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Different Foaming Properties of Papaya Pulp

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Abstract:
Papaya (*Carica papaya* L.) is a tropical fruit. It's importance in fruit crops due to its medicinal and high nutritional value. The papaya, papaw or pawpaw is the fruit of the plant *Carica papaya,* in the genus Carica. The botanical name of papaya is *Carica papaya* L. belong to the family *Caricaceae.* There is discussion in the research paper regarding different foaming properties of papaya pulp. It was concluded by the Design Expert Software (*Ver. 13*), the optimum condition obtained for the foam mat drying were: concentration of whey protein isolate 10% (w/w), concentration of glycerol monostearate 4% (w/w) and whipping time 20 min, at maximum desirability. The foaming properties at optimum condition as foam expansion, foam density and foam stability was observed as 74.76%, 0.512 g/cc and 98%, respectively.

Keywords: Foaming properties, Foam expansion, Foam density, Foam stability

I. INTRODUCTION

Papaya (*Carica papaya* L.) is a tropical fruit. In India it is widely popular. This fruit having importance because of its medicinal and high nutritional value. The papaya, papaw or pawpaw is the fruit of the plant *Carica papaya,* in the genus Carica. Papaya, botanically known as *Carica papaya* belong to the family *Caricaceae*. Papaya is the most economically important fruit in the *Caricaceae* family.

It is native to the tropics of the Americas, and was first cultivated in Mexico several centuries before the emergence of the Mesoamerican classic cultures. Brazil is the biggest producer of the papaya; it is supplying 25% of the world demand. The other followed by Mexico at 14%, Nigeria at 11%, India & Indonesia at 10%. The Venezuela, China, Peru, Congo and Ethiopia are also papaya growing nations. (Shashikalabai *et al.,* 2016).

The botanical classification of papaya is given according in the table below:

Table 1: Botanical classification of papaya

No.	Classification	Name
1	Domain	*Flowering plant*
2	Kingdom	*Plantae*
3	Subkingdom	*Tracheobionta*
4	Class	*Magnolipsida*
5	Subclass	*Dilleniidae*
6	Division	*Magnoliophyta*
7	Superdivision	*Spermatophyta*
8	Phyllum	*Steptophyta*
9	Order	*Brasssicales*
10	Family	*Caricaceae*
11	Genus	*Carica*
12	Botanical name	*Carica papaya L.*

Papaya is a rich source of three antioxidant vitamin C, vitamin A and vitamin E. Papaya is well known for its exceptional nutritional and medicinal properties throughout the world. Ripe papaya is eaten fresh, after cleaning out the outer skin and the inner seeds of fruit. Generally, they are cut in small pieces and mixed with other fruits for a fruit salad. When papaya that is not completely ripe, it can be cut in pieces and cooked with sugar and eaten as dessert.

The value added products from papaya are papaya juice, papaya snacks/desserts, papaya milk shake, papaya medicine, ice-cream, jam, jellies, papaya candy and papaya pickles.
In foreign and local markets, the demand for dehydrated papaya is demanding rapidly, with the majority of it being utilized to prepare convenience foods. Because of this, better methods of processing and preserving this crucial crop need to be developed. From this investigation, drying is an acceptable approach since it reduces the volume and also transportation costs, allowing for the delivery of a high-quality product at an affordable price. Thus, farmers will be able to maximize their harvest and production. Therefore, in this view, drying is the most appropriate and relatively inexpensive approach to meet the needs (Mozumder *et al.,* 2012).
Among various methods of preservation, foam mat drying is an alternate technique to mitigate the post-harvest losses and enhance keeping quality. Foam mat drying is one of the simple techniques of drying where liquid concentrate is transformed into suitable foam with the help of foaming agents. Foam mat drying is an appropriate method for heat sensitive and thick materials as compared to drum and spray drying due to better reconstitution property of final dried material. In this research paper, we have discussed about different foaming properties *viz.* foam expansion, foam density and foam stability, which are important for the foaming of the pulp. The study was conducted to develop process technology for foam mat drying of papaya using protein rich source whey protein isolate (foaming agent) and glycerol monostearate as foam stabilizer.
Argade *et al.* (2026) stated that foam mat drying is a promising technique for producing shelf-stable, high-quality fruit powders, particularly from heat-sensitive, viscous, and underutilized fruits. This review critically examines the roles and effectiveness of food-grade foaming agents, including proteins, carbohydrates, and hydrocolloids, in enhancing foam formation, stability, and overall drying efficiency. Protein-based agents *viz.* whey protein isolate, soy protein isolate and egg albumin provide excellent foam expansion and structural integrity. Carbohydrate-based compounds such as pectin, maltodextrin and modified starch primarily function as stabilizers, improving viscosity and nutrient retention. Hydrocolloids-based agents *viz.* carboxymethyl cellulose, methylcellulose, xanthan gum and guar gum further strengthen foam structure. Synergistic combinations of these foaming and stabilizing agents significantly improve powder quality, solubility, and preservation of bioactive compounds. Despite advancements, key challenges remain, including the development of novel, plant-based and allergen-free alternatives, limited application to underutilized fruits, and a lack of techno-economic and environmental sustainability assessments. This study provides a framework to guide future research and industrial applications aimed at optimizing foam mat drying for value-added, efficient and sustainable fruit processing. Therefore, in this research paper, I will have discussed about foam mat drying properties *viz.* foam expansion, foam density and foam stability using whey protein isolate, as a foaming agent and glycerol monostearate as a foam stabilizer.

II. MATERIALS AND METHODS

The experiments of different foaming properties of papaya pulp were conducted during the doctoral research work under the discipline of processing & food engineering. The different foaming properties of foamed papaya pulp *viz.* foam expansion, foam density and foam stability. It was procured Greenberry variety of papaya from the local market of the Anand, Gujarat, India, for conducting the experiments of different foaming properties of papaya pulp. Now, in materials and methods, I will be discussing for experimental design of foam mat drying of foamed papaya pulp. The experimental design was used CCRD (Central Composite Rotatable Design) for framing the experiments.

Experimental Design for Foam Mat Drying

Whey protein isolate (WPI) was selected as foaming agent and glycerol monostearate (GMS) was selected as stabilizer. The concentration of whey protein isolate (5, 10, 15, 20 and 25% w/w) with concentration of glycerol monostearate (1, 2, 3, 4 and 5% w/w) and whipping time (5, 10, 15, 20 and 25 min) were selected for find out the foaming properties *viz.* foam expansion, foam density and foam stability.

Table 2 : Following set of experiments were planned and conducted for foam mat drying experiments

Treatment no.	Concentration of whey protein isolate, % (w/w)		Concentration of glycerol monostearate, % (w/w)		Whipping time, min	
	Coded	Uncoded	Coded	Uncoded	Coded	Uncoded
1	-1	10.00	-1	2.00	-1	10.00
2	1	20.00	-1	2.00	-1	10.00
3	-1	10.00	1	4.00	-1	10.00
4	1	20.00	1	4.00	-1	10.00
5	-1	10.00	-1	2.00	1	20.00
6	1	20.00	-1	2.00	1	20.00
7	-1	10.00	1	4.00	1	20.00
8	1	20.00	1	4.00	1	20.00

9	-1.68	6.6	0	3.00	0	15.00
10	1.68	23.4	0	3.00	0	15.00
11	0	15.00	-1.68	1.3	0	15.00
12	0	15.00	1.68	4.7	0	15.00
13	0	15.00	0	3.00	-1.68	6.6
14	0	15.00	0	3.00	1.68	23.4
15	0	15.00	0	3.00	0	15.00
16	0	15.00	0	3.00	0	15.00
17	0	15.00	0	3.00	0	15.00
18	0	15.00	0	3.00	0	15.00
19	0	15.00	0	3.00	0	15.00
20	0	15.00	0	3.00	0	15.00

PROCEDURE

It was required to arrange the laboratory base small device to take the experiment of foaming of the pulp. Therefore, a laboratory scale foaming device was developed to produce foam from papaya pulp. It consists an air pump, portable hand blender and cylindrical vessel having diameter 22 cm and height 23.50 cm. A transparent cylindrical plastic vessel was used for keeping the pulp. Air pump (M/s. Sobo, Model : SB-988, China) having 3 air nozzles at flow rate 4 lit/min per nozzle for flowing air in the cylinder. The nozzles were kept about 120°C angular distance for maintaining uniformity. The Thompson portable hand blender (M/s. Vishal Home Appliances, Mumbai, India) was taken for proper mixing of air with the pulp. Controlled rate of compressed air flow rate 0.012 m^3 per minute was introduced at the bottom of vessel and started blender.

Development of Foam

The 300 ml of sample was taken into the vessel of foaming device. Based on preliminary experiments for formation of foam, also added along with predetermined quantity of foaming agents according to Table 2. Controlled rate of compressed air flow rate was introduced at the bottom of vessel and started portable hand blender. After predetermined time period, air flow and rotation of whipping blade were stopped simultaneously.

Foaming Properties: Foaming properties such as foam expansion, foam density and foam stability were determined at different concentration of foaming agents with different whipping time.

(i) Foam expansion

Foam expansion of sample was calculated from the volume of papaya pulp before and after whipping using following formula reported by Durian (1995).

$$\text{Foam Expansion (\%)} = \frac{\text{Final volume of foam,cc} - \text{Initial volume of pulp,cc}}{\text{Initial volume of pulp,cc}} \times 100$$

…(1)

(ii) Foam density

The density of foamed sample was calculated in terms of mass by volume (g/cm^3) by Falade *et al.* (2003).

$$\text{Foam density (g/cc)} = \text{density of pulp, g/cc} \times \left[\frac{\text{Initial volume of pulp, cc}}{\text{Final volume of pulp, cc}}\right]$$

…(2)

(iii) Foam stability

Foam stability of sample was calculated by keeping sample in a transparent beaker and kept for 3 hours. The reduction in foam volume was measured for foam stability for every 30 min. The stable foam after 1 h was considered as mechanically and thermally stable foams for entire drying period (Kundra & Ratti, 2006). Foam stability was determined by using following formula:

$$\text{Foam stability (\%)} = \left[\frac{\text{Volume of foam at 180 min, cc}}{\text{Initial volume of foam including the liquid volume without foaming, cc}}\right] \times 100$$

…(3)

III. Results and Discussion

Analysing Responses for Foaming Properties

Responses of foaming properties *viz.* foam expansion, foam density and foam stability to changes in independent variables (whey protein isolate, glycerol monostearate and whipping time) are shown in Table 3. The ability of a full second order model to connect response variation with independent factors was evaluated. Three-dimensional response surfaces (Fig.1-9) were generated in Design Expert Software to help visualize response variance in relation to processing factors (design expert - *Ver. 13*).

Table 3: Foaming properties with different combination of treatments

Treat Ment No.	Concentration of whey protein isolate, % (w/w)		Concentration of glycerol monostearate, % (w/w)		Whipping time, min		Foam expansion	Foam density	Foam stability
	Coded	Uncoded	Coded	Uncoded	Coded	Uncoded	(%)	(g/cc)	(%)
1	-1	10.00	-1	2.00	-1	10.00	33.92	0.67	94.44
2	1	20.00	-1	2.00	-1	10.00	63.93	0.54	95.00
3	-1	10.00	1	4.00	-1	10.00	24.51	0.71	97.72
4	1	20.00	1	4.00	-1	10.00	55.91	0.57	98.27
5	-1	10.00	-1	2.00	1	20.00	52.59	0.57	96.66
6	1	20.00	-1	2.00	1	20.00	39.34	0.63	98.03
7	-1	10.00	1	4.00	1	20.00	78.28	0.49	98.38
8	1	20.00	1	4.00	1	20.00	69.35	0.53	98.41
9	-1.68	6.60	0	3.00	0	15.00	38.41	0.70	97.61
10	1.68	23.40	0	3.00	0	15.00	55.59	0.57	98.30
11	0	15.00	-1.68	1.30	0	15.00	31.84	0.68	97.82
12	0	15.00	1.68	4.70	0	15.00	46.51	0.63	98.03
13	0	15.00	0	3.00	-1.68	6.60	32.76	0.67	95.74
14	0	15.00	0	3.00	1.68	23.40	58.98	0.54	98.00
15	0	15.00	0	3.00	0	15.00	58.19	0.56	96.42
16	0	15.00	0	3.00	0	15.00	61.02	0.55	96.49
17	0	15.00	0	3.00	0	15.00	63.84	0.54	96.55
18	0	15.00	0	3.00	0	15.00	58.19	0.56	96.42
19	0	15.00	0	3.00	0	15.00	61.02	0.55	96.49
20	0	15.00	0	3.00	0	15.00	63.84	0.54	96.55

(i) Foam Expansion

Foam expansion of papaya pulp ranged from 24.51% to 78.28%. The maximum expansion was 78.28% at coded point (-1, 1, 1) and the minimum expansion was 24.51% at coded point (-1, 1, -1) shown in Table 3. The average value of foam expansion was found 52.40%. The results of the regression analysis and ANOVA for foam expansion are shown in Table 4.

The calculated F-value for foam expansion was 13.54, which was statistically significant ($p<0.05$). A P-value less than 0.05 indicates that the associated model terms are significant. R^2 and adjusted R^2 values of the model are 0.9242 and 0.8559 respectively, suggesting a good fit. The adequate precision value of 14.0922 indicates that the model can be used to predict the response within the design space as it is greater than 4.0 (Montgomery, 2001). Additionally, the coefficient of variation (CV) for foam expansion was 10.46%, indicating that the experimental results were consistent and reliable (Table 4).

Considering the criteria, following response model was selected for representing the variation of foam expansion for the further analysis.

$$\text{Foam expansion} = 60.75+4.99x_1+4.59x_2+7.72x_3+0.7137x_1x_2-10.45x_1x_3+9.14x_2x_3-3.03x_1^2-5.71x_2^2-3.43x_3^2 \quad ...(4)$$

Following observations can be made from Table 4 and Eq. 4. The coefficients of is x_1, x_2 and x_3 are positive. Therfore, increase in whey protein isolate, glycerol monostearate and whiping time may increase foam expansion of papaya pulp. The coefficient of model terms x_1x_2 and x_2x_3 are positive, it may be due to interaction effect of whey protein isolate with glycerol monostearate and glycerol monstearate with whipping time. The coefficient of model terms x_1x_3 is negative, it indicates that the foam expansion may decrease with the combined effect of whey protein isolate and whipping time. The coefficient of model terms x_1^2, x_2^2 and x_3^2 are negative. It shows that the least and excessive amounts of whey protein isolate, glycerol monostearate and whipping time may decrease the foam expansion.

Table 4: Analysis of variance for foam expansion for papaya pulp

Source	Co-efficient of model terms	Sum of squares	df	Mean Square	F Value	Prob>F
Model***		3661.58	9	406.84	13.54	0.0002
Constant	60.75					
x_1	4.99	339.81	1	339.81	11.31	0.0072
x_2	4.59	289.94	1	289.94	9.65	0.0111
x_3	7.72***	813.24	1	813.24	27.07	0.0004
x_1x_2	0.7137	4.08	1	4.08	0.1356	0.7203
x_1x_3	-10.45***	873.41	1	873.41	29.07	0.0003
x_2x_3	9.14***	668.50	1	668.50	22.25	0.0008
x_1^2	-3.03	132.11	1	132.11	4.40	0.0624
x_2^2	-5.71**	486.74	1	486.74	16.20	0.0024
x_3^2	-3.43*	169.27	1	169.27	5.63	0.0390
Complete model						
Regression		3661.58	9	406.84	13.54	0.0002
Lack of Fit		268.53	5	53.71		
Pure Error		31.92	5	6.38		
Residual		300.45	10	30.05		
Total		3962.03	19			
R^2		0.9242		Std. Dev.	5.48	
Adjusted R^2		0.8559		Mean	52.40	
Adequate Precision		14.0922		C.V.%	10.46	

Level of Significance: * P<0.05, **P<0.01, *** P<0.001, ns: not significant; df: degrees of freedom

x_1 = why protein isolate, x_2= glycerol monostearate, x_3 = whipping time

Analysis of variance of Eq. 4 shows that F values for interaction term of whey protein isolate and whipping time (x_1x_3) is 29.07 at P values of 0.0003, and glycerol monostearate and whipping time (x_2x_3) is 22.25 at P values of 0.0008, showing that the term is highly significant. F-values for square terms of glycerol monostearate (x_2^2) and whipping time (x_3^2) are 16.20 and 5.63 at P values of less than 0.0024 (P<0.01) and 0.0390(P<0.05), showing that terms x_2^2 and $x_3^2$are significant terms.

It can be observed from Fig. 1 that foam expansion increased with increase in whey protein isolate and glycerol monostearate. It can also have observed from Fig. 1 that foam expansion was rapidly increased at initial up to certain limit than stable with whey protein isolate. Higher foam expansion indicates that more air was trapped in the foam. Kandasamy *et al.,* 2012a was also investigated during foam mat experiment.

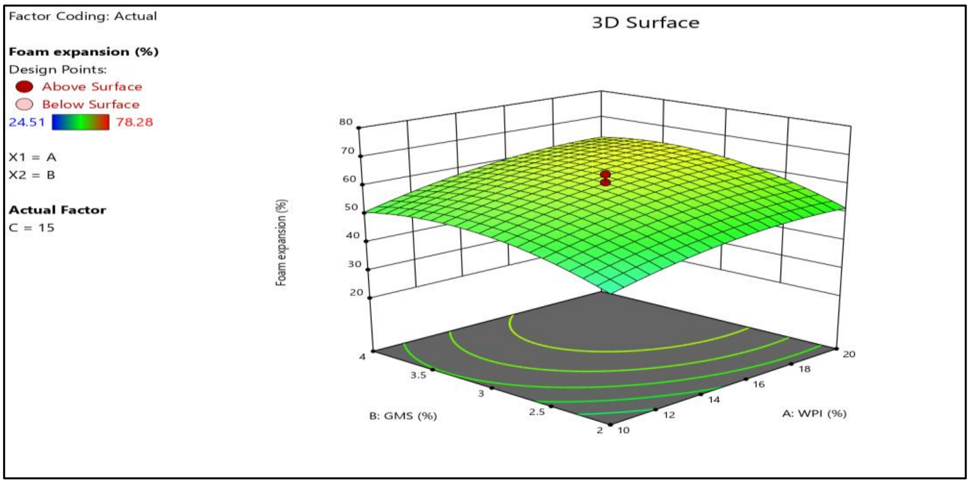

Fig. 1. Variation of foam expansion with respect to whey protein isolate and glycerol monostearate in papaya pulp

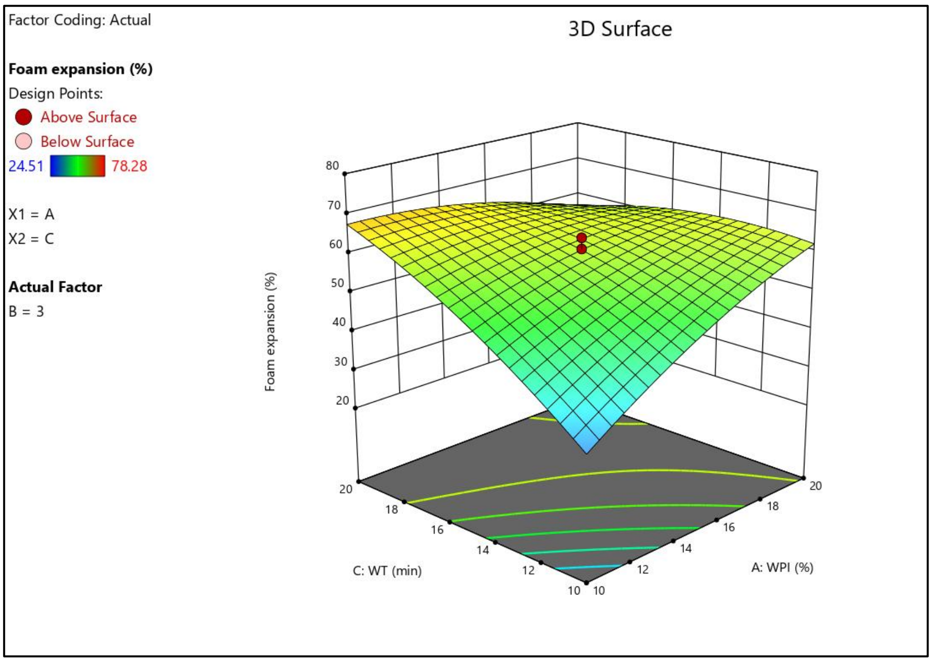

Fig. 2 Variation of foam expansion with respect to whey protein isolate and whipping time in papaya pulp

It can be seen from Fig. 2 that foam expansion increased with increase in whey protein isolate. It can be observed from Fig. 2 that foam expansion increased with increase in whipping time. This may be due to the extended whipping duration allowing more air to be incorporated into the mixture, resulting in greater air entrapment within the foam structure. The continued mechanical agitation during prolonged whipping produced a finer and more stable distribution of air bubbles, thereby enhancing the overall foam volume (Shaari *et al*., 2018). Similar observations were made by (Shaari *et al*., 2018), that increased whipping time in pineapple fruit led to higher foam expansion.

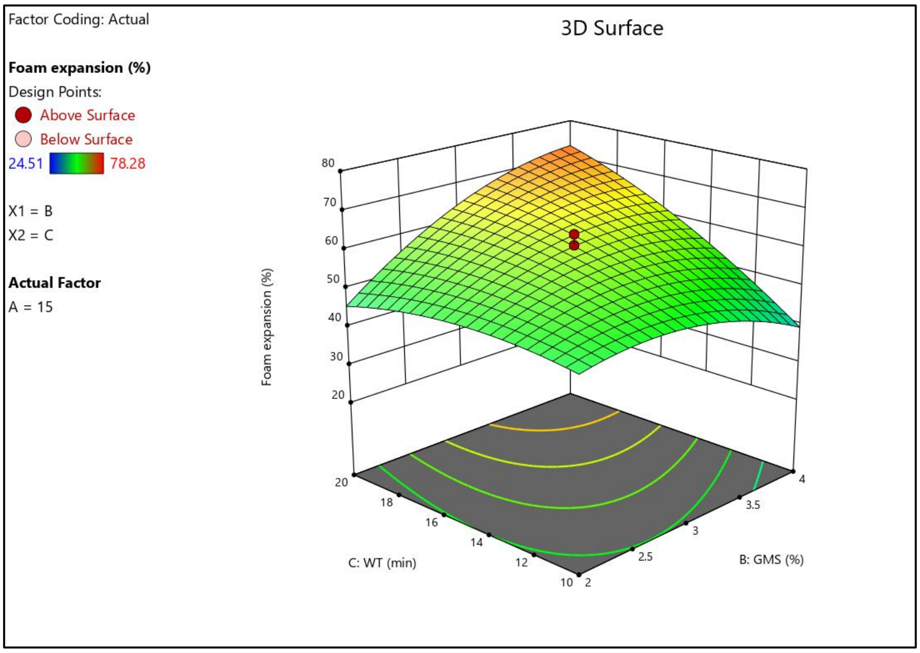

Fig. 3 Variation of foam expansion with respect to glycerol monostearate and whipping time in papaya pulp

It can be observed from Fig. 3 that the foam expansion rapidly increased at initial up to certain limit than it stables with glycerol monostearate. It can also be seen from Fig. 3 that the foam expansion increased with increase in whipping time. At lower concentration of glycerol monstearate, the air bubbles were not stable because the critical thickness is required to create foams. It was investigated by (Kandasamy *et al.,* 2012a) using methyl cellulose as foaming agent.

(ii) Foam Density

The foam density ranged from 0.49 to 0.71 g/cc. The minimum foam density (0.49 g/cc) of papaya pulp was at coded point (-1, 1, 1). The maximum foam density (0.71 g/cc) was at coded point (-1, 1, -1) (Table 3). The average value of foam density was 0.59 g/cc. The coefficient of model and other statistics are given in Table 5.

Table 5: Analysis of variance for foam density for papaya pulp

Source	Co-efficient of model terms	Sum of squares	df	Mean Square	F Value	Prob> F
Model***		0.0717	9	0.0080	9.20	0.0009
Constant	0.5514					
x_1	-0.0285	0.0111	1	0.0111	12.76	0.0051
x_2	-0.0142	0.0028	1	0.0028	3.18	0.1046
x_3	-0.0358	0.0175	1	0.0175	20.18	0.0012
x_1x_2	-0.0037	0.0001	1	0.0001	0.1298	0.7261
x_1x_3	0.0463**	0.0171	1	0.0171	19.75	0.0012
x_2x_3	-0.0312*	0.0078	1	0.0078	9.02	0.0133
$x_1{}^2$	0.0201*	0.0058	1	0.0058	6.69	0.0271
x_2^2	0.0268**	0.0107	1	0.0107	12.33	0.0056
x_3^2	0.0095	0.0013	1	0.0013	1.49	0.2509
Complete model						
Regression		0.0717	9	0.0080	9.20	0.0009
Lack of Fit		0.0083	5	0.0017	20.66	0.0024
Pure Error		0.0004	5	0.0001		
Residual		0.0087	10	0.0009		
Total		0.0804	19			
R^2		0.8922		Std. Dev.	0.0294	
Adjusted R^2		0.7952		Mean	0.5900	
Adequate Precision		10.8863		C.V.%	4.99	

Level of Significance: * P<0.05, **P<0.01, *** P<0.001, ns: not significant; df: degrees of freedom

x_1 = why protein isolate, x_2= glycerol monostearate, x_3 = whipping time

The model F value of 9.20 implies that the model is significant (P<0.05). A P-value less than 0.05 signifies that the related model terms are significant. R^2 and adjusted R^2 values of the model are 0.8922 and 0.7952 respectively, suggesting a good fit. The adequate precision value of 10.8863 indicates that the model can be used to predict the response within the design space as it is greater than 4.0 (Montgomery, 2001). With an adequate precision value of 10.8863, which exceeds the threshold of 4.0 (Montgomery, 2001), the model is considered reliable for predicting variations in foam density within the experimental design. Additionally, the coefficient of variation was 4.99%, indicating that the experimental results for foam density of papaya pulp were consistent and dependable (Table 5).

Considering the criteria, following response model was selected for representing the variation of foam density for the further analysis.

$$\text{Foam density} = 0.5514\text{-}0285x_1-0.0142x_2-0.0358x_3-0.0037x_1x_2+0.0463x_1x_3-0.0312x_2x_3+0.0201x_1^2+0.0268x_2^2+0.0095x_3^2 \quad ...(5)$$

Analysis of variance of Table 5 and Eq. 5 shows that F values for interaction terms of x_1x_3 and x_2x_3 are 19.75 and 9.02 at P values of 0.0012 and 0.0133 respectively, showing that the term x_1x_3 and x_2x_3 are significant term. F-values for square terms of whey protein isolate (x_1^2) and glycerol monostearate (x_2^2) are 6.69 and 12.33 at P values of 0.0271 (P<0.05) and 0.0056 (P<0.01), showing that terms are also significant.

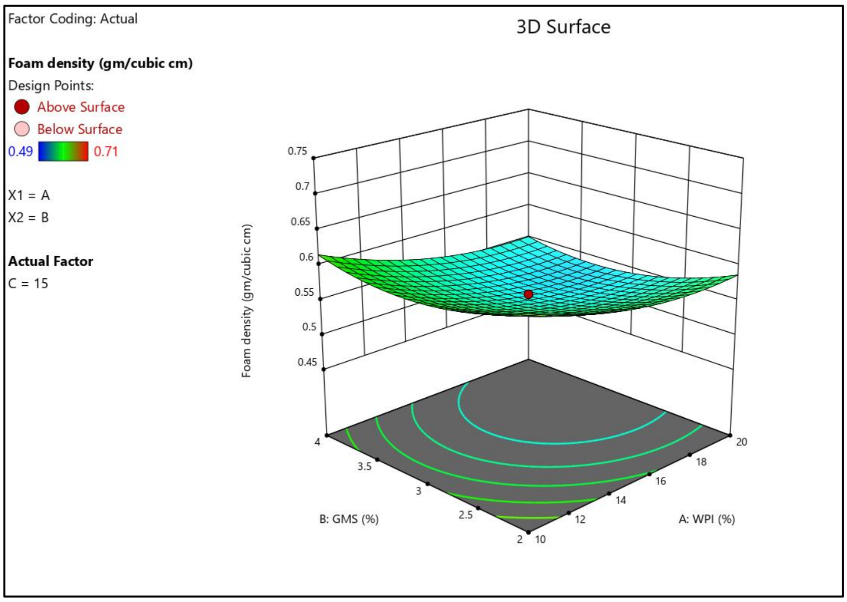

Fig. 4 Variation of foam density with respect to whey protein isolate and glycerol monostearate in papaya pulp

It was observed from Fig. 4 that foam density of papaya pulp decreased with increase in whey protein isolate and glycerol monostearate up to certain value and then after it stable with whey protein isolate and glycerol monostearate. Rajkumar & Kailappan (2006) was observed similar result for mango pulp. As shown in Fig. 4, foam density decreased with increasing whey protein concentration. It may be due to the action of the foaming agent, which migrated to the air-liquid interface, decreased surface tension and expanded the surface area ultimately improving foaming ability and lowering foam density (Shaari *et al*., 2018). A similar trend was analyzed by Shaari *et al*. (2018), who found that foam density in pineapple significantly decreased ($p<0.05$) with increased egg albumin (EA) concentration.

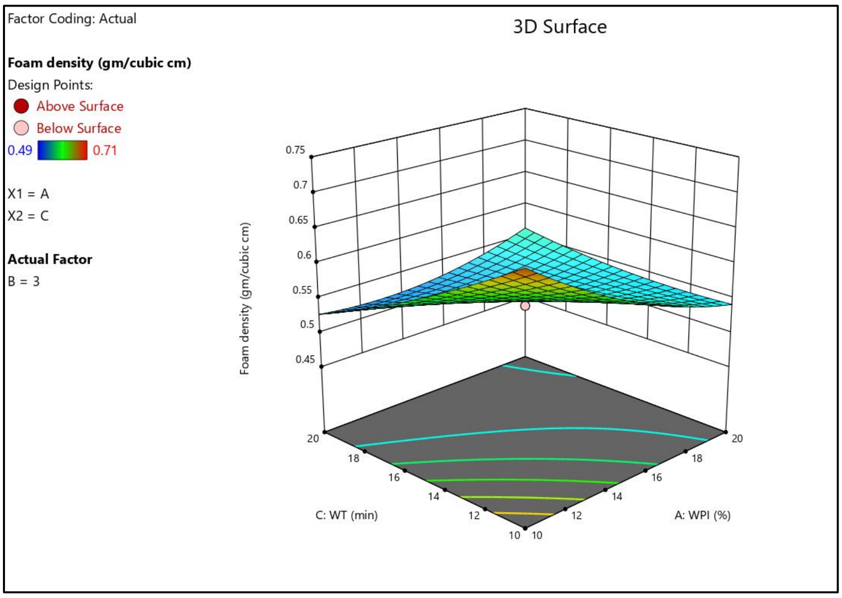

Fig. 5 Variation of foam density with respect to whey protein isolate and whipping time in papaya pulp

It can be seen from Fig. 5 that foam density of papaya pulp decreased with increase in whey protein isolate. Foam density also decreased with increase in whipping time. Reduction in foam density with increasing foaming agent has been also noticed in bael fruit pulp by Bag *et al.,* 2011.

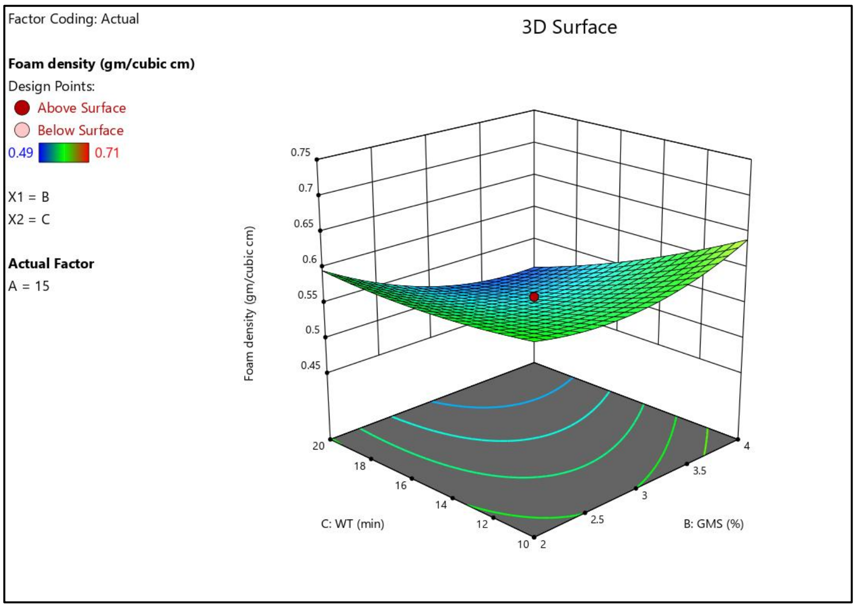

Fig. 6 Variation of foam density with respect to glycerol monostearate and whipping time in papaya pulp

It was observed from Fig. 6 that the foam density of papaya pulp experienced a quadratic effect with respect to glycerol monostearate and whipping time. It can be seen from Fig. 6 that foam density decreased with increase in glycerol monostearate. It can also be observed from Fig. 6 that foam density also decreased with increase in whipping time. Reduction in foam density with increasing foaming agents has also been reported by Shivani *et al.* (2019) in papaya pulp.

(iii) Foam Stability

The minimum foam stability (94.44%) of papaya pulp was observed at coded point (-1, -1, -1). The maximum foam stability (98.41%) was at coded point (1, 1, 1). The average value of foam stability was found 97.07%. The maximum foam stability upto more than 97.00% was also observed at coded point (-1, 1, -1), (1, 1, -1), (1, -1, 1), (-1, 1, 1), (1, 1, 1), (-1.68, 0, 0), (1.68, 0, 0), (0, -1.68, 0), (0, 1.68, 0) and (0, 0, 1.68) (Table 3). The coefficient of model and other statistics are given in Table 6. The model F value of 4.98 implies that the model is significant ($P<0.05$). R^2 and adjusted R^2 values of the model are 0.8175 and 0.6533 respectively, reflecting a good fit. The adequate precision value 7.7533 indicates that the model can be used to predict the response within the design space. An adequate precision value of 7.7533, being higher than the threshold of 4.0 (Montgomery, 2001), confirms the model's capability to predict foam stability within the experimental range. Additionally, the coefficient of variation (CV) was 0.7048%, indicating that the experimental results for foam stability of papaya pulp were accurate and dependable (Table 6).

Table 6: Analysis of variance for foam stability for papaya pulp

Source	**Co-efficient of model terms**	**Sum of squares**	**df**	**Mean Square**	**F Value**	**Prob>F**
Model***		20.97	9	2.33	4.98	0.0097
Constant	96.50					
x_1	0.2689	0.9867	1	0.9867	2.11	0.1771
x_2	0.6536	5.89	1	5.89	12.58	0.0053
x_3	0.7217	7.11	1	7.11	15.18	0.0030
x_1x_2	-0.1687	0.2278	1	0.2278	0.4868	0.5013
x_1x_3	0.0363	0.0105	1	0.0105	0.0225	0.8838
x_2x_3	-0.5562*	2.48	1	2.48	5.29	0.0443
x_1^2	0.4084*	2.39	1	2.39	5.12	0.0472
x_2^2	0.3909	2.28	1	2.28	4.87	0.0518
x_3^2	0.0240	0.0083	1	0.0083	0.0177	0.8968
Complete model						
Regression		20.97	9	2.33	4.98	0.0097

Lack of Fit		4.66	5	0.9326		
Pure Error		0.0169	5	0.0034		
Residual		264.290	10	26.430		
Total		25.65	19			
R^2		0.8175		Std. Dev.	0.6841	
Adjusted R^2		0.6533		Mean	97.07	
Adequate Precision		7.7533		C.V.%	0.7048	

Level of Significance: * P<0.05, **P<0.01, *** P<0.001, ns: not significant; df: degrees of freedom
x_1 = whey protein isolate, x_2 = glycerol monostearate, x_3 = whipping time

$$\textit{Foam stability} = 96.50+0.2689x_1+0.6536x_2+0.7217x_3-0.1687x_1x_2+0.0363x_1x_3-0.5562\,x_2x_3+0.4084x_1^2+0.3909x_2^2+0.0240x_3^2 \quad \text{... (6)}$$

Following observations can be made from Table 6 and Eq. 6. The coefficients of x_1, x_2 and x_3 are positive. Therfore, increase in whey protein isolate, glycerol monostearate and whiping time may increase foam stability of papaya pulp. Analysis of variance of Eq. 6 shows that F values for interaction term of x_2x_3 is 5.29 at P value of 0.0443 (P<0.05), showing that the term x_2x_3 is significant term. The F-values for square terms of whey protein isolate (x_1^2) is 5.12 at P values of 0.0472 (P<0.05), showing that term is also significant.

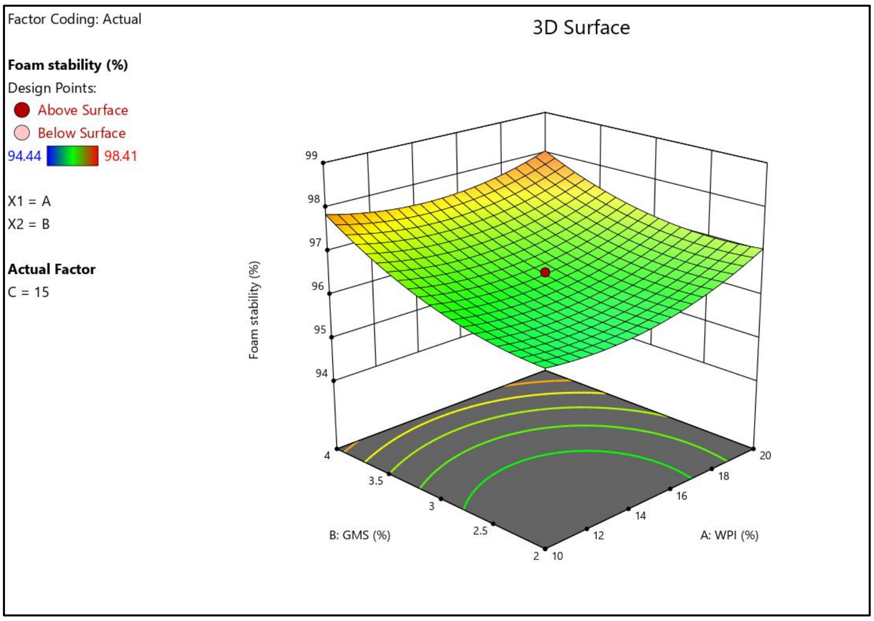

Fig. 7 Variation of foam stability with respect to whey protein isolate and glycerol monostearate in papaya pulp

It can be seen from Fig. 7 that foam stability initially decreased and then increased with increase in whey protein isolate. It can also be observed from Fig. 7 that foam stability increased with increase in glycerol monostearate. According to (Shivani *et al.,* 2019), same result was observed by using glycerol monostearate, foam stability was increased in the foam mat drying of papaya pulp.

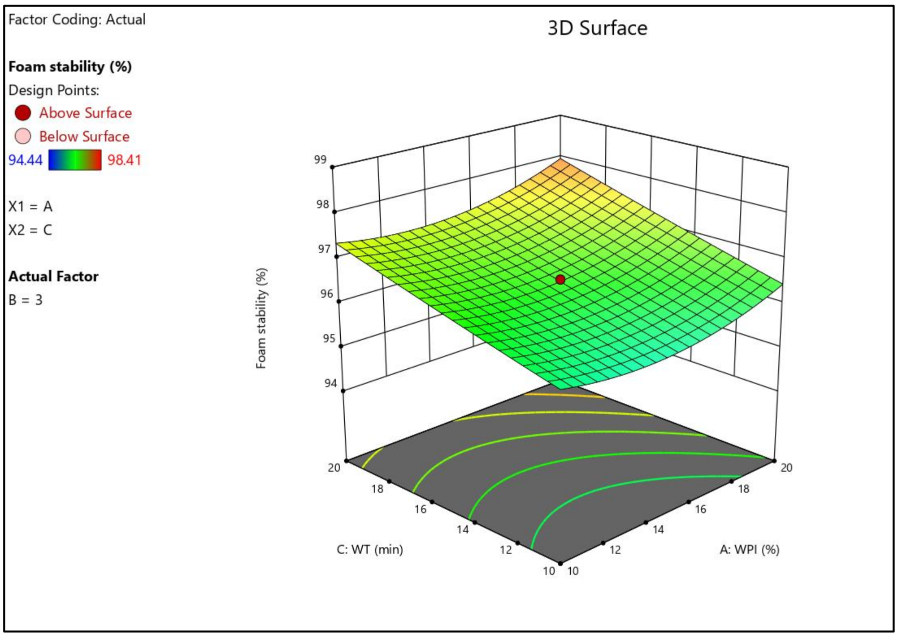

Fig. 8 Variation of foam stability with respect to whey protein isolate and whipping time in papaya pulp

It can be observed from Fig. 8 that foam stability of papaya pulp initially decreased and then increased with increase in whey protein isolate. It can also be seen from Fig. 8 that foam stability was steadily decreased with decreased in whipping time. The increase in stable foam may be due to reduction in surface energy levels between the bubbles created continuously during whipping. Similar increase in foam stability with increase in methyl cellulose was also stated by Kandasamy *et al.,* 2012a.

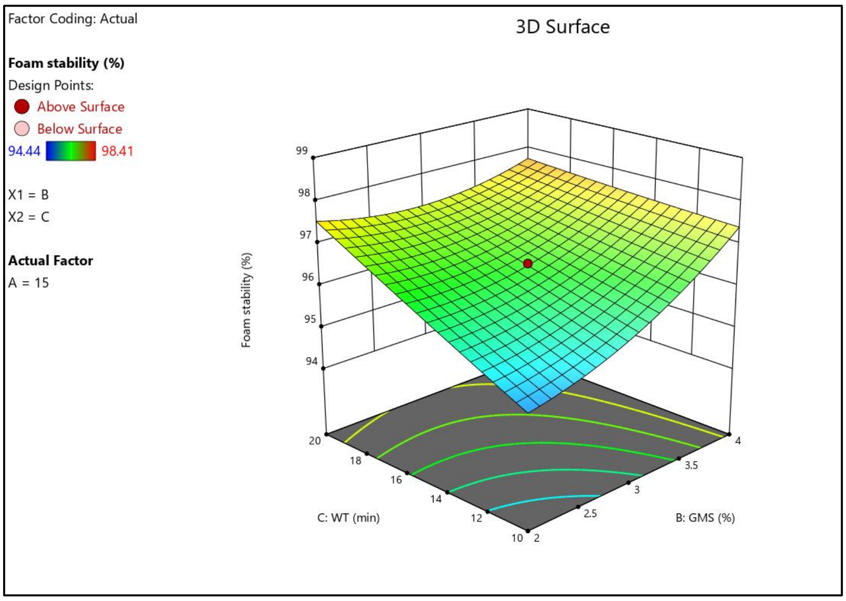

Fig. 9 Variation of foam stability with respect to glycerol monostearate and whipping time in papaya pulp

It can be seen from Fig. 9 that foam stability increased with increase in glycerol monostearate. It can also be observed from Fig. 9 that foam stability was steadily increased with increase in whipping time. Foam stability demonstrated an increasing trend with increasing whipping time, as illustrated in Fig. 9. This enhancement can be attributed to the prolonged whipping process, which allowed for increased air incorporation and promoted protein unfolding at the air-water interface. This, in turn, strengthened the interfacial film and enhanced the overall foam structure. Consequently, the foam became more stable due to the formation of a cohesive and elastic matrix that resisted structural collapse. Similar findings were reported by Kumar *et al*. (2022), who observed that extended whipping time led to improved foam stability in mango pulp, corresponding with increased foam expansion.

IV. CONCLUSIONS

Argde *et al.* (2026) has review critically examines the roles and effectiveness of food-grade foaming agents, including proteins, carbohydrates, and hydrocolloids, in enhancing foam formation, stability, and overall drying efficiency. Protein-based agents *viz.* whey protein isolate, soy protein isolate and egg albumin provide excellent foam expansion and structural integrity. Carbohydrate-based compounds such as pectin, maltodextrin and modified starch primarily function as stabilizers, improving viscosity and nutrient retention. Hydrocolloids-based agents *viz.* carboxymethyl cellulose, methylcellulose, xanthan gum and guar gum further strengthen foam structure. Synergistic combinations of these foaming and stabilizing agents significantly improve powder quality, solubility, and preservation of bioactive compounds. Therefore, according to the Argade *et al.* (2026), it was taken foaming agent as well as foam stabilizer combination conducting the experiments of foaming properties of papaya pulp.

The standardized optimum condition obtained by Design Expert Software *(Ver. 13).* The standardized optimum condition criteria applied for numerical optimization were maximum foam expansion, minimum foam density and maximum foam stability for rapid drying. The optimum condition obtained for the foam mat drying were: concentration of whey protein isolate 10% (w/w), concentration of glycerol monostearate 4% (w/w) and whipping time 20 min, at maximum desirability. The foaming properties at optimum condition as foam expansion, foam density and foam stability was observed as 74.76%, 0.512 g/cc and 98%, respectively.

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