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Optimization of ingredients for the production of foamed banana powder using response surface methodology

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Abstract
For this study, Box-Behnken Experimental Design of Response Surface Methodology (RSM) was used for designing the experiments and to select their optimum value. The independent variables selected were carboxy methyl cellulose (0.5, 1.5 and 2.5%) as foam stabilizer, egg albumin (3, 7 and 11%) as foaming agent, temperature (60, 70 and 80 ºC) and whipping time (6, 12 and 18 min). The method of drying used for this study is foam mat drying. The dependent variable measured were foam density, foam expansion and foam stability. Foam density and foam expansion affected the foam mat drying of banana powder. Optimization of ingredients obtained by optimization of responses were carboxy methyl cellulose (X_1) as 2.5%, egg albumin (X_2) as 10.2%, temperature (X_3) as 80 ºC and whipping time (X_4) as 18min.

Keywords: Egg albumin, Carboxy methyl cellulose, foam density, foam expansion

Introduction

Banana with its scientific name *Musa spp.* belonging to family Musaceae and class Liliopsida is considered as one of the most consumed fruits in tropical and subtropical regions of Southeast Asia. India occupy first position in the world in banana production, contributing to 27% of world's banana production. In Uttarakhand, Great Naine variety is mostly grown but cultivation and production of banana is negligible. Banana helps in reducing risk of heart diseases when used regularly and is recommended for patients suffering from high blood pressure, arthritis, ulcer, gastroenteritis and kidney disorders. Banana has been used for both dessert and processing purposes as it has a better pulp to peel ratio and has more market acceptability Banana powder is used in cake, bread, cookies, ice-cream, flavored milk, chocolates and also used as the first baby food.Banana is available throughout the year in tropical countries, like India, so there is a vast need to utilize for proper processing techniques. Moreover banana fruits have high initial moisture content of about 72 to 77% (wb), which make it highly perishable and lower shelf life. There are more chances of spoilage or deterioration so marketing of fresh fruits to different and distant places is very difficult. Hence, it serve as a necessity to convert it into value added products which retain its colour, flavour and nutrients for longer shelf life.

Foam mat drying is regarded as one of the very effective method where removal of moisture takes place from the fruit pulps to obtain a free flowing powder that have good reconstitutions characteristic (Sharada, 2013) [1]. Foam mat drying, originally develop by Morgan *et al.*, 1961 [2], is a process in which the liquid or semi food is converted to form stable foam by cooperation with foaming agents or stabilizing agents. The foam is then spread into a thin sheet and dried by using hot air at lower temperature compared to other drying techniques such as spray drying and steam drying. Mass transfer is enhanced leading to shorter dehydration times due to the porous structure of the foamed materials. The dried banana sheet is grinded and is finally sealed in air tight sealed pouches to extend the shelf life of the food and to prevent deterioration of the product by microbiology and environmental factors. Foam mat drying techniques are mostly used for heat sensitive, sticky, viscous and high sugar content food products. Different fruits dried using foam mat drying by various researchers includes tomato (Fernandes *et al.*, 2013) [3], papaya (Ibidapo and Erukainure, 2012) [4], mango (Jaya and Das, 2004) [5], cow pea (Falade *et al.*, 2003) [6], malta (Chand and Pandey, 2012) [7], starfruit (Karim and Wai, 1999)) [8], banana (Kolawole and Okocha, 2010) [9] and yogurt (Krasaekoopt and Bhatia, 2012) [10].

Since banana foams are very porous, the use of foaming and hot air drying is thus a suitable option to produce crisp foamed banana chips. Egg Albumin is used as the foaming agent because it induces and increases foam from 6 to 8 times the volume. Carboxy methyl cellulose is used as foam stabilizer because it acts as thickening agents, binders, emulsifiers, stabilizers, suspension aids, reduces stickiness of powder and produces a non sticky, free flowing powder.

Box Behnken design of Response surface methodology (RSM) has been used to develop products and find out the effect of variable on the responses. Balasubramanian *et al.*, 2016 [11] and Chand and Pandey, 2012 [7]. It is used to get an optimum process conditions considering single response or multiple responses. Conversion of this excellent fruit into powder form could be useful not only to minimize the post-harvest losses but also to retain the nutritional qualities in the processed products. In view of the above, the main objectives of this study was undertaken to optimized the ingredients and to measure the quality parameters (foam density, foam expansion and foam stability).

Material and methods

Raw material

Banana of the variety Great Naine were procured from local market at Pantnagar, Uttarakhand. Fresh, fully ripened banana at a mature stage of 5, which contained total soluble solids of approximately 23-25ºBrix were selected. The fruits selected were free from physical damage and bruises. For this study, various chemicals such as carboxy methyl cellulose, egg albumin powder and sodium metabisulphite were used in the sample preparation for the drying banana powder and are listed as food grade chemicals.

Sample preparation

The ripe banana were peeled and pre-treated by immersing them in 1% (w/w) sodium metabisulphite for 2min and rinsed them with distilled water for 30s to prevent discoloration. The pre-treated banana were then grinded in a food processor for 1 min to make puree, the ingredients such as egg albumin powder as foaming agent and carboxy methyl cellulose (CMC) as stabilizer at a concentration of 3, 7 and 11% and 0.5, 1.5 and 2.5% respectively were added to the puree and then was whipped by Orpat hand blender for 6, 12 and 18min in order to mix the ingredients uniformly and to incorporate air for foaming. The mixture were then spread evenly on a petridish and dried in a batch type cabinet drier (tray drier) at a temperature of 60, 70 and 80 ºC. The dried samples thus obtained were grinded in grinder to produce the required powder.

Determination of foam density

Foam density was determined by measuring the mass (m) of a fixed volume (V) of the foam and expressed as g/ cm^3 as recommended by Falade *et al.* (2003) [6]

$$Foam\ density = \frac{m}{V} \quad \text{... (1)}$$

Where, m is the mass of the puree (g) and v is the volume of foam puree (ml)

Determination of foam expansion

Foam expansion was determined by comparing the volume of puree and volume of corresponding foamed puree according to the method described by Rajkumar *et al.* (2007) [12]. Foam expansion was calculated using the following relationship:

$$Foam\ expansion = \left[\frac{V_1 - V_0}{V_0}\right] \times 100 \quad \text{... (2)}$$

Where, V_0 is the initial volume of puree, ml^3 and V_1 is the volume of foam, ml^3.

Determination of foam stability

Foam stability of mango pulp was determined by taking 100 ml of the foamed pulp in a transparent graduated beaker and kept at room temperature for 3 hours. The reduction in foam volume was measured as an index for the foam stability for every 30 minutes by using the following relationship (Akiokato *et al.*, 1983) [13].

$$Foam\ stability = V_0 \frac{\Delta t}{\Delta V} \quad \text{... (3)}$$

Where, ΔV is the change in volume of foam occurred during the time interval Δt and V_0 is the volume of the foam at zero time.

Experimental Design

Four independent parameters namely carboxy methyl cellulose (X_1), egg albumin (X_2), temperature (X_3) and whipping time(X_4) were selected for the study based on the literature review and preliminary experiment conducted. The Box-Behnken designs (BBD) of response surface methodology with four levels were used for the study. The process was optimized on the basis of four input variables whose interactions were studied as four major responses. On the basis of preliminary single factor experiments the levels of input variables were determined and are as follows: concentration of egg albumin: 3, 7 and 11% (w/w), concentration of carboxy methyl cellulose: 0.5, 1.5 and 2.5% (w/w), temperature: 60, 70 and 80^0 C, whipping time: 6, 12 and 18 min. Twenty nine runs were carried out to select the best combination of input variables which could result in most suitable form. The test factors were coded according to the following equation:

$$x_i = \frac{X_i - X_0}{\Delta X_i} \times 100 \quad \text{..(4)}$$

where,
x_i = dimensionless value of an independent variable,
X_i = level or value of controllable factor *i* in original units of measurement,
X_0 = midpoint of the range of values for factor *i*,
ΔX_i = range of values over the factor *i* will vary.

Low and high levels of each factor were coded as –1 and +1 keeping 0 as mid-point. Since the various responses were the result of various interactions of independent variables, therefore the following second order polynomial regression equation was fitted to the experimental data of all responses.

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum_{x-1}^{j=1} \sum_{j=2}^{k} \beta_{ij} X_i X_j + \in \quad \text{... (5)}$$

where,
y = predicted response, β_0 = a constant, β_i = linear coefficient, β_{ii}= squared coefficient, β_{ij}= interaction coefficient, X_i and X_j are the independent variables and ∈ is noise or error.

Statistical analysis

Full second order model was fitted in various responses and independent variables using least square regression analysis. Regression analysis and analysis of variance (ANOVA) was used for fitting the models represented by Equation (5) and also to examine the statistical significance of the model terms. The coefficient of determination (R^2) and Fisher's F-test were used to test the adequacy of the model at 1% and 5% level of significance. If the model was adequate, then the effect of independent variables on responses were interpreted. Design-Expert 8.0.7.1 software was used for optimization of added ingredients and temperature based on the powder properties.

Results and Discussion

Effect of influencing factors that is carboxy methyl cellulose, egg albumin, temperature and whipping time on the responses (foam density, foam expansion and foam stability) were determined and statistically analyzed. Experimental design along with different value of responses has been shown in Table 1 and results of regression analysis shown in Table 2 are discussed in details as under.

Table 1: Experimental design along with their responses value for the development of foamed banana powder.

Expt No.	Coded Levels				Responses	
	CMC, %(X_1)	EA, %(X_2)	T, ºC(X_3)	WT, min(X_4)	FD (g/ml)	FE (%)
1	-1	-1	0	0	0.405	147.15
2	1	0	0	-1	0.516	93.86
3	0	0	0	0	0.38	143.13
4	1	1	0	0	0.392	155.25
5	-1	1	0	0	0.379**	162.68*
6	0	0	-1	1	0.396	152.84
7	1	0	1	0	0.43	132.63
8	0	0	0	0	0.423	146.35
9	0	0	0	0	0.428	136.63
10	0	1	-1	0	0.388	157.6
11	1	-1	0	0	0.794*	26.02**
12	0	-1	0	-1	0.597	67.49
13	0	0	0	0	0.393	131.32
14	0	-1	1	0	0.508	97.04
15	0	1	0	-1	0.422	136.8
16	0	1	0	1	0.392	155.36
17	0	0	1	1	0.402	148.95
18	0	0	1	-1	0.438	128.53
19	1	0	-1	0	0.442	126.17
20	-1	0	0	-1	0.454	120.49
21	0	0	-1	-1	0.441	126.9
22	1	0	0	1	0.449	122.94
23	0	-1	0	1	0.615	62.56
24	-1	0	-1	0	0.399	150.41
25	-1	0	1	0	0.382	155.28
26	-1	0	0	1	0.392	160.16
27	0	-1	-1	0	0.525	90.48
28	0	0	0	0	0.41	143.11
29	0	1	1	0	0.391	156
* Maximum, ** Minimum, CMC= Carboxy Methyl Cellulose, EA= Egg Albumin, T= Temperature, WT= Whipping Time, FD= Foam Density and FE= Foam Expansion						

Table 2: Result of regression analysis of foamed banana powder.

Cons.	Foam density		Foam expansion	
	Coeff.	P (%)	Coeff.	P (%)
	0.41	0.01*	140.11	0.01*
X_1	0.051	0.06*	-19.93	0.01*
X_2	-0.09	0.01*	36.07	0.01*
X_3	-0.00333	77.9	1.17	73.39
X_4	-0.018	13.47	10.73	0.67*
X_1X_2	-0.094	0.04*	28.45	0.02*
X_1X_3	0.00125	95.15	0.4	94.67
X_1X_4	-0.00125	95.15	-2.65	65.72
X_2X_3	0.005	80.79	-2.04	73.2
X_2X_4	-0.012	56.16	5.87	33.16
X_3X_4	0.00225	91.28	-1.38	81.66
X_1^2	0.02	23.56	-2.33	61.92
X_2^2	0.066	0.09*	-19.66	0.08*
X_3^2	-0.017	30.55	6.4	18.43
X_4^2	0.030	8.25***	-11.84	2.17**
R^2	90.07		93.84	
F	9.0681 (1% 3.698)		15.223 (1% 3.698)	
LOF	NS		NS	
*,** and *** Significant at 1, 5 and 10% level of significance respectively Coeff. = Coefficient, NS= Non significant, Cons.= Constant, LOF= Lack of Fit X_1= Carboxy methyl cellulose, X_2 = Egg albumin, X_3 = Temperature and X_4 = Whipping time				

Effect of influencing factors on foam density

It was recognized that as the concentration of egg albumin increased, the foam density decreased, indicating higher air bubble cooperation. As the mixing time increased, the foam density increases; but if it was mixed beyond the ability of foam to hold the air bubbles, the foam collapsed causing stiffness of the foam, resulting in higher foam density. Also at the higher concentration of carboxy methyl cellulose, the solution becomes too viscous and observed that high viscosity liquid prevent the trapping of air during whipping. The effect of influencing factors at linear, quadratic and interaction levels are shown in Table 3. The effects on foam density of all influencing factor at linear and quadratic level were highly significant at 1% level of significance (p<0.01), while for interactive it was significant at p<0.05, as their F_{cal} was greater than F_{tab}.

Table 3: ANOVA for foam density

Source	DF	SS	MS	F_{cal}
Model	14	0.206929	0.014781	9.0681*
Linear	4	0.13224	0.03306	20.282*
Quadratic	4	0.03904	0.0098	6.0123*
Interactive	6	0.03571	0.00595	3.65**
Error	14	0.022811	0.00163	
Total	28	0.2297		

*, ** and *** Significant at 1, 5 and 10% level of significance respectively

The analysis was done by means of Fisher's 'F'-test and the results of the regression analysis on foam density is given in Table 2. The model was found highly significant with F-value 9.0681 which is greater than F_{tab} (3.698) at 1%. Regression analysis revealed that the coefficient of determination (R^2) for the regression model of foam expansion was 0.9007, which implies that the model could account for 90.07% data. R^2 -adj (0.8014) value was observed to be relatively close to R^2 (0.9007) value, it ensures a relatively satisfactory adjustment of the quadratic model to the experimental data. The lack of fit was found non-significant for the model hence the model can be used to navigate the design. Significant predictive equation for foam density (g/ml) is given below

$$Y= 0.41+0.051X_1-0.09X_2-0.094X_1X_2+0.066X_2^2+0.03X_4^2 \quad ... (6)$$

Where Y is foam density (g/ml), X_1, X_2, X_3 and X_4 are coded variables for carboxy methyl cellulose, egg albumin, temperature and whipping time.

Graphical analysis of foam density

At linear level Fig. 1, shows the effect of carboxy methyl cellulose on foam density at optimum values of egg albumin 0.8% (10.2%), temperature 1% (80 ºC) and whipping time 1% (18min) and was observed that foam density increases with increase in regressor of carboxy methyl cellulose. From Fig. 2, shows the effect of egg albumin on foam density at optimum value of carboxy methyl cellulose 1% (2.5%), temperature 1% (80 ºC) and whipping time 1% (18min). It was found that foam density decreases with increase in regressor of egg albumin. Minimum foam density was found due to the effect of egg albumin. Fig. 3 shows the effect of whipping time on foam density at optimum values of carboxy methyl cellulose 1% (2.5%), egg albumin 0.8% (10.2%) and temperature 1% (80 ºC). The foam density slightly decreases with increase in regressor of whipping time at the centre point and after it, little increment was found at the higher level of whipping time. Fig. 4 exhibit the variation of foam density with carboxy methyl cellulose and egg albumin at optimum point of temperature 1.0% (80º ºC) and whipping time 1% (18min.) at interactive level of the model. The foam density of banana foam decreased with increase in the level of egg albumin from -1(3%) to 1(11%) while the foam density increases with increase in the level of carboxy methyl cellulose. Maximum foam density was found at the highest level (0.794g/ml) of 2.5% of carboxy methyl cellulose.

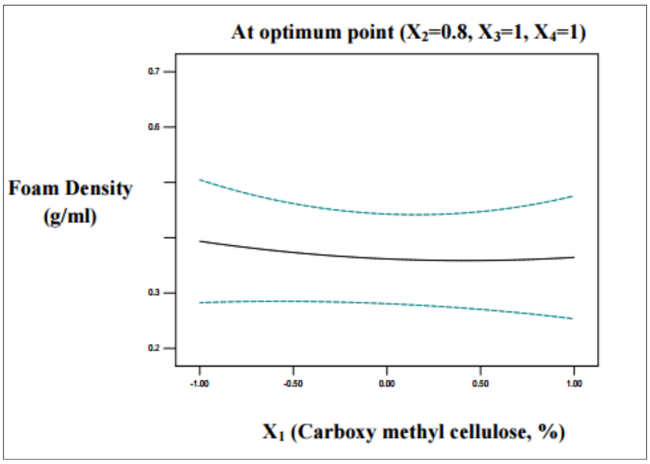

Fig 1: Effect of Carboxy methyl cellulose (%) on Foam density (g/ml)

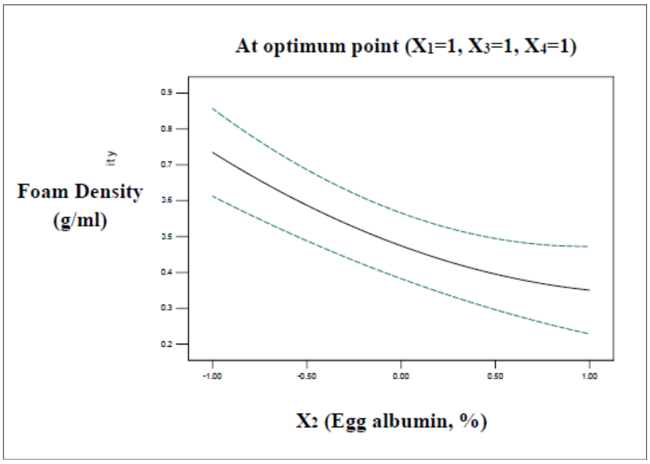

Fig 2: Effect of Egg albumin (%) on Foam density (g/ml)

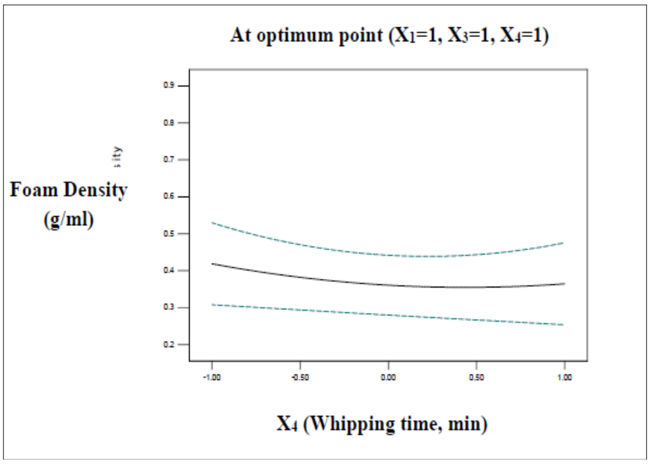

Fig 3: Effect of Whipping time (min) and Foam density (g/ml)

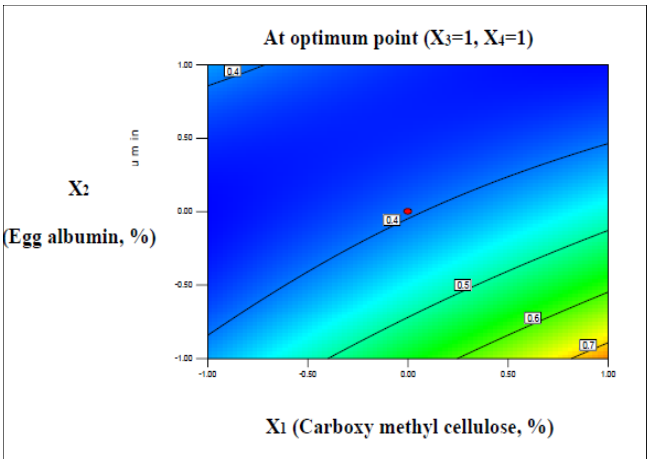

Fig 4: Variation of Foam density (g/ml) with Egg albumin (%) and Carboxy methyl cellulose (%)

Effect of influencing factors on foam expansion

It was observed from the study that the egg albumin and whipping time was responsible for foam expansion. Foam expand more with higher concentration of egg albumin, allowing air bubble corporation. It was also observed that the increase in foam expansion occurs by increasing the whipping operation and after that it causes stiffness of the foam and become almost constant or decreasing. Higher concentration of carboxy methyl cellulose decreases the foam expansion due to the thickening of the banana foam preventing incorporation of air while whipping. The effect of influencing factors were analyzed by using ANOVA (analysis of variance) appropriate for the experimental design used and shown in Table IV. It was reported that the effects on foam expansion of all influencing factor at linear and quadratic level were highly significant 1% level of significance ($p<0.01$), while for interactive it was significant at $p<0.05$.

Table 4: ANOVA for foam expansion.

Source	DF	SS	MS	F_{cal}
Model	14	29066.39	2076.171	15.223*
Linear	4	21781.12	5445.28	41.763*
Quadratic	4	3716.79	929.198	6.813*
Interactive	6	3427.36	571.23	4.188**
Error	14	1909.374	136.3838	
Total	28	30975.76		

*, ** & *** Significant at 1, 5 and 10% level of significance respectively

The fit of the model was also expressed by the coefficient of regression R^2, which was found to be 0.9384 indicating that 93.84% the variability in the response could be explained by the model. The closer the value of *R* (correlation coefficient) to 1, the better is the correlation between the experimental and predicted values. Here the value of R^2(0.9384) being close to 1 indicated a close agreement between the experimental results and the theoretical values predicted by the model equation. R^2 -adj (0.8767) value was observed to be relatively close to R^2 (0.9384) value, it ensures a relatively satisfactory adjustment of the quadratic model to the experimental data. The model was found to be highly significant (p<0.01) as F_{cal} value (15.223) was greater than F_{tab} (3.698) at 1% level of significance.

Significant predictive equation for foam expansion (%) is given below

$$Y=140.11-19.93X_1+36.07X_2+10.73X_4+28.45X_1X_2-19.66X_2^2-11.84X_4^2 \quad \ldots (7)$$

Where Y is foam expansion (%), X_1, X_2, X_3 and X_4 are coded variables for carboxy methyl cellulose, egg albumin, temperature and whipping time.

Graphical analysis of foam expansion

It was observed that foam expansion decreases with increase in regressor of carboxy methyl cellulose. The effect of egg albumin on foam expansion at linear level was shown in Fig. 5 at optimum value of carboxy methyl cellulose 1% (2.5%), temperature 1% (80º ⁰C) and whipping time 1% (18min), shows. It was observed that foam expansion increases with increase in regressor of egg albumin. Maximum foam expansion was found due to the effect of egg albumin. Fig. 6 at linear level shows the effect of whipping time on foam expansion at optimum values of carboxy methyl cellulose 1% (2.5%), egg albumin 0.8% (10.2%) and temperature 1% (80 ºC). It was noticed that the foam expansion increases with increase in regressor of whipping time. Fig. 7 at linear level shows the effect of whipping time on foam expansion at optimum values of carboxy methyl cellulose 1% (2.5%), egg albumin 0.8% (10.2%) and temperature 1% (80 ºC). Fig. 8 shows the variation of foam expansion with carboxy methyl cellulose and egg albumin at optimum point of temperature 1.0% (80 ºC) and whipping time 1% (18min.) at interactive level of the model. The foam expansion of banana foam increases with increase in the level of egg albumin from -1(3%) to 1(11%) while the foam expansion decreases with increase in the level of carboxy methyl cellulose. Maximum foam expansion was found at the highest level (162.6%) of 11% of egg albumin.

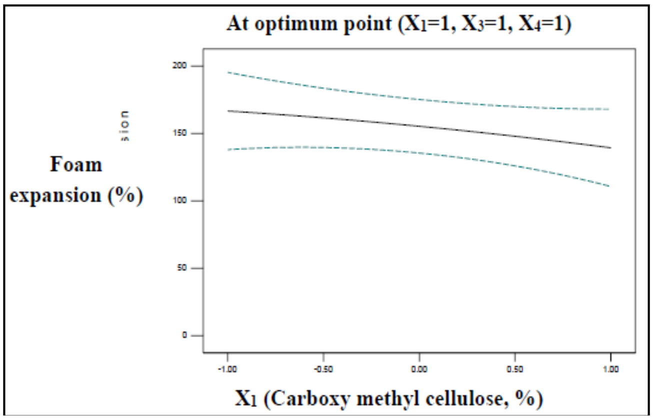

Fig 5: Effect of Carboxy methyl cellulose (%) on Foam expansion (%)

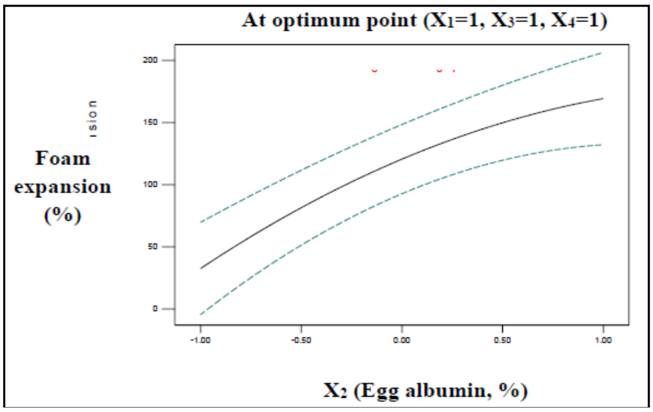

Fig 6: Effect of Egg albumin (%) on Foam expansion (%)

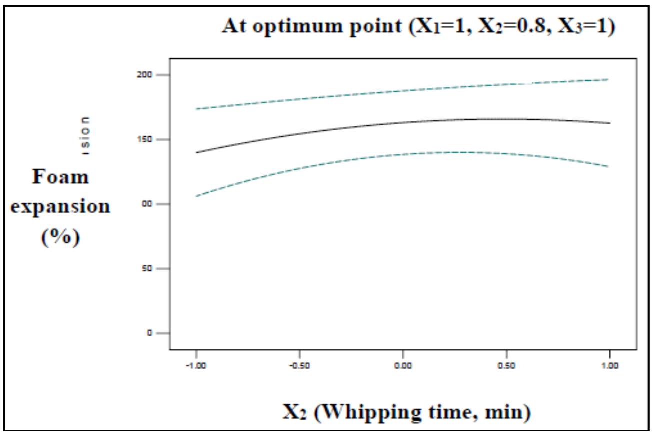

Fig 7: Effect of Whipping time (min) on Foam expansion (%)

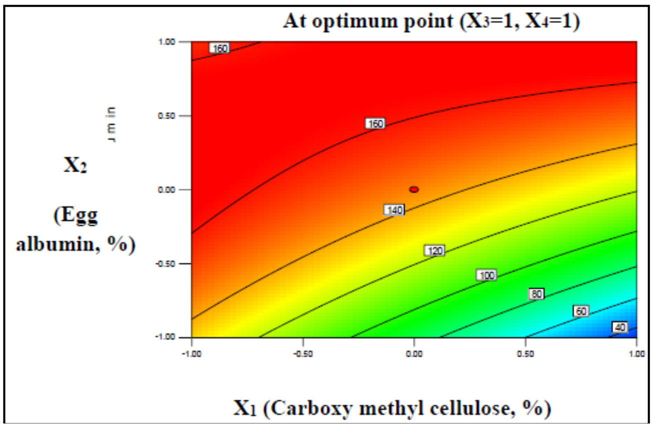

Fig 8: Variation of Foam expansion (%) with Egg albumin (%) and Carboxy methyl cellulose (%)

Conclusion

The study shows that the foam density ranges from 0.379 to 0.794 g/ml while foam expansion ranges from 26.02 to 162.6%. It was observed that foam density increases with increase in the concentration of carboxy methyl cellulose from 0.5 to 1.5% and decreases with increase in egg albumin. Lower density values provide a greater contact surface area exposed to the drying air which accelerates faster removal of water. The study also observed that increase in carboxy methyl cellulose results in improper foaming and uneven mixing, change in colour, leathery texture until drying continue till constant moisture content (7%) is obtained, difficult to remove from the foil and are tough in grinding. While increase egg albumin gives proper foaming and mixing, does not change colour, easily remove from the foil and easy in grinding because of its porous structure. Foam expansion show decreasing trend with increase in the concentration of carboxy methyl cellulose (0.5-2.5%) and increases with increase in egg albumin (3 to 11%) and whipping time (6-18min). Whipping time of 18min was not desirable because the foam collapse due to higher air corporation. Foam stability were maintained for longer time due to its porous network like structure during the drying process, thereby sustaining the banana foam to longer retention time for the faster water evaporation. Optimization level of influencing process parameters obtained by optimization of responses were carboxy methyl cellulose (X_1) as 2.5%, egg albumin (X_2) as 10.2%, temperature (X_3) 80 $^{\circ}$C as and whipping time (X_4) as 18min. Therefore Box behnken design of Response Surface Methodology was successfully used in optimization of ingredients for the production of foamed banana powder. Thus the study focus and widen the horizon on the view of combination of foaming and drying process inorder to produce a quick and efficient heat transfer, reduced loss of nutrients, low and economic utilisation of temperature.

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