibre content was determined using the acid and alkali digestion methods. About 2 g ± 0.0001 (W_1) of the dried ground sample was weighed into a 600 mL beaker fitted with a flux condenser, followed by the addition of 200 mL of warm 0.255 N H_2SO_4. After that, the mixture was boiled for 30 minutes. The weight of the filter paper used throughout the experiment was recorded. Next, the contents were filtered while hot using ashless filter paper (Whatman No. 541). The residue was washed with hot water until free from acid (check with litmus paper). Then, the insoluble material was transferred quantitatively into the original beaker. Twenty mL of warm 0.313 N NaOH was added and boiled for 30 minutes, followed by the addition of 3–5 drops of n-octanol as an antifoam agent. The contents were filtered, and the leftover was washed with hot water, followed by 15 mL of 1% hydrochloric acid twice, and followed with a hot water wash until the contents were neutral or free of acid. Then, the insoluble material was transferred to a weighed crucible and dried in an oven at 105°C overnight until a constant weight was obtained. The residual weight and crucible (W_2) were recorded. Next, the dried sample was burned on a Bunsen burner until the smoke no longer developed when heated vigorously. The residue was ignited in a muffle furnace at 550ºC for 3 hours. The crucible was cooled down in a desiccator and weighed. Lastly, the weight of the ash and crucible (W_3) was recorded. The loss in weight at ignition represents the weight of crude fibre. The percentage of crude fibre was calculated using the formula:

$$\text{Percentage of crude fibre (\%)} = \frac{W_2 - W_3}{W_1} \times 100 \qquad (10)$$

Where, W_1 is the weight of sample taken in gram, W_2 is the weight of weigh of crucible with dried residue in gram, and W_3 is the weight of crucible with ash in gram.

Carbohydrate

Carbohydrate content was calculated according to FAO (1982) by the following differences, Equation 11.

Statistical Analysis

The process variable optimisation was accomplished via Box-Behnken Design (BBD), Design Expert Software (version 13, 2022). The statistical significance of model terms was determined using regression analysis and the analysis of variance (ANOVA). Lack-of-fit and R^2 (coefficient of determination) values were used to evaluate the model's suitability. By getting F-values at 5% levels of probability, it was statistically possible to assess the significance of each polynomial model term. The proximate analysis was conducted in triplicate, and the results were expressed as the mean ± standard deviation.

$$1 \text{ mL } 0.1 \text{ M HCl} = 1.4 \text{ mg N}$$

$$\text{Total nitrogen (g) per 100g food sample} = \frac{(\text{titre} - \text{blank}) \times 1.4}{1000 \times \text{sample weight (g)}} \times 100 \qquad (9)$$

$$\text{Carbohydrate \%} = 100 - (\text{moisture \%} + \text{protein \%} + \text{ash \%} + \text{crude fibre \%}) \qquad (11)$$

RESULTS AND DISCUSSION

Effects of Egg Albumin (EW), Carboxymethyl Cellulose (CMC), and Whipping Time on Foam Properties

Foam Density

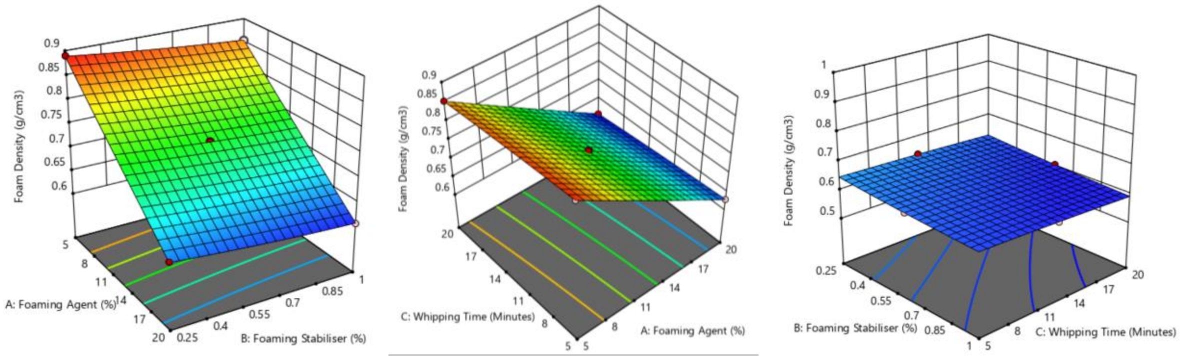
Foam density is commonly adopted as the fundamental criteria for measuring foam quality, notably whipping properties. The foam density decreases when more air is included during the whipping process. Higher foaming potential indicates more air is incorporated into foam. The effect of EW, CMC concentration, and whipping time on foam density is presented in Equation 12. The statistical significance of the equation was evaluated by ANOVA (Table 2). The linear factors (A, B, and C) and second-order interactions (B^2 and C^2) showed high reliability ($p < 0.05$), except for the A^2 and double interactions (AB, AC, and BC) which did not have an effect on the foam density. The high values of R^2 (0.9999) and adjusted R^2 (0.9998) for foam density were obtained (Table 3). The lack of fit is insignificant ($p = 0.080 > 0.05$) and the significant model ($p < 0.0001 < 0.05$) suggests that the selected model is fitted to describe the behaviour and to predict the foam density.

Where A is EW (%), B is CMC (%), and C is whipping time (minutes).

Figure 1 shows the response surface plots for the effect of independent variables (A, B, and C) on foam density. The result indicated that the EW and CMC concentrations, as well as whipping time, have a quadratic effect on the foam density. The low foam density range of 0.61 to 0.89 g/cm^3 resulted in an increase in foam expansion, which helped in good heat transfer during the drying process.

The foam density was found to decrease with increasing foaming agent and foaming stabiliser concentrations (Figure 1a) at constant whipping time (12.5 minutes), which reached an optimum value of 20% of EW and 0.592% of CMC. The foam density also reduced when whipping time increased (Figures 1b and 1c) and reached 0.63 g/cm^3 across the designated region, with the optimum values of EW (20%), CMC% (0.592%), and whipping time (5 minutes). Razali [17] found that higher foaming agent concentrations can lead to better foam density and powder's solubility, browning index, and flowability.

$$\text{Foam density} = 0.7422-0.125A-0.0164B-0.0131C+0.001AB+0.001AC-.00075BC+0.0015A^2+0.00278B^2-0.00173C^2 \tag{12}$$



(a) (b) (c)

Figure 1. Response surface plot of foam density as a function of (a) whipping time, (b) CMC %, (c) EW%

Table 2. ANOVA for the response surface quadratic model for foam density.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.129	9	0.014	7663.77	< 0.0001	significant
A-Foaming Agent	0.125	1	0.125	67049.81	< 0.0001	
B- Foaming Stabiliser	0.002	1	0.002	1150.64	< 0.0001	
C- Whipping Time	0.001	1	0.001	739.22	< 0.0001	
AB	4.000 E-06	1	4.000 E-06	2.15	0.186	
AC	4.000 E-06	1	4.000 E-06	2.15	0.186	
BC	2.250 E-06	1	2.250 E-06	1.21	0.308	
A^2	9.792 E-06	1	9.792 E-06	5.25	0.056	
B^2	0.000	1	0.000	17.39	0.004	
C^2	0.000	1	0.000	6.72	0.036	
Residual	0.000	7	1.864 E-06			
Lack of fit	0.000	3	3.417 E-06	4.88	0.080	Not significant
Pure Error	2.800 E-06	4	7.000 E-06			
Cor Total	0.129	16				

Table 3. Regression analysis of foam properties in term of R^2, adjusted R^2, and predicted R^2.

	R^2	Adjusted R^2	Predicted R^2
Foam density	0.9999	0.9998	0.9987
Foam expansion	0.9982	0.9959	0.9775
Foam stability	0.9993	0.9989	0.9988

Table 3 also shows all the predicted R^2 for the response variables were in reasonable agreement with the adjusted R^2 as the difference among them was less than 0.2.

Foam Expansion

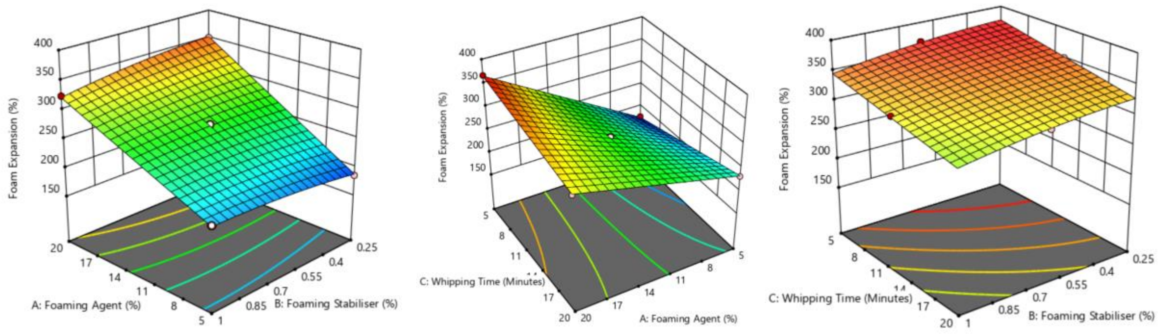
The trapping of air in the foam was measured using the expansion in volume of the foam, which indicates the percentage increase in volume of the mixture. Analysis of variance (ANOVA) statistical analysis implied that the model was established with linear coefficients, double interaction, and squares of the factors (Table 3). The EW concentration (A), whipping time (C), interactions (AB and AC), and second-order interaction (B^2) were shown to have significant impacts on foam expansion ($p < 0.05$); however, the CMC concentration (B), interaction (BC), and second order interactions (A^2 and C^2) were not affected ($p > 0.05$). The significant parameters that influenced the foam expansion are given in Equation 13. The R^2 (0.9982) and adjusted R^2 (0.9959) for response variables were observed. The lack of fits is insignificant ($p = 0.091 > 0.05$), and the p-value of the model was lower than 0.05, which indicated the goodness of fit of the model.

Where A is EW (%), B is CMC (%), and C is whipping time (minutes).

$$\text{Foam expansion} = 272.40 + 69.25A - 2.12B + 3.12C - 13AB - 27AC + 0.25BC + 0.175A^2 - 5.075B^2 - 0.075C^2 \quad (13)$$

Table 4. ANOVA for the response surface quadratic model for foam expansion.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	42179.99	9	4686.67	437.71	< 0.0001	significant
A-Foaming Agent	38364.50	1	38364.50	3583.08	< 0.0001	
B-Foaming Stabiliser	36.12	1	36.12	3.37	0.109	
C- Whipping Time	78.13	1	78.13	7.30	0.031	
AB	676.00	1	676.00	63.14	< 0.0001	
AC	2916.00	1	2916.00	272.34	< 0.0001	
BC	0.25	1	0.25	0.02	0.883	
A^2	0.13	1	0.13	0.012	0.916	
B^2	108.44	1	108.44	10.13	0.015	
C^2	0.02	1	0.02	0.0022	0.964	
Residual	74.95	7	10.71			
Lack of fit	57.75	4	19.25	4.48	0.091	Not significant
Pure Error	17.20	3	4.30			
Cor Total	42254.94	16				



(a) (b) (c)

Figure 2. Response surface plot of foam expansion as a function of (a) whipping time, (b) CMC %, (c) EW%.

The response surface of the variables is presented in Figure 2. It was observed that EW and CMC concentrations have an inverse effect on foam expansion as compared to foam density. This is because both reactions are related, and greater foam expansion resulted in lower foam density. The combination of variables maximises the foam expansion (367%) at optimum values of EW (20%), CMC (0.592%), and whipping time (5 minutes), respectively.

At a constant whipping time of 12.5 minutes (Figure 2a), foam expansion volume was found to increase as the concentrations of EW and CMC were increased from 5% to 20% and 0.25% to 0.592%, respectively. The foam expansion was optimised at 5 minutes of whipping time (Figures 2b and 2c) and tends to slightly decrease after 5 minutes. The high protein content of EW may be the cause of the EW foam's voluminous consistency. EW consists of proteins that denature at the interface and interact with one another to generate a stable, viscoelastic interfacial layer, which leads to the creation of foam when it is whipped.

Foam Stability

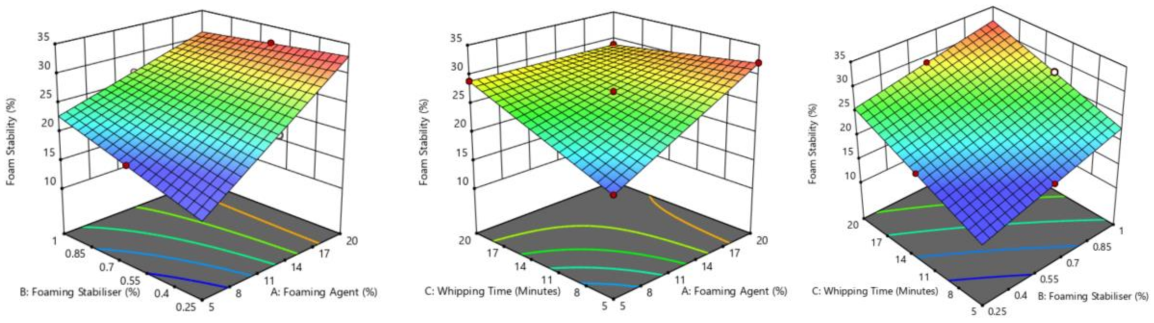
The result of the ANOVA analysis indicated that the model is established with the coefficients of linearity and interaction (Table 4). All the linear factors (A, B. and C) and double interactions (AB, AC, and BC) significantly influenced the foam stability. The high reliability ($p < 0.05$) that improved the foam stability was given in Equation 14, and the obtained coefficients of determination of the model were R^2 (0.9993) and adjusted R^2 (0.9989). The p-value of the model was lower than 0.05, and the lack of fits was insignificant ($p = 0.9049 > 0.05$), which indicated the fitness of the 2FI model.

Where A is EW (%), B is CMC (%), and C is whipping time (minutes).

$$\text{Foam stability} = 27.10+3.31A+1.12B+1.78C-2.52AB-3.33AC-0.4525BC \quad (14)$$

Table 5. ANOVA for the response surface 2FI model for foam stability.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	193.67	6	32.28	2429.42	< 0.0001	significant
A-Foaming Agent	87.65	1	87.65	6596.92	< 0.0001	
B-Foaming Stabiliser	10.08	1	10.08	758.68	< 0.0001	
C- Whipping Time	25.35	1	25.35	1907.77	< 0.0001	
AB	25.35	1	25.35	1908.07	< 0.0001	
AC	44.42	1	44.42	3343.46	< 0.0001	
BC	0.82	1	0.82	61.64	< 0.0001	
Residual	0.13	10	0.01			
Lack of fit	0.04	6	0.00	0.31	0.9049	Not significant
Pure Error	0.09	4	0.02			
Cor Total	193.80	16				



(a) (b) (c)

Figure 3. Response surface plot of foam expansion as a function of (a) whipping time, (b) CMC %, (c) EW%.

Figure 3 shows the response surface plots of each pair of factors (AB, AC, and BC) on foam stability. The results indicated that EW, CMC concentration, and whipping time significantly influenced foam stability. At constant 5 minutes, the foam stability ranged between 18.75% and 32.05% as the EW and CMC concentrations increased from 5 to 20% and 0.25 to 0.625%, respectively (Figure 3a). When whipping time and CMC % were kept constant at 5 minutes and 0.625% (Figures 3b and 3c), the foam stability increased with increasing EW concentration until it reached a maximum of 20%.

Mounir [7] stated that after 20 minutes of whipping, the stabilised EW foams typically collapse and are found to be unstable thereafter. In this case, foam stabilisers may be used to improve the long-term stability of the foam. The impact of foam stabiliser can be described by establishing a three-dimensional network that impedes component motion within the foam or by increasing the viscosity of the continuous phase [18].

Multiple Response Optimization

Foaming agent, foam stabiliser, and whipping time were chosen as independent factors to optimise the foaming properties. Multiple response optimisations were performed to minimise foam density and maximise foam expansion and stability. The optimum values of foam density (0.63 g/cm^3), foam expansion (367 %), and foam stability (32.05%) were obtained at EW concentration (20%), CMC concentration (0.625%), and whipping time (5 minutes), with a desirability of 0.954. A verification experiment was performed to verify the predicted values. Based on the optimised factors, the experimental values for foam density, foam expansion, and foam stability were 0.61 g/cm^3, 365.9%, and 31.99%, respectively. The results showed that the difference between experimental and predicted outcomes had minimal variability (Table 5).

Table 6. Predicted and actual value of response by using optimal foaming conditions.

Foam Properties	Predicted Value	Actual Value (SD)
Foam density (g/cm^3)	0.63	0.61
Foam expansion (%)	367.00	365.90
Foam stability (%)	32.05	31.99

Table 7. The physical properties of foam-mat oven dry banana peel powder.

Physical properties	Average ± std. dev.
Hygroscopicity (%)	1.73 ± 0.11
Degree of caking (%)	3.12 ± 0.16
Flowability (˚)	25.99 ± 0.30
Wettability (s)	652.00 ± 2.42
Water solubility index (%)	14.79 ± 0.07

Physical Analysis of Foam-Mat Oven Dry (FMOD) Banana Peel Powder

The physical properties of FMOD banana peel powder were evaluated in terms of hygroscopicity, degree of caking, flowability, wettability, and water solubility index. These are the important criteria for a high-quality powder that is easy to handle, transport, store, and has an extended shelf life compared to fresh products.

Hygroscopicity

Hygroscopicity is defined as the ability of a material to absorb or adsorb water from its surroundings. It is an important quality indicator in the food powder industry as it will influence the processing, handling, storage, and consumption processes. A product's hygroscopicity is associated with its moisture levels, and higher drying temperatures will produce powders with lower moisture levels [19]. The hygroscopic value of FMOD banana peel powder was 1.73% (< 10%), indicating that the powder obtained is non-hygroscopic [20]. This might be due to the high processing temperature in convection oven drying, which resulted in a high moisture content loss, thus lowering its capacity to absorb moisture from the surrounding [21].

Degree of Caking

Caking can be defined as the tendency of powder to form lumps or bulk. Table 6 shows that the degree of caking of the FMOD banana peel powder was 3.12%, which could be categorised as non-caking powder (<10%). According to the GEA Niro Research Laboratory [13], powder with a caking degree of 20.1% to 50% is classified as very caking powder, whereas powder with a caking degree of 10.1% to 20% is classified as slightly caking powder. Caked powders can disrupt processing and reduce the quality of the finished goods.

Flowability

The flowability of powdered materials is described as the ease of a material to flow under certain conditions. It could be determined by the angle of repose. In this study, a non-cohesive powder was formed in a regular conical heap, and the angle of repose obtained was 25.99°. An angle between 25–30° shows excellent flow, meaning the powder was moving through the filter funnel very smoothly [22]. The low hygroscopicity and degree of caking could be the main factors causing the very free flow property of the studied FMOD banana peel powder.

Wettability

Wettability is described as the ability of a powder to absorb water on a surface and be wetted According to Shuen [12], excellent wettability is defined as a powder's ability to get saturated in less than 30 seconds, while poor wettability is defined as a powder's capacity to become saturated in more than 180 seconds. The study found that FMOD powder has poor wettability, as the obtained wettability was 652 s. This could be explained by the high temperature in oven drying, which led to low moisture content and, hence, deteriorated the wetting properties [23].

Water Solubility Index

The water solubility index (WSI) is one of the crucial quality indicators for powder reconstitution in the aqueous phase [24]. WSI also determines a powder’s ability to dissolve in water [25]. As presented in Table 6, FMOD powder had a low WSI of 14.79%, which was aligned with the poor wettability of the FMOD banana peel powder. This is probably due to high drying temperatures that damaged the surface pores and hydrophilic proteins, causing water molecules to be unable to permeate the powder after it is destroyed, resulting in reduced solubility [26].

Table 8. The proximate properties of FMOD banana peel powder.

Proximate properties	**Average ± std dev**
Protein (%)	1.45 ± 0.99
Crude fibre (%)	10.62 ± 0.17
Moisture (%)	14.35 ± 0.09
Ash (%)	24.99 ± 0.72
Carbohydrate (%)	51.41 ± 0.49

Proximate Analysis of Foam-Mat Oven Dry (FMOD) Banana Peel Powder

About 1.45%, 10.62%, 14.35%, 24.99%, and 51.41% of protein, crude fibre, moisture, ash, and carbohydrate were reported for FMOD banana peel powder (Table 7), respectively. The protein value reported was lower than the study by [27], which is 1.94–2.73% and [2], which is 5.5–7.87%. The variety and geographical location of bananas might be the reason for these differences [28]. However, the protein value obtained was higher than the finding (0.9%) by [29]. This is likely due to the method of drying the banana peel without adding any carrier agents. In fact, the addition of EW as a foaming agent slightly increases the protein value of the sample. According to Ibiyinka [27], the ripeness also affected the protein content and moisture content of the banana peels. The moisture content stated was also lower than the value reported. This might be due to the higher amount of heat applied in *removing the moisture within the sample by using* oven drying. Besides that, the crude fibre obtained in this study was similar to the value reported by [27]. Meanwhile, ash is the inorganic waste left over when heating is used to remove water and organic materials. The ash content obtained in the FMOD banana peel powder was 24.99%, which is higher than the value reported by [27], which is 11.3–14.7%. The result indicated that the FMOD banana peel powder has good sources of minerals. Lastly, FMOD banana peel consisted of good carbohydrate content (51.41%), in which a similar trend (51.3%) was also observed by [27].

CONCLUSION

The optimisation of foaming conditions by using RSM and characterisation of the FMOD banana peel powder were successfully performed and demonstrated. The optimised foam expansion, density, and stability were found to be 367%, 0.63 g/cm^3, and 32.05%, respectively, with foaming agent and stabiliser concentrations of 20% and 0.625% and a whipping time of 5 min. The physical analysis also revealed that banana peel powder produced from FMOD has hygroscopicity (1.73%), degree of cacking (3.12%), flowability (25.99%), wettability (652 sec), and water solubility index (14.79%). Furthermore, the chemical analysis, including protein, crude fibre, moisture, ash, and carbohydrate, was reported as 1.45%, 10.62%, 14.35%, 24.99%, and 51.41%, respectively. Overall, it was proposed that banana peel powder produced from FMOD contained properties with great application and was potentially to be developed as an alternative ingredient in the food processing industry.

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