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Optimization of Vacuum Impregnation Conditions Using Response Surface Methodology for soaking of *pantoa*

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Abstract
Vacuum impregnation (VI) is a new technology which has significant advantages over conventional soaking of food product. An attempt was made to optimize the conditions for VI of pantoa. *Pantoa* was fried at the optimized sub-baric frying conditions (122 °C for 360 s at 200 mm Hg vacuum). Sub-baric fried *pantoa* balls were soaked in sugar impregnation unit having sugar syrup concentration of 40, 50 and 60 ºBrix at room temperature for 3, 5 and 7 min. The sugar syrup of 40, 50 and 60 ºBrix was prepared by mixing 40, 50 and 60 parts of crystalline sugar in 60, 50 and 40 parts of portable water, respectively. The face-centered central composite design consisting of 13 runs used for the optimization of VI conditions of *pantoa*. The response surface models developed in this study for predicting overall acceptability, expansion ratio, sugar content, hardness and chewiness. The conditions for VI were optimized at 55°C for 6 min at 32± 2 ºC temperature. VI helped to reduce soaking time to a great extent as compared to soaking time required for conventional method (2-4 h)

Key wards: Vacuum impregnation, *Pantoa* and sub-baric frying

Introduction

Soaking is the process of rehydration of dried or fried food products, which imparts characteristic body and texture to final product. Rehydration typically composes of three simultaneous processes, absorption of water into fried material, swelling of the rehydrated products and leaking of soluble. The wide variety of dehydrated foods that are available today to the consumers and the concern of meeting quality specifications and conserving energy emphasize that need for a thorough understanding of the rehydration process (Lee *et al.,* 2006) [2]. The concentration of sugar syrup in which the fried balls are soaked is very important to obtain good penetration of sugar syrup for ideal sweetness, texture and shelf-life of final product.

Vacuum impregnation is a recent technology applied in the food industry and it is possible to rapidly introduce several types of solutions in the porous structure of foods under vacuum. Mass transfer in this process is a result of mechanically induced difference in pressure. Vacuum impregnation makes it possible to fill large volumes of intracellular spaces in tissues of fruit and vegetables and helps in immense improvements in the physical–chemical, nutritional and sensory properties of foods take place leading to significant advantages such as longer shelf-life, optimization of further processes and the introduction of innovative products in the food market (Zhao *et al.,* 2004) [9].

Response surface methodology (RSM) is used to optimize vacuum soaking conditions with minimal loss of quality and to produce desired flavour or colour with superior quality. Response surface methodology is used to obtain mathematical models for describing the effects of the independent variables on the dependent variables and obtain optimized conditions for vacuum frying and soaking of food products. Response surface methodology enables a reduction in the number of experimental trials needed to evaluate multiple parameters and their interactions, thus, requiring less time and labor to complete a successful evaluation of the experimental parameters (Myers *et al.,* 2009) [3]. Response surface methodology has been widely applied for optimizing processes in the food industry (Kumar *et al.,* 2009) [1]

Materials and methods

Preparation of *pantoa* dough balls

Pantoa dough balls were prepared by using dairy ingredients *khoa, chhana* and other minor non-dairy ingredients as followed by Nath (1992) [4] and Neethu (2013) [5]. Fresh cow milk containing 3.8-4.0% fat and 8.5% solids-not-fat (SNF) was used to make *khoa* and *chhana*. The *khoa* was prepared by heating the cow milk continuously till it attains semi-solid consistency (26% moisture content) while another batch of cow milk continuously heated at 90 ºC, then cooled it to 70 ºC and added 2% citric acid to obtain solid coagulated mass called *chhana. Pantoa* dough balls (spherical in shape) were prepared by blending *khoa* and *chhana (*4:5 ratio) with non-dairy ingredients such as refined wheat flour, semolina and arrowroot powder (3% each) and ground sugar (0.7%) followed by kneading the blend and rolling it into spherical in shape dough balls of each having 12 g for sub-baric frying.

Sub-baric soaking (vacuum impregnation) of *pantoa*

Soaking was also main unit operation involved in the preparation of *pantoa. Pantoa* was fried at the optimized sub-baric frying conditions (122 °C for 360 s at 200 mm Hg vacuum) in sunflower oil. Sub-baric fried *pantoa* balls were soaked in sugar impregnation unit of sub-baric thermal processor having sugar syrup concentration of 40, 50 and 60 ºBrix at room temperature for 3, 5 and 7 min. The sugar syrup of 40, 50 and 60 ºBrix was prepared by mixing 40, 50 and 60 parts of crystalline sugar in 60, 50 and 40 parts of portable water, respectively. The solution was allowed to boil in a stainless steel container and then few mL of milk was added to remove impurities from sugar syrup in the form of scum. The concentration of sugar syrup was determined using ERMA (Japan) hand refractrometer having range 32-60 °Brix and the Brix was adjusted by adding either water or sugar. The clarified sugar syrup was then transferred to vacuum impregnation chamber of sub-baric thermal processor.

After sub-baric frying, a basket tray was transferred into vacuum impregnation unit. The basket tray was suspended in the vacuum chamber at 600 mm Hg vacuum for 10 min and then the tray was immersed into sugar syrup (40, 50 and 60 ºBrix) at ambient temperature. The chamber was pressurized to atmospheric pressure and then the tray was retained in the chamber containing sugar syrup for required time for soaking. After soaking, samples were removed from vacuum impregnation unit and sugar adhering to the surface of *pantoa* was removed by wiping it with a sterilized soft tissue, then samples were stored in plastic container for further analysis.

Expansion ratio (ε)

The expansion ratio of a product can be defined as the ratio of final cross sectional area to initial cross sectional area. It was determined using the Eq.

$$\varepsilon = \frac{A_t}{A_0} \qquad \textbf{(1)}$$

Where, A_t was the cross sectional area of *pantoa* at time't' and A_0 was the cross sectional area of *pantoa* at zero time.

Determination of Hardness and Chewiness

Textural profile analysis (TPA) was done using TA.XT Plus Texture Analyzer (Stable Micro Systems, Texture Technologies Corp., Goldaming, UK) equipped with 50 kg load cell TPA to characterize the hardness and chewiness of the product after VI. (Neethu *et al.,* 2014) [6]

Sugar estimation

The sugar was estimated by using Seliwanoff's colorimetric method reported by Pantulu *et al*. (1981) for ice cream was slightly modified. Representative sample of 2 g was taken after finely mashing the final product and was diluted to 500ml with 1 ml of 40% lead acetate solution and distilled water. One ml of filtrate of this mixture was made up to 10ml using distilled water and aliquots (0.5 and 1.0 ml) of this diluted sample filtrate were taken in test tubes. Two milliliters of 0.1% aqueous solution of resorcinol was added followed by the addition of 6ml of concentrated (12N) hydrochloric acid. The contents were vortexed and incubated at 70 ºC for 30 min for optimal colour development. The solution was cooled to room temperature and the developed colour was measured for absorbance at 490 nm using a spectrophotometer. The level of sucrose was quantified with the help of a standard curve drawn using standard sucrose solution.

Overall acceptability of the product

The Overall acceptability of the *Pantoa* was estimated by a panel of judges on a 9-point hedonic scale. Wherein a score of 1 represented 'dislike extremely' and score of 9 represented 'like extremely', the samples for evaluation were served to the judges for sensory evaluation.

Results and discussions

Model fitting of response variable

The face-centered central composite design consisting of 13 runs used in the optimization of sub-baric soaking conditions of *pantoa* using design expert software 7.0.0. The second order polynomial response surface model was fitted to each response variables (Y) namely, overall acceptability (sensory evaluation), expansion ratio, sugar content, hardness and chewiness. The experimental design along with factors such as sugar concentration and soaking time (z_1, z_2) and responses is presented in the Table 1

Table 1: Experimental design and data for the response surface analysis (Face-Centered Central Composite Design) for sub-baric soaking of *pantoa*

Run	Factors		Reponses				
	Sugar conc. (Z_1), °C	Soaking time (Z_2), min	OA (Y_1)	Expansion ratio (Y_2)	Sugar content,% (Y_3)	Hardness (Y_4), N	Chewiness (Y_5), N
1	40(-1)	3(-1)	7.52	1.14	28.75	3.29	1.92
2	50 (0)	5 (0)	8.40	1.28	32.71	3.70	2.28
3	50 (0)	5 (0)	8.25	1.25	32.45	3.68	2.21
4	50 (0)	5 (0)	8.35	1.20	31.86	3.64	2.13
5	50 (0)	7(+1)	8.50	1.30	37.12	3.21	2.11
6	60(+1)	5 (0)	8.30	1.19	36.19	3.91	1.91
7	40(-1)	7(+1)	7.80	1.22	32.45	3.11	1.99

8	40 (-1)	5 (0)	7.85	1.23	32.01	3.01	1.82
9	50 (0)	5 (0)	8.60	1.21	34.15	3.74	2.16
10	60(+1)	7 (+1)	8.25	1.26	40.36	3.39	1.84
11	50 (0)	5 (0)	8.30	1.22	33.79	3.70	2.12
12	60(+1)	3(-1)	7.40	1.12	30.65	4.12	2.35
13	50 (0)	3 (-1)	7.30	1.13	29.45	3.99	2.24

Effect of sub-baric soaking process conditions on different responses of *pantoa*

Overall acceptability (OA) of *pantoa*

The optimized sub-baric fried *pantoa* soaked with different levels of sugar concentration and soaking time had overall acceptability (OA) score ranged from 7.30 to 8.60. The response surface generated by the second order polynomial model for the OA of *pantoa* is shown in the Fig. 1. Sub-baric soaking of *pantoa* was done at ambient temperature (32±2 ºC). The maximum OA score was observed with the *pantoa* soaked in 50 ºBrix sugar syrup for 5 min, while minimum OA score was observed with the *pantoa* soaked in 50 ºBrix sugar syrup for 3 min. The overall acceptability of *pantoa* samples was found to increase with increase in sub-baric soaking time. It was found that 60 ºBrix sugar syrup was highly viscous which resulted in reduced absorption of syrup into the core of the product, thereby decreasing the overall acceptability of product.

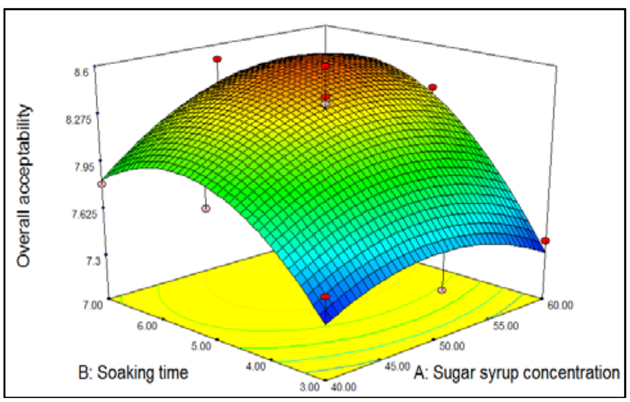

Fig 1: Response surface for the effect of sub-baric soaking process conditions on the overall acceptability (OA) of *pantoa*

The regression model describing the effect of sub-baric soaking process variables such as sugar concentration and soaking time on the OA of *pantoa* in terms of actual levels of variables was given as:

$$OA = 0.120 + 0.211z_1 + 0.860z_2 + 7.102\times10^{-3} z_1 z_2 - 2.338\times10^{-3} z_1^2 - 0.102 z_2^2 \quad (2)$$

Sugar syrup concentration, soaking time and quadratic effects of sub-baric soaking time affected the OA of *pantoa* significantly ($p<0.05$). However, from two main factors, sub-baric soaking time had a profound effect on OA of *pantoa*. The interaction effect and quadratic effects of sugar syrup concentration were found to be insignificant ($p>0.05$).

Effect of sub-baric soaking process conditions on expansion ratio of *pantoa*

The expansion ratio of a product can be defined as the ratio of change in final cross sectional area to initial cross sectional area. The response surface generated by the second order polynomial model for the expansion of *pantoa* soaked in sub-baric conditions is shown in the Fig. 2. The expansion ratio of the *pantoa* ranged from 1.12 to 1.30. The expansion ratio of the *pantoa* increased with increase in soaking time and decreased with increase in sugar concentration because penetration of highly viscous syrup into to the core of the product was reduced at higher concentration. Soaking for higher time resulted in increased expansion ratio of the product. The response surface model fitted in terms of actual levels of variables for expansion ratio of *pantoa* given as:

$$\text{Expansion ratio} = 1.066 - 0.033z_1 + 0.032z_2 \quad (3)$$

From the model developed for expansion ratio of *pantoa* soaked in sub-baric conditions, both soaking time and sugar concentration effects on expansion ratio of the product during soaking were significant ($p<0.05$). However, the other quadratic and interaction effects were found to be insignificant ($p>0.05$). Between the two, soaking time was the most significant factor affecting expansion ratio in the product.

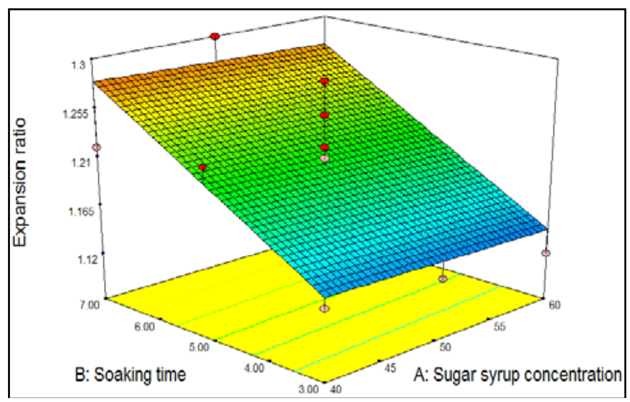

Fig 2: Response surface for the effect of sub-baric soaking process conditions on the expansion ratio of *pantoa*

Effect of sub-baric soaking process conditions on sugar uptake of *pantoa*

The sugar uptake of *pantoa* samples soaked in sub-baric conditions varied from 44.11 to 57.12%. The minimum sugar uptake of the *pantoa* sample soaked in sub-baric condition obtained at 40 ºBrix for 3 min soaking while maximum sugar uptake of the *pantoa* sample soaked in sub-baric condition was observed at 60 ºBrix for 7 min at ambient temperature (32±2 ºC) Sugar uptake was increased with increasing sugar syrup concentration and soaking time. The penetration of sugar syrup in to core of *pantoa* increased with increase in soaking time and sugar syrup concentration during sub-baric soaking.

The response surface generated by the second order polynomial model for the sugar content of *pantoa* soaked in sub-baric condition is shown in the Fig. 3. The response surface model fitted in terms of actual levels of variables for sugar content is given as:

$$\text{Sugar content (\% w.b.)} = 31.566 - 0.143z_1 - 1.203z_2 + 0.075z_1z_2 \quad (4)$$

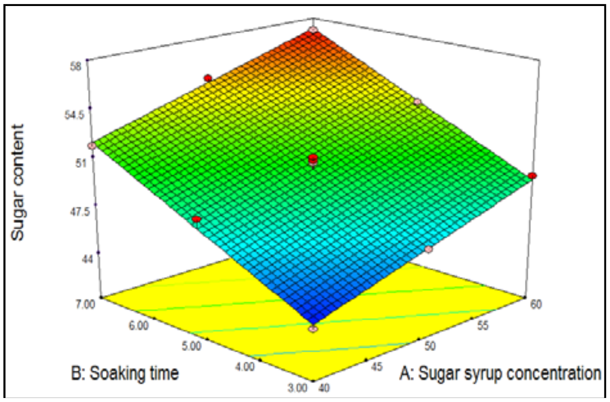

Fig 3: Response surface for the effect of sub-baric soaking process conditions on the sugar content of *pantoa*

Both sugar syrup concentration and soaking time effects on sugar content value of the *pantoa* during sub-baric soaking were significant ($p<0.01$). Both main factors had a profound effect on sugar content of *pantoa* during sub-baric soaking.

Effect of sub-baric soaking process conditions on hardness of *pantoa*

The response surface generated by the second order polynomial model for the hardness of soaked *pantoa* in sub-baric condition is shown in the Fig. 4. The hardness of the soaked *pantoa* ranged from 3.02 to 3.99 N. The hardness of *pantoa* increased as a function of the sugar concentration while decreased with increased soaking time. Higher hardness of *pantoa* at higher sugar syrup concentration due to less penetration of syrup into the core of the product and faster rate of sugar syrup diffusion into product was observed at lower sugar syrup concentration thereby, decrease in hardness was seen with higher soaking time. The response surface model fitted in terms of actual levels of variables for hardness of *pantoa* given as:

$$Hardness = -3.675 + 0.217z_1 + 0.687z_2 - 7.375\times10^{-3}z_1z_2 - 1.563\times10^{-3}z_1^2 - 0.048z_2^2 \quad (5)$$

Sugar syrup concentration and soaking time effects on hardness of *pantoa* during sub-baric soaking were significant ($p<0.05$). The quadratic and interaction effects were also found to be significant ($p<0.05$). Between the two main factors, sugar syrup concentration was the most significant factor affecting hardness of *pantoa*.

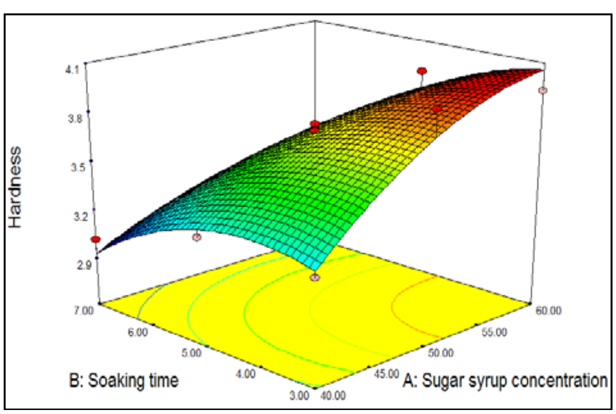

Fig 4: Response surface for the effect of sub-baric soaking process conditions on the hardness of *pantoa*

Effect of sub-baric soaking process conditions on chewiness of *pantoa*

The chewiness values of soaked *pantoa* ranged from 1.75 to 2.35 N during sub-baric soaking. The response surface generated by the second order polynomial model for the chewiness of the *pantoa* samples is shown in the Fig. 5. The chewiness of *pantoa* increased with increase in the sugar syrup concentration. The response surface model fitted in terms of actual levels of variables for chewiness is given as:

$$Chewiness = -4.761 + 0.250z_1 + 0.278z_2 - 7.00\times10^{-3}z_1z_2 - 2.087\times10^{-3}z_1^2 - 9.482\times10^{-4}z_2^2 \quad (6)$$

Sugar syrup concentration and soaking time effects on the chewiness of sub-baric soaked *pantoa* were found to be significant ($p<0.05$). The soaking time had a profound effect on chewiness of the *pantoa*. Increase in chewiness of the *pantoa* with respect to sugar syrup concentration and soaking time might be due to the increase in hardness and decrease in cohesiveness of *pantoa*. The results were in agreements with the results reported for fried *Paneer* (Rao and Patil, 2001) and *pantoa* (Neethu, 2013) [5].

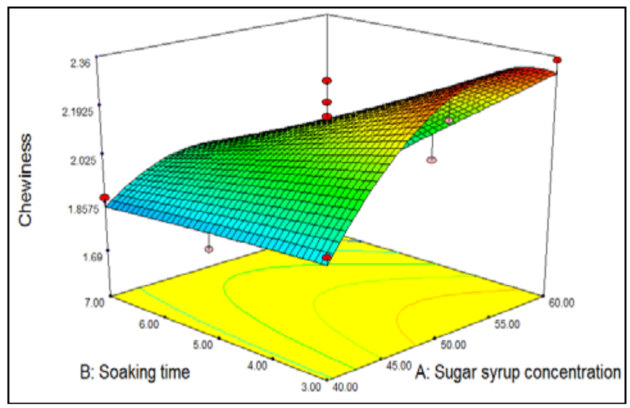

Fig 5: Response surface for the effect of sub-baric soaking process variables on the chewiness of *pantoa*

Optimization of sugar syrup concentration and soaking time for sub-baric soaking of *pantoa*

The desired goals for each factors and responses were selected considering the desirable weightage of sensory evaluation data. Different weights were assigned to each goal to adjust the desirability function. In this study, sugar syrup concentration and soaking time conditions were optimized based on maximizing overall acceptability and expansion ratio of the product and other responses such as sugar content, hardness and chewiness were set in range. The program was run to get the optimum conditions and solutions.

The optimized solutions given by the design expert software was presented in the Table 2 which indicate the optimum sugar syrup concentration, soaking time and the predicted values of the responses namely overall acceptability, expansion ratio, sugar content, hardness and chewiness. Solution having the maximum desirability value was selected. The optimum sugar syrup concentration and soaking time combination for sub-baric soaking of *pantoa* was found to be 55 ºBrix for 6 min at ambient temperature (32±2 ºC).

Table 2: Predicted optimum conditions for sub-baric soaking of *pantoa*

Sugar syrup conc.,°Brix	Soaking time, min	OA	Expansion ratio	Sugar content,%	Hardness, N	Chewiness, N	Desirability
55.44	6.0	8.48	1.274	38.82	3.194	1.880	0.860
55.65	6.0	8.41	1.270	38.90	3.193	1.873	0.856

OA – Overall acceptability

Validation of optimized sub-baric soaking conditions

The overall acceptability, expansion ratio, sugar content hardness and chewiness of *pantoa* were determined at optimum sub-baric soaking conditions. The experimental values (mean of three measurements) and the predicted values of various quality attributes are showed in the Table 3. For all the responses (Table 3), t-test was used to calculate the significance difference between predicted and actual response values at 5% level of significance and no significant difference was found, so the response surface optimization model was adequate.

Table 3: Comparison of experimental values with predicted values obtained at 55 °Brix for 6 min at ambient temperature (32±2 ºC)

Response	Predicted value	Experimental value ± SD
Overall acceptability	8.42	8.35±0.45
Expansion ratio	1.27	1.29±0.47
Sugar content,%	56	55±0.89
Hardness, N	3.20	3.25±0.48
Chewiness, N	1.88	1.90±0.52

Conclusion

The optimized VI conditions obtained from this study would be useful in manufacturing *pantoa* with controlled physico-chemical changes and optimum quality for growing allegiance of healthy consumers. The data derived from the present investigation opens up new avenues in improvements in equipment design and development. Sugar impregnation process can also be investigated for non-destructive infusion of nutrients, niacin, prebiotics, enzymes, silver nanoparticles *etc.* into dairy products like *Paneer, cheese, khoa, rasogolla*, *etc.* to improve their functional and keeping qualities.

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