Optimization of HTST process parameters for production of ready-to-eat potato-soy snack

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Abstract Ready-to-eat (RTE) potato-soy snacks were developed using high temperature short time (HTST) air puffing process and the process was found to be very useful for production of highly porous and light texture snack. The process parameters considered viz. puffing temperature (185–255 °C) and puffing time (20–60 s) with constant initial moisture content of 36.74% and air velocity of 3.99 m.s^{-1} for potato-soy blend with varying soy flour content from 5% to 25% were investigated using response surface methodology following central composite rotatable design (CCRD). The optimum product in terms of minimum moisture content (11.03% db), maximum expansion ratio (3.71), minimum hardness (2,749.4 g), minimum ascorbic acid loss (9.24% db) and maximum overall acceptability (7.35) were obtained with 10.0% soy flour blend in potato flour at the process conditions of puffing temperature (231.0 °C) and puffing time (25.0 s).

Keywords Puffing · High temperature short time · Potato · Soy · Ready-to-eat · Snack food

Introduction

In India, several ready-to-eat (RTE) products from potato are available in the market, such as potato chips, french

fried, etc. apart from several instant products, namely, potato granules, potato powder and quick cooking potato cubes, etc. Potato chips are a very popular snack food in India. It contains high amount of fat, which is harmful for the human health and moreover due to its high oil content the product becomes rancid making its shelf life very short and difficult. The oil contents in chips are 36.8–38.1% (Singh et al. 2004), which requires inert packing of the product leading to higher unit cost and thereby preventing the product from becoming popular and widely accepted in India.

The main factors which affect puffing are puffing-temperature, puffing-duration, initial moisture content of the material to be puffed and also starch content of the raw materials. Puffing caused the moisture within suddenly to expand into steam and so to cause the materials to be puffed and simultaneously be cooked. Puffing ideally creates an aerated, porous, snack-like texture with the added benefits of dehydration. Blending the puffed products with different flavours and marketing them in moisture impermeable plastic film pouches provides enormous opportunities for increasing acceptance and usage of puffed products (Arya 1992).

Expansion of starchy vegetables, like potato, leading to a porous structure has been also achieved by High Temperature Short Time (HTST) fluidized bed drying (Gutterson 1971; Torry 1974; Hanson 1975). It suggested that HTST pneumatic drying, when applied to a variety of vegetables, brought about porous structure in the products, which resulted in considerable reduction in drying and dehydration time with improvement in texture of the cooked products. Jayaraman et al. (1982) developed a HTST pneumatic drying technique for production of quick cooking vegetables from starchy vegetables like potato, sweet potato, green peas, carrot etc. An optimum temper-

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ature of 170 °C and drying time of 8 min were recommended for best quality product from fresh potatoes in terms of low bulk density and reconstitution. Highest expansion was achieved with potato and least with green peas. The authors reported that partial drying before HTST treatment was detrimental for the product quality of quick cooking vegetables. Chandrasekhar and Chattopadhyay (1988) puffed rice in hot air at about 250 °C in the continuous heated air fluidized bed puffing machine while, Mukherjee (1997) and, Nath et al. (2007) optimized ready-to eat dehydrated puffed potato cubes and ready-to eat potato snack respectively with long shelf life by HTST whirling bed treatment using central composite rotatable design (CCRD).

Soybean, being a rich source of protein and fat, seems to be the right substitute for solving the problem of protein-energy malnutrition. Soybean has been used as a food for a long time, but only in this century, has it been subjected to a variety of processing technologies. It is a fairly new crop for Indian consumers and few resources have been directed toward enhancing utilization of soybean in the daily diets of people in the country. Saimanohar et al. (2005) prepared a high protein nutritional baked snack food comprises of vegetable sources as wheat flour, roasted peanut paste, sesame seed, soybean flour and well balanced mixture of vitamins, minerals and others. Ingredients dissolved in formula water after powdering, dehulling as required etc. are mixed to get homogeneous dough. Dough is sheeted and cut using circular die of 3.0–4.0 mm dia. It is baked at 180–220 °C for 4–6 min. Blending of potato flour with soy flour improves the nutritional qualities of the product. But till date no literatures are available for production and optimization of HTST air puffed RTE potato-soy snack. This RTE potato-soy snack could be an alternate and right substitute for solving the problem of protein-energy malnutrition.

Therefore, the present study was undertaken to optimize the process parameters for HTST air puffing for developing RTE potato-soy snack.

Materials and methods

Production of potato and soy flour The freshly harvested potatoes (*Kufri chandramukhi*) were procured from the market, washed, brushed and peeled. The eyes and all bruises were pitted out. Immediately after peeling, the potatoes were dipped in water containing a small amount of potassium metabisulfite (1,000 ppm). The potatoes were boiled for 30 min in water. The boiled potatoes were sliced (1.0–1.5 mm thickness) and uniformly layered in a tray and dried at a temperature of 60 °C in a hot air cabinet drier for 4 to 5 h (Kulkarni et al. 1988). The dried and shredded

potatoes were ground to pass through the sieve no. 72 (British Sieve Standards). The powdered potato flour was packed in air-tight containers. A flow diagram for production of potato flour is shown in Fig. 1. Soy flour was obtained from whole soybean by grinding with the help of laboratory grinder (Khetarpaul et al. 2004).

Preparation of materials for puffing Materials were prepared from potato flour blended with soy flour (5–25%) by adding required amount of chilled water (5 °C) and common salt. Kneading was done for 10–15 min to yield an uniform mixture. In this puffing experiments, Dolly Pasta Machine (Model: DOLLY, LaMonferrina Make, Italy) was used for obtaining desired shape of the product as well as more surface exposures during puffing process. A rectangular shape of 18 mm length, 10 mm width and 1.5 mm thickness was considered for this study.

The experimental setup and high–temperature–short–time (HTST) air puffing Puffing was done in a HTST fluidized bed air puffer (Nath et al. 2007). The experimental setup for high temperature short time (HTST) air puffing system consisted of different sections, viz., air supply unit, heating unit cum plenum chamber and fluidizing bed column

Fig. 1 Flow chart for potato flour production

Table 1 Coded levels for RSM design

Variables	Code	Levels					Interval of variation
		−1.68	−1	0	+1	+1.68	
Soy flour, %	X_1	6.6	10.0	15.0	20.0	23.4	5.0
Temperature, °C	X_2	186.4	200.0	220.0	240.0	253.6	20.0
Time, sec	X_3	23.2	30.0	40.0	50.0	56.8	10.0

$$X_1 = (\text{Soy flour, \%} - 15)/5, X_2 = (\text{Temperature, } ^\circ\text{C} - 220)/20, X_3 = (\text{Time, sec} - 40)/10$$

(puffing chamber). Air was supplied by a centrifugal blower to the plenum chamber where air was heated with the help of a burner fueled by liquid petroleum gas (LPG). The cylindrical fluidized bed column (puffing chamber) was mounted on the top of the plenum chamber. The air temperature inside the air puffer was measured by 26 gauge Iron-constantan thermocouples connected to a six channel digital temperature indicator having a range of 0–600 °C with a least count of 1 °C. The time was noted by a stopwatch (least count 0.1 s). The samples were fed into the puffing chamber where

puffing took place. The puffed potato-soy snack was discharged from the collector fitted on the top of the puffing column. A sample size of 100 g was selected for each HTST treatment. After the material was discharged from the HTST air puffer, the changes in moisture content, expansion ratio, texture, ascorbic acid loss and overall acceptability score were measured.

Moisture content (MC) The moisture content of the samples at every stage of the process was determined by hot air oven method as described by Ranganna (1995).

Table 2 Treatment combinations for HTST puffing with 3 variable 2^{nd} order RSM designs

Run orders	Process variables (actual)			Responses				
	Soy flour (%)	Temperature (°C)	Time (sec)	MC, % db	ER	H, g	AA loss, % db	OAA
1	20.0	240.0	50.0	7.9	2.9	3,605.4	32.2	6.3
2	20.0	240.0	30.0	9.9	2.7	3,411.4	23.5	6.5
3	20.0	200.0	50.0	11.1	2.5	3,425.6	16.0	6.7
4	20.0	200.0	30.0	12.3	2.2	3,212.7	6.2	6.8
5	10.0	240.0	50.0	7.9	3.8	2,963.5	27.9	6.9
6	10.0	240.0	30.0	10.0	3.7	2,814.7	17.6	7.2
7	10.0	200.0	50.0	11.0	3.7	3,017.8	12.9	7.4
8	10.0	200.0	30.0	12.1	3.6	2,911.1	4.6	7.3
9	23.4	220.0	40.0	10.6	1.2	3,733.6	27.6	6.2
10	6.6	220.0	40.0	10.6	3.9	2,634.2	8.3	7.5
11	15.0	253.6	40.0	7.4	3.4	3,337.5	36.2	6.5
12	15.0	186.4	40.0	13.1	3.0	3,122.7	13.3	6.7
13	15.0	220.0	56.8	7.5	3.4	3,483.9	33.2	6.7
14	15.0	220.0	23.2	12.4	3.1	2,905.4	9.6	7.1
15	15.0	220.0	40.0	10.5	3.5	3,116.1	22.1	6.9
16	15.0	220.0	40.0	10.2	3.6	3,355.4	28.0	6.9
17	15.0	220.0	40.0	10.7	3.5	3,142.3	28.0	6.8
18	15.0	220.0	40.0	10.7	3.6	3,140.5	28.4	6.9
19	15.0	220.0	40.0	10.5	3.3	3,133.7	27.9	7.1
20	15.0	220.0	40.0	9.7	3.6	3,150.5	28.2	6.9
Mean	15.0	220.0	40.0	10.3	3.2	3,180.9	21.6	6.9
SD	4.2	17.0	8.5	0.51	0.19	99.2	3.7	0.13

MC Moisture content; ER Expansion ratio; H Hardness; AA Ascorbic acid; OAA Overall acceptability

Table 3 Regression coefficients of the second-order polynomial model for the response variables (in coded units)

Variables/factors	Estimated coefficients				
	MC,% db	ER	H, g	AA loss,% db	OAA
Intercept	10.36	3.51	3,174.18	27.22	6.91
X ₁	0.01	−0.66	278.01	3.47	−0.34
X ₂	−1.50	0.12	43.13	7.32	−0.12
X ₃	−1.08	0.09	119.74	5.63	−0.09
X ₁ X ₂	−0.03	0.08	66.16	0.70	−0.01
X ₁ X ₃	−0.01	0.04	18.94	−0.02	−0.01
X ₂ X ₃	−0.22	−0.01	2.89	0.10	−0.06
X ₁ ²	0.08	−0.30	−3.45	−3.97	0.00
X ₂ ²	−0.04	−0.08	12.89	−1.55	−0.09
X ₃ ²	−0.15	−0.05	0.37	−2.74	0.02
R ²	0.95	0.95	0.93	0.92	0.93
Adj R ²	0.90	0.91	0.87	0.85	0.86
C.V.%	4.96	6.18	3.12	4.40	1.86

X₁: Soy flour (%), X₂: Temperature (°C), X₃: Time (s); MC, ER, H, AA, OAA: see Table 2

Expansion ratio (ER) Expansion ratio was measured using rape seed displacement method (Segnini et al. 2004). For this the following expression was used:

$$\text{Expansion ratio} = \frac{\text{volume after puffing}}{\text{volume before puffing}} \quad (1)$$

Hardness (H) measurement The texture characteristics of puffed RTE potato snacks in terms of hardness was measured using a Stable Micro System TA-XT2 texture analyzer (Texture Technologies Corp., UK) fitted with a 25 mm cylindrical probe. Hardness value was considered as mean peak compression force and expressed in grams. The studies were conducted at a pre test speed of 1.0 mm/s, test speed of 0.5 mm/s, distance of 30% strain, and load cell of 5.0 kg (Cruzcyelis et al. 1996).

Ascorbic acid (AA) loss The ascorbic acid content of the samples was determined by visual titration method using 2, 6-dichlorophenol-indophenol (Ranganna 1995). The reagents used were 3% HPO₃ and the dye solution containing 50 mg 2, 6-dichlorophenol-indophenol in 200 ml water. First the dye was standardized, by titrating a mixture of HPO₃ and ascorbic acid standard (5 ml each) with the dye solution and an aliquot of 5 ml of the extract was titrated with dye solution to a pink end-point. The ascorbic acid content of the sample was calculated by the formula

Ascorbic acid content(mg/100g)

$$= \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Aliquot of extract} \times \text{Volume of sample}} \quad (2)$$

Table 4 ANOVA for different models

Variables/factors	DF	F-Values				
		MC,% db	ER	H, g	AA loss,% db	OAA
Model	9	20.26***	21.5***	14.9***	13.3***	13.99***
X ₁	1	0.01	150.8***	107.3***	11.88**	98.23***
X ₂	1	117.8***	5.34*	2.58	52.8***	11.98**
X ₃	1	61.40***	2.65	19.9**	31.3***	6.15*
X ₁ X ₂	1	0.03	1.39	3.56	0.28	0.08
X ₁ X ₃	1	0.00	0.33	0.29	0.00	0.08
X ₂ X ₃	1	1.46	0.02	0.01	0.01	1.91
X ₁ ²	1	0.31	31.77***	0.02	16.35**	0.00
X ₂ ²	1	0.09	2.16	0.24	2.50	6.86*
X ₃ ²	1	1.19	1.05	0.00	7.82*	0.28
Residual	10					
Lack of fit	5	2.91	3.83	1.42	3.63	2.39
Pure error	5					
Total	19					

Significant *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$; MC, ER, H, AA, OAA: see Table 2; X₁, X₂, X₃: see Table 3

Fig. 2 Contour graphs for the effect of **a** soy flour (%) vs temperature (°C), **b** soy flour (%) vs time (sec) and **c** temperature (°C) vs time (sec) on moisture content of ready-to-eat potato-soy snack

Overall acceptability (OAA) The overall acceptability of puffed RTE potato-soy snacks was carried out by the standard method (BIS 1971). The product was evaluated by a panel of 10 judges. The effect of different process parameters during air puffing on overall acceptability score of the puffed product were evaluated. A nine point hedonic scale was used in which the sample scoring 1 was rated as disliked extremely, while those scoring 9 as liked extremely.

Experimental design At first the ranges of experimental parameters were selected based on preliminary trials for soy flour (S), puffing temperature (T) and puffing time (t) with uniform moisture content (37.0% wb) and air velocity (4.0 m.s^{-1}). The experimental design was applied after selection of the ranges. The process variables considered were: puffing temperature (185–255 °C) and puffing time (20–60 s) with varying soy flour content from 5% to 25%. A centre composite RSM design was used to show interactions of soy flour, puffing temperature and puffing time on the quality of the products in 20 runs, of which initial 14 were for non-centre points, and rest 6 were for the centre points (Montgomery 2001). Commercial statistical package, Design Expert—version 7.0 was used for generating the experimental design and statistical analysis. The levels, codes and interval of variation of the independent variables are given in the Table 1, while the treatment combinations with responses are presented in Table 2.

The following second order polynomial response surface model (Eq. 3) was fitted to each of the response variable (Y_k) with the independent variables (X)

$$Y_k = b_{k0} + \sum_{i=1}^3 b_{ki}X_i + \sum_{i=1}^3 b_{kii}X_i^2 + \sum_{i \neq j=1}^3 b_{kij}X_iX_j + \varepsilon \quad (3)$$

where b_{k0} , b_{ki} , b_{kii} , and b_{kij} are the constant, linear, quadratic and cross-product regression coefficients respectively, X_i 's are the coded independent variables of X_1 (soy flour, %), X_2 (puffing temperature, °C) and X_3 (puffing time, sec) and ε (random error).

Numerical optimization technique of the Design-Expert software was used for simultaneous optimization of the multiple responses. The desired goals for each variables and response were chosen. All the independents variables were kept within range while the responses were either maximized or minimized. In order to search a solution maximizing multiple responses, the goals are combined into an overall composite function, $D(x)$, called the desirability function (Myers and Montgomery 2002), which is defined as:

$$D(x) = (d_1 \times d_2 \times \dots \times d_n)^{\frac{1}{n}} \quad (4)$$

where $d_1, d_2, \dots, d_n$ are responses and n is the total number of responses in the measure.

The numerical optimization finds a point that maximizes the desirability function. The characteristics of a goal may be altered by adjusting the weight or importance (Design Expert 2002). Verification of the model was carried out by one sample T -test using the statistical software 'SPSS 10.0 for Windows' to compare the mean actual values of the responses with the predicted value.

Results and discussion

The observations for expansion ratio, hardness and overall acceptability score with different combinations of the process parameters are presented in Table 2. Response surface analysis was applied to the experimental data using a commercial statistical package 'Design Expert'. The second order polynomial response surface model (Eq. 2) was fitted to each of the response variable (Y_k). Regression analysis and ANOVA were conducted for fitting the model and the statistical significance of the model terms examined. The estimated regression coefficients of the quadratic polynomial models for the response variables, along with the corresponding R^2 and coefficient of variation (CV) values are given in Table 3. Analysis of variance showed that the models are highly significant ($p \leq 0.001$) for all the responses (Table 4).

The lack of fit (Table 4), which measures the fitness of the model, did not result in a significant F -value in case of expansion ratio, hardness and overall acceptability, indicating that these models are sufficiently accurate for predicting those responses. The coefficient of determination (R^2) values of all responses are quite high (>0.9) indicating a high proportion of variability was explained by the data and the RSM models were adequate (Table 3). As a general rule, the coefficient of variation (CV) should not be greater than 10% (Snedecor and Cochran 1967). In this study, the coefficients of variation were less than 7% for all the responses (Table 3), a relatively lower value of the coefficient of variation indicates better precision and reliability of the experiments carried out.

Effect of process conditions on moisture content during puffing The observations for MC with different combinations of the process parameters are presented in Table 2. The experimentally minimum (7.35%,db) and maximum (13.12%,db) MC was obtained at temperature of 253.64 °C and 186.36 °C with soy flour of 15% and time duration of 40 s respectively. The regression equation describing the effect of the process variables on MC of

Fig. 3 Contour graphs for the effect of **a** soy flour (%) vs temperature (°C), **b** soy flour (%) vs time (sec) and **c** temperature (°C) vs time (sec) on expansion ratio of ready-to-eat potato-soy snack

Fig. 4 Contour graphs for the effect of **a** soy flour (%) vs temperature (°C), **b** soy flour (%) vs time (sec) and **c** temperature (°C) vs time (sec) on hardness of ready-to-eat potato-soy snack

RTE potato-soy snack in terms of actual level of the variables are given as:

$$MC = 14.06 - 0.02 S - 0.02 T + 0.25 t - 2.9E - 04 ST - 1.6E - 04 St - 1.1E - 03 Tt + 0.003 S^2 - 9.8E - 05 T^2 - 1.4E - 03 t^2 \quad (5)$$

Where, 'S' is the soy flour,%; 'T' is the puffing temperature, °C; 't' is the puffing time, sec.

Analysis of variance showed that MC was dependent significantly on linear terms of temperature ($p \leq 0.001$) and time ($p \leq 0.001$). while, the effect of MC on quadratic terms and interaction terms were found to be non significant. Temperature and time duration were the main factor affecting the MC as revealed by the respective regression coefficient and *F*-value. Regression model explained 95% of the total variability ($p \leq 0.001$) on MC of RTE potato-soy snack (Table 3). Figure 2 showed MC of RTE potato-soy snack as a function of soy flour, temperature and time. Maximum (12.35%,db) and minimum (8.35%,db) values of MC were observed at soy flour=5–25%/temperature=185–197 °C (Fig. 2a and b) and soy flour=5–25%/time=57–60 s (Fig. 2b and c) respectively. Optimum moisture content of 0.0978 kg/kg (d.b.) was obtained for RTE dehydrated puffed potato cubes at the optimized temperature and time combination by oven toasting method (Mukherjee 1997). This finding was in accordance with the present study. Both the temperature and time for HTST air puffing was responsible for bring down moisture content of RTE potato-soy snack to the desired level, which is but obvious.

Effect of process conditions on expansion ratio(ER) The observations for expansion ratio with different combinations of the process parameters are presented in Table 2. It varied from 1.22 to 3.94 within the combination of variables studied. The regression equation describing the effect of the process variables on expansion ratio of RTE potato-soy snack in terms of actual level of variables are given as:

$$ER = 7.7E - 03 S + 0.08T + 0.05t + 8.3E - 04 ST + 8.0E - 04 St - 5.3E - 05 Tt - 0.01S^2 - 1.9E - 04T^2 - 5.4E - 04 t^2 - 6.30 \quad (6)$$

It can be observed from ANOVA (Table 4) that soy flour is most significant parameter affecting the expansion ratio ($p \leq 0.001$) followed by temperature ($p \leq 0.05$) at linear level, while only soy flour ($p \leq 0.001$) at quadratic term, however,

Fig. 5 Contour graphs for the effect of **a** soy flour (%) vs temperature (°C), **b** soy flour (%) vs time (sec) and **c** temperature (°C) vs time (sec) on ascorbic acid loss (% db) of ready-to-eat potato-soy snack

there was no significant contribution of time to expansion ratio. The negative coefficients of soy flour indicated that expansion ratio decreased with increase of this variable while positive coefficients of temperature and time caused increase in expansion ratio at linear level. Soy flour was the main factor affecting the expansion ratio as revealed by the respective regression coefficient and *F*-value. Regression model explained 95% of the total variability ($p \leq 0.001$) in expansion ratio of RTE potato-soy snack (Table 3). Figure 3 showed ER of RTE potato-soy snack as a function of soy flour, temperature and time. Soy flour exerts a negative linear effect on ER as depicted in Fig. 3. Maximum (3.83) and minimum (1.59) values of ER were observed at soy flour=7.5–12.5%/temperature=210–240 °C (Fig. 3a and b) and soy flour=22–23.5%/time=20–60 s (Fig. 3b and c) respectively. Since, soybean is nearly devoid of starch, soy snack products may not show good expansion (Kulkarni and Joshi 1992). High expansion is primarily dependent on starch content in the raw materials to be puffed. Potato flour is rich in starch content while soy flour adds more protein in the products and therefore addition of soy flour showd significant reduction in expanation ratio. Mukherjee (1997) obtained maximum volume expansion of 2.605 times while optimizing RTE dehydrated puffed potato cubes with long shelf life by high temperature short time (HTST) whirling bed treatment at an air temperature of 210 °C, retention time of 80 s, initial moisture content of 40% and air velocity 3.76 m/s. These observations are consistent with the present findings.

Effect of process conditions on hardness (*H*) The observations for hardness with different combinations of the process parameters are presented in Table 2. It varied between 2,634.18 g and 3,733.55 g within the combination of variables studied. The regression equation describing the effect of the process variables on hardness of RTE potato-soy snack in terms of actual level of variables are given as:

$$H = 5459.37 - 100.96 S - 22.53 T + 2.81 t + 0.66 ST + 0.38 St + 0.01 Tt - 0.14 S^2 + 0.03 T^2 + 3.7E - 03 t^2 \quad (7)$$

Analysis of variance showed that hardness was dependent significantly on linear terms of soy flour ($p \leq 0.001$) and time ($p \leq 0.01$). However, there was no significant contribution of quadratic and interaction terms on hardness of RTE potato-soy snack. Soy flour was the main factor affecting the hardness as revealed by the respective

Fig. 6 Contour graphs for the effect of **a** soy flour (%) vs temperature (°C), **b** soy flour (%) vs time (sec) and **c** temperature (°C) vs time (sec) on overall acceptability of ready-to-eat potato-soy snack

regression coefficient and *F*-value. Regression model explained 93% of the total variability ($p \leq 0.001$) on hardness of RTE potato-soy snack (Table 3). Figure 4 showed *H* of RTE potato-soy snack as a function of soy flour, temperature and time. Soy flour exerts a positive linear effect on *H* as depicted in Fig. 4. Maximum (3,671.15 g) and minimum (2,731.03 g) values of *H* were observed at soy flour=21.0–25.0%/temperature=218–255 °C (Fig. 4a and b) and soy flour=5–11.5%/time=20–55 s (Fig. 4b and c) respectively. Increase in soy flour content caused a decreased in the expansion ratio as explained earlier which in turn increased hardness of snack.

The effect of incorporation of defatted soy flour (15 to 35%) in maize flour and its extrusion in a single screw extruder at 125 °C to 175 °C was investigated by Adesina et al. (1998). These authors reported that extrudates from maize alone were the most hard, while those of soy alone or the blends showed considerably low hardness. Formation of fibrous structure from proteins and their alignment has been proposed to be the cause for low hardness in the case of soy (Bressani et al. 1974). These above findings do not correspond with the present findings. However, Kulkarni et al. (1997) reported that addition of soy flour to corn caused increase in hardness of extrudates which varied in the range of 74.6–119.7 N, while Chandrasekhar (1989) reported decrease in hardness with increase in expansion ratio in case of rice puffing. Similar finding was also reported by Nath and Chattopadhyay (2007) in HTST air puffed potato snack. These findings were in accordance with the present study.

Effect of process conditions on ascorbic acid (AA) loss during puffing The observations for AA loss with different combinations of the process parameters are presented in Table 2. The experimentally minimum (4.56%,db) and maximum (36.18%,db) AA loss was obtained at soy flour of 10% and 15%, temperature of 200 °C and 253.64 °C and time duration of 30 s and 40 s respectively. The regression equation describing the effect of the process variables on AA loss of RTE potato-soy snack in terms of actual level of the variables are given as:

$$\begin{aligned}
 AA \text{ loss} = & 3.93 S + 1.95 T + 2.66 t + 0.007 ST \\
 & - 3.8E - 04 St + 4.8E - 04 Tt - 0.16S^2 \\
 & - 3.9E - 03T^2 - 3.7E - 03t^2 - 326.48 \quad (8)
 \end{aligned}$$

The positive coefficients of the first order terms of soy flour, temperature and time (Eq. (8)) indicated that AA loss increases with increase of these variables while negative coefficients of interaction terms (soy flour X time) and quadratic terms of temperature were found non-significant (Table 4). Increase in significant AA loss with increase in temperature may be due to thermal degradation of ascorbic acid which occurred during high temperature processing.

Analysis of variance showed that AA loss was dependent significantly on linear terms of soy flour ($p \leq 0.01$), temperature ($p \leq 0.001$) and time ($p \leq 0.001$). while, the effect of AA loss on interaction terms were found to be nonsignificant. However, AA loss was also found to be significant on quadratic terms soy flour $p \leq 0.01$ and time $p \leq 0.05$. Temperature and time duration were the main factor affecting the AA loss as revealed by the respective regression coefficient and F -value. Regression model explained 92% of the total variability ($p \leq 0.001$) on AA loss of RTE potato-soy snack (Table 3). Figure 5 showed AA loss of RTE potato-soy snack as a function of soy flour, temperature and time. Maximum (33.86%,db) and minimum (5.09%,db) values of AA loss were observed at soy flour=14–22%/temperature=238–255 °C (Fig. 5a and b) and temperature=185–220 °C and time=20–33.5 s (Fig. 5b and c) respectively.

Mukherjee (1997) reported maximum ascorbic acid loss of 24.8 (%d.b.) for RTE dehydrated puffed potato cubes at the optimized temperature and time combination by oven toasting method. Haase and Weber (2003) and Laing et al. (1978) also observed degradation of ascorbic acid during processing of French fries and potato chips. During processing total losses of AA were about 52% for French fries and about 26% for potato chips. Effect of thermal processing on changes in the content of soluble solids and vitamin C in sour cherry pulp was reported by Jovan and Mirjana (1980). The authors observed blanching and subsequent pasteurization decreased vitamin C from 14.9 to 9.1 and 4.8 mg/100 g, respectively. These findings were in accordance with the present study. Loss of vitamin C during processing depends on the degree of heating, leaching into the cooking medium, surface area exposed

to oxygen and any other factors that facilitate oxidation (Eitenmiller and Laden 1999).

Effect of process conditions on overall acceptability (OAA)

The observations for overall acceptability score with different combinations of the process parameters are presented in Table 2. The experimentally minimum(6.2) and maximum (7.5) overall acceptability score was obtained at soy flour of 23.41% and 6.59% with temperature of 220 °C and time duration of 40 s respectively. The regression equation describing the effect of the process variables on overall acceptability score of RTE potato-soy snack in terms of actual level of the variables are given as:

$$\begin{aligned} OAA = & 0.11 T - 0.03 S + 0.05 t - 1.2E - 04 ST \\ & - 2.5E - 04 St - 3.1E - 04 Tt + 4.73E \\ & - 06 S^2 - 2.2E - 04 T^2 + 1.78E - 04 t^2 \\ & - 4.1 \end{aligned} \quad (9)$$

Analysis of variance showed that overall acceptability score was dependent significantly on linear terms of soy flour ($p \leq 0.001$), temperature ($p \leq 0.01$) and time ($p \leq 0.05$). while, the effect of overall acceptability score on interaction terms were found to be nonsignificant. However, overall acceptability score was also found to be significant on quadratic term temperature $p \leq 0.05$. The negative coefficients of the first order terms of soy flour, temperature and time (Table 3) indicated that overall acceptability decreased with increase of these variables while positive (soy flour and time) and negative (temperature) coefficients of their quadratic terms suggested increase and decrease in OAA of the product respectively. However, the interaction terms showed negative effect on overall acceptability. Soy flour was the main factor followed by temperature and time, affecting the overall acceptability score as revealed by the respective regression coefficient and F -value. Regression model explained 93% of the total variability ($p \leq 0.001$) on overall acceptability score of RTE potato-soy snack (Table 3). Figure 6 showed OAA score of RTE potato-soy snack as a function of soy flour, temperature and time.

Table 5 Optimization criteria for different process variables and responses

Factors/Responses	Goal	Lower limit	Upper limit	Importance
Soy flour,%	maximize	5.00	25.00	5
Temperature, °C	in range	185	255	4
Time, sec	in range	20	60	4
MC,% db	minimize	7.35	13.12	3
ER	maximize	1.22	3.94	4
H, g	minimize	2,634.18	3,733.55	4
AA loss,% db	minimize	4.56	36.18	4
OAA	maximize	6.2	7.5	5

MC, ER, H, AA, OAA: see Table 2

Table 6 Solutions for optimum conditions

S. No	Process variables			Responses					Desirability
	Soy flour,%	Temp. °C	Time, sec	MC,% db	ER	H, g	AA loss,% db	OAA	
1	10.00	231.00	25.00	11.03	3.71	2,749.4	9.24	7.35	0.95
2	7.08	223.47	34.74	10.54	3.78	2,725.7	9.52	7.31	0.94
3	10.01	230.00	26.00	11.15	3.73	2,758.3	10.41	7.33	0.92
4	8.71	205.93	36.72	10.23	3.80	2,722.8	9.35	7.25	0.91
5	12.24	230.00	22.15	11.35	3.58	2,805.3	10.57	7.21	0.86
6	9.38	232.14	23.33	11.67	3.66	2,736.5	9.85	7.26	0.83
7	10.31	229.93	25.48	11.24	3.69	2,755.1	10.46	7.32	0.81

MC, ER, H, AA, OAA: see Table 2

Maximum (7.34) and minimum (6.02) values of OAA score were observed at soy flour=5–7.5%/temperature=185–246 °C (Fig. 6a and b) and soy flour=23.5–25%/time=44–60 s (Fig. 6b and c) respectively.

The above findings revealed that soy flour was the major parameter responsible for RTE potato-soy snack. Increase in soy flour caused low expansion and more hardness in the snack product. Rise in temperature and time up to certain limit helped puffing by increasing the rate of vaporization and therefore light texture product obtained. Though time has lesser importance on OAA but it plays an important role on quality of the puffed snack. Lesser residence time caused less expansion and the product becomes hard texture due to insufficient vapour pressure development while higher residence time beyond a certain limit caused damage and deformation of the tissue as well as the cells along with other biochemical changes. Thus, all the parameters viz. soy flour, temperature and time had important roles to play in the OAA of the product. This finding was in accordance with the study reported by Skierkowski et al. (1990). The authors carried out instrumental and sensory evaluation of textural properties of extrudates from blends of high starch/high protein fractions of dry beans. It reported that higher the process temperature lower was the sample stress and higher was the sensory score for crispness, with this product unacceptable when processed below 121 °C. The effect of incorporation of defatted soy flour (15–35%) in

maize flour and its extrusion in a single screw extruder at 125 °C to 175 °C was investigated by Adesina et al. (1998). The authors reported that extruded sample of 75:25 at 150 °C had the highest score for the overall acceptability and was the most acceptable of all the extrudates. Gultterson 1971, Torrey 1974 and, Hanson 1975 reported that HTST pneumatic drying resulted in development of porous structure in the products which ultimately improved the texture and acceptability of the cooked product. These observations supported the present findings regarding the effects of process variables on the overall acceptability of RTE potato-soy snack.

Optimization of process parameters Numerical optimization was carried out for the process parameters for HTST air puffing for obtaining the best product. To perform this operation, Design-Expert program (V 6.0.4) of the STAT-EASE software (Design Expert 2002) was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen and different weights were assigned to each goal to adjust the shape of its particular desirability function (Table 5). Table 6 shows software generated seven optimum conditions of independent variables with the predicted values of responses. Solution no.1, having the maximum desirability value was selected as the optimum conditions of HTST air puffing for developing RTE potato-soy snack.

Table 7 Comparison of experimental with predicted values

Response	Predicted value	Actual value±SD	Standard error	% variation	Mean difference	Sig. (2 tailed)
MC,% db	11.03	11.53±0.49	0.219	4.34	0.50	0.084
ER	3.71	3.68±0.052	0.023	0.92	−3.40E-02	0.216
H, g	2,749.4	2,829.9±74.34	33.248	2.84	80.48	0.073
AA loss,% db	9.24	10.08 ±0.945	0.423	8.32	0.84	0.118
OAA	7.35	7.2±0.158	7.07E-02	2.08	−0.15	0.101

MC, ER, H, AA, OAA: see Table 2

Verification of the model High temperature short time air puffing experiment was conducted at the optimum process condition and the quality attributes of the resulting product were determined. The observed experimental values (mean of 5 measurements) and values predicted by the equations of the model are presented in Table 7. The null hypothesis was tested and there was no significant difference recorded between the actual and the predicted values (test value). No significant differences between the actual and predicted values were found at $p \leq 0.05$. Closeness between the experimental and predicted values of the quality parameters indicated the suitability of the corresponding models.

The optimum process parameters were obtained from the responses in terms of MC, ER, H, AA and OAA by the numerical optimization method and the minimum MC (11.03%, db) maximum ER (3.71), minimum H (2,749.4 g), minimum AA loss (9.24%, db) and maximum OAA (7.35) were obtained at the process condition of temperature (231.0 °C) and time (25.0 s) with soy flour (10.0%).

Conclusion

The RSM approach was used to optimize the process parameters for high temperature short time air puffing for developing ready-to-eat potato-soy snacks using moisture content, expansion ratio, hardness, ascorbic acid loss and overall acceptability as responses. Moisture content, expansion ratio, hardness, ascorbic acid loss and overall acceptability of ready to eat potato-soy snacks by high temperature short time air puffing process were dependent significantly on the process variables namely, soy flour, puffing temperature and puffing time for developing ready to eat (RTE) potato-soy snack. Soy flour and puffing temperature had the maximum influence, whereas the effects of puffing time was comparatively less on the quality attributes of potato-soy snack.

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