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## Optimization of foaming and stabilizing process parameters for foam mat drying of prickly pear (*Opuntia elatior* Mill.) pulp

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**Abstract**

Foaming of prickly pear pulp was carried out by using foaming agent and foaming stabilizer for drying in thin layer. Whey protein isolate was used as foaming agent and methyl cellulose was used as foaming stabilizer. Based on preliminary trials pectin (0.375%, w/w) was added as thickener and stabilizer. The effect of three foaming parameters viz., foaming agent (2.5, 5.0, 7.5, 10.0 and 12.5%, w/w), foaming stabilizer (0.0, 0.125, 0.250, 0.375 and 0.5%, w/w) and whipping time (5, 10, 15, 20 and 25 min) were optimized on maximum foam expansion, maximum foam stability and minimum foam density of prickly pear pulp using response surface methodology. The optimum foaming conditions were found to be 5.36% foaming agent, 0.50% foaming stabilizer and 12.08 min whipping time. At this condition, it would be possible of foaming properties of prickly pear pulp with a foam expansion of 405.28%, foam stability of 81.25% and foam density of 0.25 g/cc.

**Keywords:** Foaming parameters, prickly pear, *Opuntia elatior* Mill., foam mat drying

**Introduction**

Prickly pear or cactus pear is a wild fruit that grows under arid and semiarid conditions and the fruit is harvested from diverse species of the prickly pear cactus, genus *Opuntia* of the cactus family (Cactaceae). Cactaceae family is properly tailored to arid and semiarid climates, in which water is a restricting factor for cultivation. These fruits are recognized as an important source of vitamins for local people at the natural growth sites of the plant. This folklore medicinal plant, broadly obtainable inside the state of Gujarat is thought as "Hathlo thore", botanically recognized as *Opuntia elatior* Mill. It is discovered that each cactus in India did now no longer belong to one species, however to a few species dispensed over distinctive areas in India. *Opuntia dillenii* Haw is found in particular with inside the southern region of the India at the same time as *O. vulgaris* Mill. (*Syn Opuntia monacantha* Haw.) is found particularly with inside the northern parts; *O. Elatior* Mill. is being reported in western India. Among them, *O. elatior* is available in Saurashtra region of Gujarat (Patel *et al.*, 2015) [8].

Cactus pear could be very specific for the presence of betalain, an extensively used herbal colorant with inside the food industry (Piga, 2004) [9]. Unfortunately, cactus fruits have a brief shelf life from 3–4 weeks, therefore restricting long-time period storage and global distribution. Typically, a high pH value which varies from 5.3 to 7.1 is found, and the very low acidity (0.05-0.18% citric acid equivalents) compromises prolonged fruit storage (Sepulveda and Sáenz, 1990) [12]. Foam mat drying is a method via way of means of which liquid or semi-stable foods are whipped to form foam with inside the presence of foaming and/or stabilizing agents. The foam is then spread in a thin layer and dried in a warm air stream (Rajkumar *et al.*, 2007; Thuwapanichayanan *et al.*, 2008) [11, 13]. Foam mat drying is considered cheaper than vacuum, spray and freeze drying for the production of food powders (Kadam *et al.*, 2010) [5]. Prickly pear fruits are wealthy in betalains, taurine, minerals and antioxidants and hence suits properly in health-promoting trend. Hence, it's far taken into consideration and are anticipated a promising future crop for commercial food applications. Foam mat drying has been successfully applied for many fruit crops like mango, banana, guava, apple, sapota and papaya. However, application of foam mat drying of prickly pear pulp is not reported, therefore the investigation was carried out to optimize foaming process parameters for foam mat drying of prickly pear pulp.

## Materials and methods

### Extraction of pulp, selection of foaming agents and whipping time

The ripened prickly pear (*Opuntia elatior* Mill.) fruits were procured from the local market of Junagadh, Gujarat. The prickly pear fruit is not commercially cultivated but it is found on boundary of farms and in uncultivated land. Due to this fact, variety of collected fruit was unknown. The fully ripe fresh, bright red and purple colour fruits, without any visual defects, were selected for the experimental work. The longitudinally cut fruit was then scooped out with spoon. The scooped pulp consisting of both, pulp and seeds was blended using blender at low speed for 5-10 seconds just for separation of seed from pulp. The whole mixture of blended pulp and seed was then transferred to a domestic sieve having sieve size of 8 mesh for the separation of seeds from the pulp. The pure pulp without any seeds was finally used in the further foaming process.

Prickly pear foam was made by using whey protein isolate (WPI) and methyl cellulose (MC) as foaming agent and foaming stabilizer, respectively within the limits stipulated in the Prevention of Food Adulteration Act 1955 of the Government of India and based on preliminary foaming tests conducted (Rajkumar *et al.* 2007) [11]. The concentration levels of whey protein isolate were ranges between 2.5-12.5% (w/w) with concentration of methyl cellulose was 0.0-0.5% (w/w) for whipping time of 5-25 min. Three variable (five levels of each variable) central composite rotatable experimental design was prepared for the study (Table1) using Design Expert version 10.0.8 (Trial version; STAT-EASE Inc., Minneapolis, MN, USA)

### Foaming of ripe prickly pear pulp

The 150g of pulp was taken into plastic vessel. Based on preliminary experiments pectin (0.375%, w/w) was added along with predetermined quantity of foaming agent and foaming stabilizer. Controlled rate of compressed air flow rate (4 lit/min per nozzle) was introduced at the bottom of vessel and blending of pulp was carried out. After pre-determined whipping time air flow rate and blending was stopped simultaneously.

## Foaming properties

### Foam expansion

Foam expansion gave the percentage increase in volume of the prickly pear pulp. Foam expansion indicates the amount of air incorporated into the pulp during whipping was calculated using the difference in the volume of pulp before and after

foaming as described by Durian (1995) [12],

$$\text{Foam expansion (\%)} = \left[ \frac{\text{Final volume of foam, cm}^3 - \text{Initial volume of pulp, cm}^3}{\text{Initial volume of pulp, cm}^3} \right] \times 100$$

### Foam Stability

Foam stability of prickly pear pulp was recorded by taking of foamed pulp in a transparent graduated beaker and kept for 3 h. The reduction in foam volume was recorded 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 (Kudra and Ratti, 2006) [7]. Foam stability was determined by using following formula,

$$\text{Foam expansion (\%)} = \left[ \frac{\text{Final volume of foam, cm}^3 - \text{Initial volume of pulp, cm}^3}{\text{Initial volume of pulp, cm}^3} \right] \times 100$$

### Foam density

The foam density prickly pear pulp was determined in terms of mass-to-volume ratio (g/cc) by Falade *et al.* (2003) [10].

$$\text{Foam stability(\%)} = \left[ \frac{\text{Volume of foam at 180 min, cm}^3}{\text{Initial volume of foam including the liquid volume without foaming, cm}^3} \right] \times 100$$

## Results and Discussion

### Foam expansion

Maximum foam expansion was observed in treatment number 18. During this treatment maximum foam expansion was 410.00%. In this treatment concentration of foaming agent, foaming stabilizer and whipping time was 7.5%, 0.25% and 15 min, respectively. Minimum foam expansion (290.00 %) was observed in treatment number 14. In this treatment, foaming agent, foaming stabilizer and whipping time was 7.5%, 0.25% and 25 min (Table1). From Table 2, it can be seen that, whipping time showed negative linear effect with significant at  $p < 0.05$ . The quadratic effect of foaming agent and whipping time were significantly negative at  $p < 0.001$ .

The calculated F, R<sup>2</sup>, Adj-R<sup>2</sup>, Pred. R<sup>2</sup> and Adeq. Precision values for foam expansion were 9.96, 0.8996, 0.8092, 0.4077 and 8.52, respectively indicating the adequacy, good fit and high significance of the model. The small value of coefficient of variation (4.42%) for foam expansion explained that the experimental results were precise and reliable.

The derived model giving the empirical relation between the foam expansion and the test variables in coded units was obtained as under:

$$\text{Foam expansion} = 390.41 - 2.55 A + 18.93 B - 3.29 C - 9.23 AB - 4.31 AC - 9.91 BC - 15.62 A^2 - 8.44 B^2 - 20.95 C^2$$

**Table 1:** Experimental data for foaming properties of prickly pear pulp

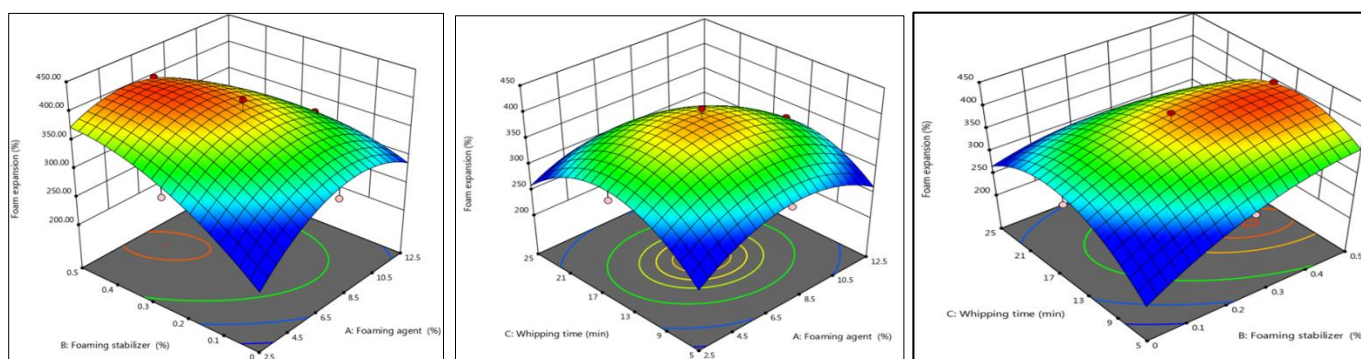
Run	Treatment	Uncoded variables			Responses		
		Foaming agent (%)	Foaming stabilizer (%)	Whipping time (min)	Foam expansion (%)	Foam stability (%)	Foam density (g/cc)
1	12	7.5	0.500	15	396.12	70.37	0.27
2	9	2.5	0.250	15	316.00	51.67	0.26
3	17	7.5	0.250	15	383.26	59.33	0.27
4	6	10.0	0.125	20	343.67	52.14	0.30
5	8	10.0	0.375	20	336.33	60.63	0.31
6	15	7.5	0.250	15	386.67	59.32	0.27
7	1	5.0	0.125	10	324.12	58.57	0.25
8	3	5.0	0.375	10	393.33	81.25	0.24
9	19	7.5	0.250	15	373.33	58.28	0.27
10	20	7.5	0.250	15	387.00	59.00	0.27
11	7	5.0	0.375	20	374.33	67.71	0.26
12	14	7.5	0.250	25	290.00	55.50	0.35
13	13	7.5	0.250	5	306.67	73.57	0.33
14	2	10.0	0.125	10	340.26	54.90	0.32

15	16	7.5	0.250	15	385.67	64.68	0.31
16	11	7.5	0.000	15	300.67	42.21	0.30
17	18	7.5	0.250	15	410.00	64.00	0.25
18	5	5	0.125	20	350.67	53.22	0.27
19	4	10	0.375	10	366.67	69.70	0.32
20	10	12.5	0.250	15	323.33	52.00	0.34

**Table 2:** Analysis of variance (ANOVA) and regression coefficients for response surface quadratic model of different foaming properties of prickly pear pulp

Source	Foam expansion	Foam stability	Foam density
Intercept	390.41	61.48	0.27
Linear terms			
A(X <sub>1</sub> )	-2.55	-1.42	0.0238
B(X <sub>2</sub> )	18.93	7.30***	-0.0038
C(X <sub>3</sub> )	-3.29*	-4.18*	0.0012*
Interaction terms			
AB(X <sub>1</sub> X <sub>2</sub> )	-9.23	-1.74	0.0025
AC(X <sub>1</sub> X <sub>3</sub> )	-4.23	-0.8814	-0.0075
BC(X <sub>2</sub> X <sub>3</sub> )	-9.91	-1.81	0.0000
Quadratic terms			
A <sup>2</sup> (X <sub>1</sub> <sup>2</sup> )	-15.62***	-1.88	0.0055
B <sup>2</sup> (X <sub>2</sub> <sup>2</sup> )	-8.44	-0.7638	0.0017
C <sup>2</sup> (X <sub>3</sub> <sup>2</sup> )	-20.95***	1.30	0.0142**
Indicators for model fitting			
R <sup>2</sup>	0.8996	0.9057	0.8935
Adj-R <sup>2</sup>	0.8092	0.8209	0.8046
Pred-R <sup>2</sup>	0.4077	0.4096	0.4012
Adeq Precision	8.5228	12.4739	7.4707
F-value	9.96	10.68	5.18
Lack of fit	NS	NS	NS
C.V. %	4.42	6.31	6.24

A or X<sub>1</sub>= Foaming agent, B or X<sub>2</sub>= Foaming stabilizer, C or X<sub>3</sub>= Whipping time, \*\*\*Significant at  $p < 0.001$ , \*\*Significant at  $p < 0.01$ , \*Significant at  $p < 0.05$ , NS = Non-significant.



**Fig 1:** Effect of foaming agent, foaming stabilizer and whipping time on foam expansion

It was observed that foam expansion increased up to certain increase of foaming agent and then it slightly decreased. The Fig.1a indicated that the increase in foam expansion as the foaming agent was increased up to 6.31% and foaming stabilizer up to 0.43%. The foam expansion at this combination was proposed to be increased up to 404.89%. With further increase in foaming agent beyond 6.31%, the foam expansion was decreased. This might be due to saturation point of foaming agent solubility under experimental conditions. Similar results were also reported by Kandasamy *et al.* (2012) [6] for foam expansion in papaya pulp. The Fig.1b showed the increase in foam expansion with an increase in foaming agent and whipping time up to 7.32% and 14.64 min, respectively. With further increase in foaming agent and whipping time, the foam expansion of pulp was found to be decreased. The possible reason is that expansion of foams increased with whipping time up to a maximum and decreased thereafter probably because excessive whipping (overbeating) could cause foam to collapse. The interaction

effect (Fig.1c) showed the increase in foam expansion with an increase in foaming stabilizer up to 0.42% and with an increase in whipping time up to 12.89 min. With further increase in whipping time, the foam expansion decreased. Similar findings were also reported by Raharitsifa *et al.* (2006) [10] on foam mat drying in apple juice foams.

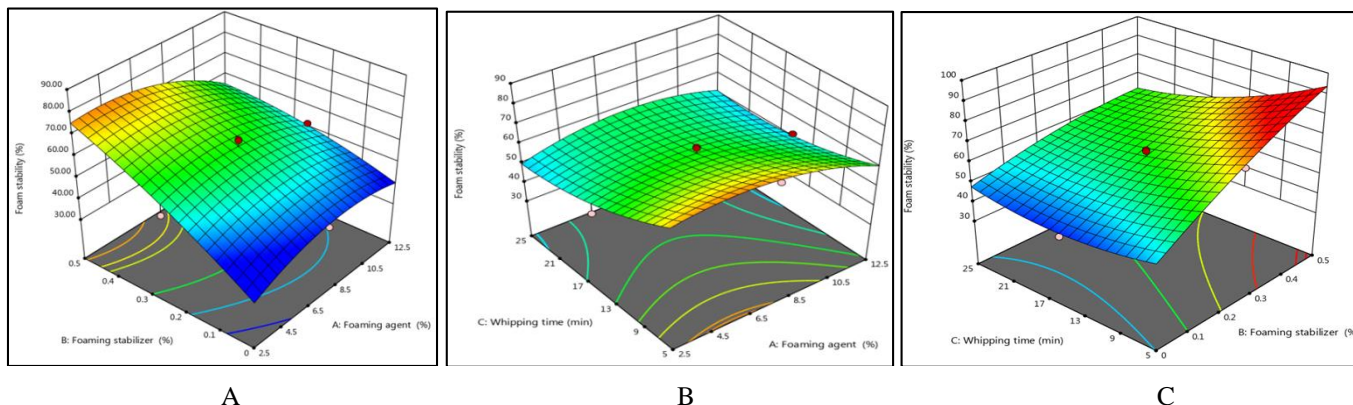
### Foam stability

During experiments maximum foam stability i.e. 81.25% was observed in treatment number 3. In this treatment concentration of foaming agent, foaming stabilizer and whipping time were 5.0%, 0.375% and 10.00 min, respectively. Also, minimum foam stability i.e. 42.21% was observed in treatment number 11. In this treatment level of foaming agent, foaming stabilizer and whipping time were 7.5%, 0.00% and 15.00 min, respectively (Table 1). From Table 2, it can be seen that, foaming stabilizer indicated significantly linear effect at  $P < 0.001$  and while whipping time indicated significantly negative linear effect at  $P < 0.05$  on



foam stability. All interaction and quadratic term were also found non-significant on foam stability of prickly pear pulp. The calculated F,  $R^2$ , Adj- $R^2$ , Pred.  $R^2$  and Adeq. Precision values for foam stability were 10.68, 0.9057, 0.8209, 0.4096 and 12.47, respectively indicating the adequacy, good fit and high significance of the model. The small value of coefficient

of variation (6.31%) for foam stability explained that the experimental results were precise and reliable. The derived model giving the empirical relation between the foam expansion and the test variables in coded units was obtained as under.



**Fig 2:** Effect of foaming agent, foaming stabilizer and whipping time on foam stability

$$\text{Foam stability} = 61.48 - 1.42 A + 7.30 B - 4.18 C - 1.74 AB + 0.8814 AC - 1.81 BC - 1.88 A^2 - 0.7638 B^2 + 1.30 C^2$$

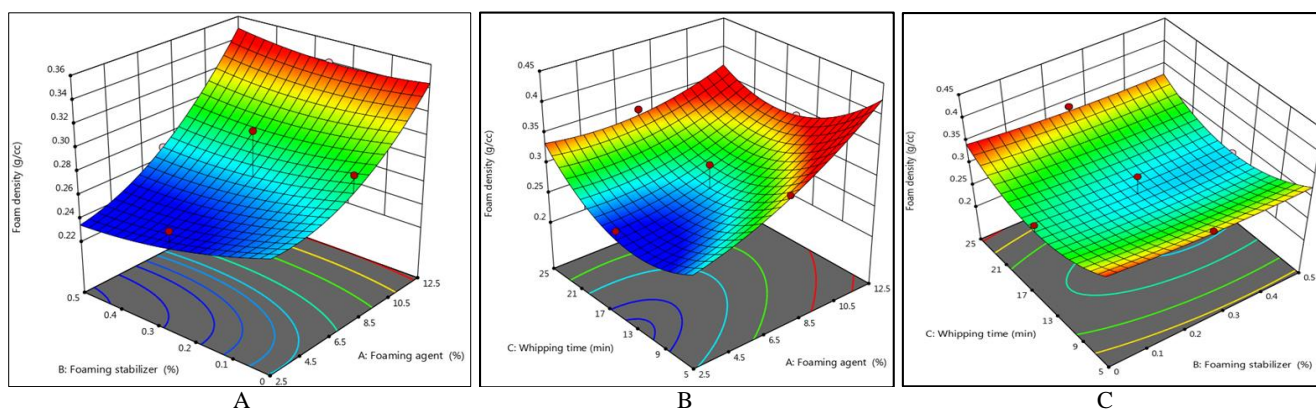
Where, A, B and C are the coded factors of foaming agent, foaming stabilizer and whipping time, respectively.

The foam stability was greatly influenced by foam stabilizer. It was observed that foam stability increased as concentration of foam stabilizers increased. The response surface curve (Fig. 2a) indicated that the increased in foam stability as the foaming agent was increased up to 4.04% and foaming stabilizer up to maximum limit of 0.5%. The foam stability at this combination was proposed to be increased up to 76.14%. With further increase in foaming agent, the foam stability of prickly pear pulp decreased up to its maximum level. The Fig. 2b showed that the increased in foam stability with an increased in foaming agent up to 5.44% and whipping time up to minimum limit of 5.0 min, respectively. At this combination of foaming agent and whipping time, the foam stability of prickly pear pulp was expected to be increased up to 76.34%. With further increase in foaming agent and whipping time, the foam stability of pulp was found to be decreased. In Fig. 2c the interaction effect showed the increase in foam stability with an increase in foaming stabilizer up to its maximum limit of 0.5% and whipping time up to its minimum limit 5.0 min. With further increase in

whipping time, the foam stability of pulp decreased. Similar result for foam stability was also reported by Kandasamy *et al.* (2012) [6] for papaya powder.

### Foam density

During experiment foam density of prickly pear pulp varied from 0.24 to 0.35 g/cc (Table 1). Maximum foam density i.e. 0.35 g/cc was obtained in treatment number 14. In this treatment concentration level foaming agent, foaming stabilizer and whipping time were 7.50%, 0.25% and 25 min, respectively. Minimum foam density i.e. 0.24 g/cc was found in treatment number 3. In this treatment concentration level of foaming agent, foaming stabilizer and whipping time were 5.0%, 0.375% and 10 min, respectively. It can be seen from the Table 2 that, whipping time showed positive linear significant effect at  $p < 0.05$  while interaction of all three terms shows non-significant. The quadratic effect of whipping time was found significant positive effect at  $p < 0.01$ , respectively. The calculated F,  $R^2$ , Adj- $R^2$ , Pred.  $R^2$  and Adeq. Precision values for foam stability were 5.18, 0.8953, 0.8046, 0.4012 and 7.47, respectively indicating the adequacy, good fit and high significance of the model. The small value of coefficient of variation (6.24%) for foam density explained that the experimental results were precise and reliable.



**Fig 3:** Effect of foaming agent, foaming stabilizer and whipping time on foam density

The derived model giving the empirical relation between the foam expansion and the test variables in coded units was obtained as under:

$$\text{Foam density} = 0.2709 + 0.0238A - 0.0038B + 0.0012C + 0.0025AB - 0.0075AC + 0.0000BC + 0.0055A^2 + 0.0017B^2 + 0.0142C^2$$

Where, A, B and C are the coded factors of foaming agent, foaming stabilizer and whipping time, respectively.

Foam density displayed low when more air is incorporated into foam during whipping. The response surface curve (Fig 3a) indicated that the decrease in foam density as the foaming agent was increased up to its minimum limit of 2.5% and foaming stabilizer up to its maximum limit of 0.50%. The foam density at this combination was proposed to be decreased up to 0.23g/cc. With further increase in foaming agent, the foam density of pulp increased. The Fig. 3b showed the decreased in foam density with an increase in foaming agent up to its minimum level of 2.50% and whipping time upto 12.34 min. At this combination of foaming agent and whipping time, the foam density of pulp was expected to be reduced up to 0.24 g/cc. With further increase in foaming agent and whipping time, the foam density of pulp was found to be increased. The interaction effect (Fig. 3c) showed the decrease in foam density with an increase in foaming stabilizer up to 0.39% and whipping time up to 14.78 min. At this combination of foaming stabilizer and whipping time, the foam density of pulp was projected to be reduced up to 0.27 g/cc. With further increase in whipping time, the foam density of pulp increased. This might be due to the bubbles not stable at lower foaming agent concentration because the critical thickness required for the interfacial film cannot be formed and the sudden increase in foam density might be due to bubble collapse and mechanical deformation during increased whipping time. Similar results were reported by Bag *et al.* (2011) <sup>[1]</sup> in bael pulp and Falade and Okocha (2012) <sup>[4]</sup> in plantain.

### Optimization and validation

The responses obtained from the foaming of prickly pear pulp were optimized using Design Expert software for maximum foam expansion, maximum foam stability and minimum foam density for creation of stable foams during drying operations. Optimization was carried out by keeping equal importance and by constraining independent variables within the range. The optimized foaming parameters were: 5.36% whey protein isolate, 0.50% methyl cellulose and 12.08 min whipping time. These optimum conditions obtained in the model were used for further drying of foamed prickly pear pulp. The analysis showed that at this combination of foaming agent, foaming stabilizer and whipping time, it would be possible to obtain foaming properties of prickly pear pulp with a foam expansion of 405.28%, foam stability of 81.25% and foam density of 0.25 g/cc. The experiment value analysis showed that at this combination of foaming agent, foaming stabilizer and whipping time, foaming properties of prickly pear pulp was foam expansion of 400.21% with a deviation of 1.25%, foam stability of 79.47% with a deviation of 2.19% and foam density of 0.24 g/cc with a deviation of 4.00%.

### Conclusion

For this study, whey protein isolate was used as foaming agent and methyl cellulose as foaming stabilizer. Initially pectin was added (0.375%, w/w) as additional stabilizer and thickener to reduce drain volume from prickly pear pulp foam. Using response surface method, the optimized values

were found to be 5.36% of whey protein isolates, 0.50% methyl cellulose and 12.08 min of whipping time.

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