

Performance Evaluation of the Batch-Type Multigrain Puffing-cum-Popping Machine For the Production of Puffed Soynuts

Abstract

Soynuts are a nutritious and tasty snack made by puffing of soybeans. The puffing of soynuts was carried out in a batch-type semiautomatic multigrain puffing cum popping machine designed and developed by the Department of Agricultural Process Engineering, CAET, VNMKV, Parbhani. This machine works on High Temperature Short Time (HTST) principle. The table salt was used as heating media for puffing of soynuts. The grain to salt ratio 1:4 was kept constant in the puffing pan for the production of puffed soynuts. The sample size was taken 1kg during the experimental trial. Soybean was dipped in a hot water at 100 °C for 3 min and then surface dried for 3 hours. Pretreated soybeans was then fed to machine for puffing. The optimization of the machine parameters for the production of puffed soynuts contained three independent variables: puffing temperature (°C), stirrer speed (RPM), and puffing time (min), assessed at three levels of 140, 150, 160 °C; 35, 40, 45 RPM; 4, 5, 6 minutes respectively was carried out using Box-Behnken Design (BBD). The dependent variables viz. puffing yield, expansion ratio, bulk density, colour, hardness and crispness were determined. The experimental data was analysed using Response Surface Methodology (RSM) to determine the optimal values of process and product quality parameters. The optimal condition of the machine parameters for production of puffed soynuts was found as a puffing temperature of 150 °C, stirrer speed of 40 rpm and puffing time of 5 minutes in a batch-type multigrain puffing cum popping machine. The puffing efficiency and capacity of developed puffing cum popping machine for puffed soynuts was 97.24 % and 80 kg/day.

Keywords: Soynuts, Box-Behnken Design (BBD), Optimization, Multigrain puffing machine.

Introduction:

Soybean [*Glycine max* (L)] is one of the oldest principal food crops and has paramount importance in Indian agricultural and oil industry. Soybean is recognized for its value in enhancing and protecting health. Soybean has a tremendous potential to be transformed into a number of traditional local foods. Different products can be prepared from soybean such as soymilk and soy-paneer (dairy analogs), soy flour, soy bakery products, soynuts etc (Kumari et al., 2025). Consumption of soy products is reported to be beneficial to prevent kidney disease, heart disease, diabetics, obesity, blood cholesterol and cancer (Bolla, 2015). It has good balance of the essential amino acids making it a good supplement for cereals that can be used to improve the diet of millions of people, especially the poor and low-income earners in developing countries because it produces the greatest amount of protein used as food by man. Puffing of

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soybean consist of hydrothermal treatment as it involves the release or expansion of vapor inside the grains, while it is subjected to intensive heating for a short time. Puffing has been also used to deactivate anti nutritional components in soybeans and to give characteristic flavor, color and enhance nutrients, mineral availability to final products of puffed soynuts. Thus, consumption of puffed soynuts provides all the nutrients available in whole soybean. Therefore, for identification of suitable variety of soybean, the physical properties, texture characteristics, color and **Organoleptic** properties of raw soybean and puffed soynuts from four different varieties were analyzed (Othzes *et al.*, 2022). The present study highlights about performance evaluation of the batch-type multigrain puffing-cum-popping machine for the production of puffed soynuts.

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Materials and Methods:

In this investigation, a bulk sample of 50 kg each of soybean sand sorghum grains was procured from the Seed Processing Center, VNMKV Parbhani and the groundnut and maize were procured from the local market of Parbhani (MS). The table salt was used as the heating medium (Jadhav, 2018) for puffing and popping the selected grains.

The various apparatus and equipment required for the quality evaluation of puffs/pops from selected grains were measuring cylinders, sieve, beakers, heat sealing machine, texture analyzer (TAXT plus), stopwatch, digital Hunter colour meter (Color Flex EZ), digital vernier caliper, electronic weighing balance, hot air oven, and multi grain puffing cum popping machine.

A multigrain puffing cum popping machine was designed and developed at the Department of Agricultural Process Engineering at the College of Agricultural Engineering, Parbhani.

Production of soynuts from soybean was carried out by varying different process variables: puffing temperature (°C), speed (rpm) and puffing time (min). The levels of process variables for the production of soybean puffs were determined based on the results of preliminary trials and literature review. The experimental design was formulated after selection of the ranges.

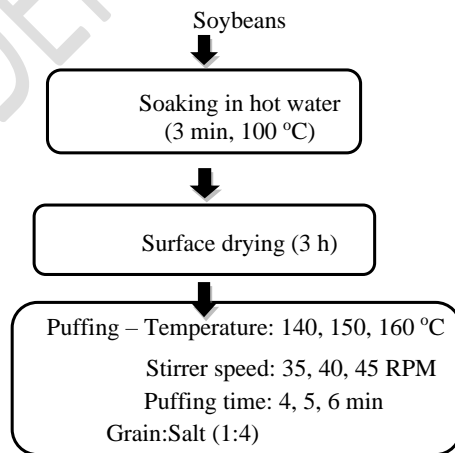
Table 1. Experimental plans for the production of puffed soynuts by varying three process parameters

Sr.	Independent parameters	Levels	Dependent
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No.			parameters
1.	Puffing Temperature (°C)	140, 150, 160 °C	1. Puffing efficiency (Puffing yield)
2.	Speed (RPM)	35, 40, 45 RPM	2. Expansion ratio 3. Bulk density
3.	Puffing Time (min)	4, 5, 6 min	4. Colour 5. Hardness 6. Crispness
			Total experiments =17

Seventeen experiments were performed to study the the performance evaluation of puffing cum popping machine and optimization of machine parameters and process parameters for production of soynuts according to a Box Behnken Design (BBD) with three process variables puffing temperature (°C), Speed (RPM) and puffing time for three levels of each variable. The effect of these three process variables on puffing efficiency (puffing yield) and on puffed soynuts quality as expansion ratio, bulk density, colour, hardness and crispness were studied for production of puffed soynuts.

The process flowchart for production of puffed soynuts is given below



↓
Puffed soynuts

Fig 1: Process flowchart for production of puffed soynuts

The details of the standard runs of process variables with responses used in the experiments were presented in Table 2

Table 2: Standard runs of process variables for production of puffed soynuts

Sr. No	Coded value			Puffing temperature (°C)	Stirrer speed (RPM)	Puffing time (min)
	S ₁	S ₂	S ₃			
1	-1	-1	0	140	35	5
2	1	-1	0	160	35	5
3	-1	1	0	140	45	5
4	1	1	0	160	45	5
5	-1	0	-1	140	40	4
6	1	0	-1	160	40	4
7	-1	0	1	140	40	6
8	1	0	1	160	40	6
9	0	-1	-1	150	35	4
10	0	1	-1	150	45	4
11	0	-1	1	150	35	6
12	0	1	1	150	45	6
13	0	0	0	150	40	5
14	0	0	0	150	40	5
15	0	0	0	150	40	5
16	0	0	0	150	40	5
17	0	0	0	150	40	5

Where, S₁ = Puffing temperature (°C), S₂ = Stirrer speed (RPM), S₃ = Puffing time (min)

3.3.7 Quality evaluation of selected grains puffs/pops prepared within the experimental range

The puffing /popping efficiency, expansion ratio, bulk density, colour (L value), hardness and crispness of puffed/popped products viz. puffed soynuts, puffed peanuts, sorghum pops and popcorns of selected grains were determined.

3.3.7.1 Puffing/popping efficiency (Puffing/popping Yield, %):

Puffing/popping efficiency was determined for the selected puffed/popped grains in terms of popping yield (%). It is the ratio of the total weight of the popped sample to the sum of the total weight of popped and unpopped grains (Jadhav, 2018).

Puffing/popping efficiency was calculated by using following formula,

Puffing/popping efficiency (%)

$$= \frac{\text{Weight of Popped grains}}{\text{Weight of popped grains} + \text{Weight of unpopped grains}} \times 100$$

3.3.7.2 Expansion ratio:

The expansion ratio was calculated for the popped and unpopped grains. It is the ratio of the total popped volume (cm³) to the volume of raw kernels (Nakade, 2019).

Expansion ratio was calculated by using following formula

$$\text{Expansion Ratio} = \frac{\text{Total popped volume (ml)}}{\text{Volume of raw grains (ml)}}$$

3.3.7.3 Bulk density:

Bulk density is the density of a material when packed or stacked in the bulk. It was determined by placing each sorghum-popped product into a 1000 ml graduated cylinder. The volume and weight of the selected grains popped and unpopped grain products were recorded to determine the bulk density as the weight of selected grains popped products per volume occupied by selected grain popped/puffed products (Jadhav, 2018).

Bulk density was calculated by using following formula

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{\text{Mass of millet puff or pop sample (g)}}{\text{Volume of millet puff or pop ample (cm}^3\text{)}}$$

3.3.7.4 Color

The Colour (L value) of the samples was determined using a Hunter Lab colorimeter. All colour measurements were conducted after two days of the popping experiment (Jadhav, 2018). The colour of the selected popped grain products was measured using a Hunter lab colorimeter (Plate 4.1). Before testing the sample, the instrument was calibrated using standard black and white tiles supplied with the instrument. Colour readings are expressed in terms of the L value. The L value represents the light-dark spectrum with a range of 0 (black) to 100 (white). It was observed that there was not much variation in the 'a' and 'b' values with changes in the process parameters. Therefore, only the L-value (lightness of colour or brightness of the product) was considered in the present investigation. The mean of the three replicates was used for each experimental sample.

3.3.7.5 Textural properties (Hardness and Crispiness):

The textural properties (Hardness and Crispiness) of the selected popped grain samples were evaluated using a texture analyzer TA.XT. Plus Texture Analyzer, Stable Micro System, UK (plate 4.2). A texture analyzer with a 50 kg load cell was used to determine the hardness and crispiness of the sorghum pops. For the measurement of crispness, a macro was developed that counts the number of major peaks represented in the force-time deformation curve during compression (Nath and Chattopadhyay, 2007).

The hardness value was considered the mean peak compression force (Bourne, 2002), and crispiness was measured in terms of a major positive number of peaks (Khodke, 2002) with the setting of the texture analyser (Table 3).

Table 3: Setting of TA.XT PLUS for production of puffed soynuts, puffed peanuts puffs, sorghum pops and popcorns

Particulars	Settings for soynuts and peanuts	Settings for pops of sorghum and maize
Mode	Measure force in compression	Measure force in compression
Option	Return to start	Return to start
Pre-test speed	0.5 mm/sec	1 mm/sec
Test speed	0.1 mm/sec	1 mm/sec
Post Test speed	1.0 mm/s	10.0 mm/s
Distance	N A	N A
Data acquisition rate	400 pps	400 pps
Strain	50 %	50 %
Testing force	0.05 N	0.05 N
Cylindrical probe	P75	P35
Tare mode	Auto	Auto

(Bourne, 2002; Nakade, 2019; Nilza, 2022; Gosavi, 2022)

3.4 Optimization of process parameters for selected grains puffs/pops

Optimization of process parameters was carried out to obtain the maximum puffing/popping yield, expansion ratio, optimal values of bulk density, hardness, colour and crispiness using Design Expert software (Version 8.0.6). Response surface graphs were generated to examine the effects of process parameters on the response variables. Response

Surface Methodology (RSM) is a systematic and efficient approach for investigating the interaction effects of various parameters by following the path of steepest ascent and identifying a stationary point. Analysis of variance (ANOVA) is necessary to assess the significance and adequacy of the mathematical models proposed by RSM. With accurate models, different combinations of factors can lead to a desired response, which is visually represented in three-dimensional surface plots.

3.4.1 Effect of process parameters on quality characteristics of prepared from different grains

Response Surface Methodology (RSM) was used to find the effect of three process parameters puffing temperature, speed of the stirrer, and puffing time on the quality characteristics of prepared soybean puffs and the effect of two process parameters, puffing/popping temperature and speed of the stirrer, on the quality characteristics of prepared peanut puffs, sorghum pops, and popcorn. Make separate statement RSM was applied to experimental data using a commercial statistical package (Design Expert version 8.0.6 Stat ease, Minneapolis, USA) to generate response surface plots and optimize process variables. The effects of process parameter viz. puffing temperature (S1), speed of the stirrer (S2) and puffing time (S3) with three levels on the quality characteristics of the puffed soynuts quality were analyzed by conducting experiments using the Box Behnken. The effects of process parameters such as puffing/popping temperature (P₁/J₁/M₁) and stirrer speed (P₂/J₂/M₂) on the quality characteristics of peanut puffs, sorghum pops, and popcorn were analyzed by conducting experiments using the Central Composite Rotatable Design (CCRD). The levels of the process parameters were based on the results of preliminary studies. Nonlinear regression equations were developed between the coded values of the independent variables (viz., P₁, P₂ and P₃) and the dependent variables. A second-order polynomial equation of the following form was assumed to relate response Y and factors as follows:

$$Y = \beta_0 + \sum_{j=1}^k \beta_i P_j + \sum_{j=1}^k \beta_{jj} P_j^2 + \sum_{i=1}^k \beta_{ii} P_i^2 + \sum_{j=2}^k \beta_{ij} P_i P_j + \epsilon$$

where,

- Y = predicted response,
- β_0 = a constant,
- β_i = linear coefficient,
- β_{ii} = squared coefficient,
- β_{ij} = interaction coefficient,
- P_i and P_j = the independent variables

ε = noise or error

3.4.2 Development of model

Second-order quadratic models were utilized to establish correlations among the independent process parameters. The coefficients of the second-order polynomial for each term in the equation were derived through multiple regression analysis using Design Expert software (Version 8.0.6). The software fitted the experimental data to compute response models, and their regression coefficients were determined. The statistical significance of the terms and coefficients in the regression equation was assessed via analysis of variance (ANOVA) for each response. The statistical significance of all terms in the polynomial was evaluated by calculating the F-value. Complete second-order quadratic models were employed to fit the data, and the model's adequacy was tested by considering R^2 (the coefficient of multiple determination, which measures the amount of variation around the mean explained by the model). Data pertaining to various quality characteristics, such as puffing/popping efficiency, expansion ratio, bulk density, textural property (hardness and crispiness) and color (L value), were tabulated and statistical analysis was conducted by subjecting the data to two-way analyses of variance.

3.4.3 Numerical optimization

In numerical optimization, simultaneous optimization of multiple responses is achieved by setting specific goals for each variable and response. In the process of optimizing multiple responses and identifying a solution, these goals were integrated into a comprehensive composite function known as desirability function (Montgomery, 2004). The desirability function serves as an objective function, representing a desirable range from zero to one for each response. Numerical optimization aims to identify the point that maximizes the desirability function. The characteristics of a goal can be modified by adjusting its weight or importance. The puffing/popping yield, expansion ratio, bulk density, color, hardness, and crispiness of the selected grains were evaluated based on the determined values of commercially and widely accepted samples of the selected grains.

3.4.4 Graphical optimization

Graphical optimization was conducted by superimposing contour plots for all responses concerning the process variables. In this optimization, all responses are superimposed to identify the optimal intersection zone for superior product quality, where the point of maximum desirability function, as determined by numerical optimization, is located. The superimposed

contours of all responses for the specified process parameters and their interaction zones delineate the ranges of the process variables. The optimal combinations of response and process variables were derived by averaging these variable ranges.

3.4.5 Validation of the developed models

The study identified the optimal conditions for processing selected puffed or popped grains, focusing on key quality characteristics. The predicted optimal response values for parameters such as puffing/popping efficiency, expansion ratio, bulk density, colour, hardness and crispiness were validated against the values obtained from grain puffs/pops prepared under these optimal processing conditions.

Results and Discussions:

Soybean MAUS 612 variety was used to prepare puffed soynuts by varying the puffing temperature (S_1) of heating media; stirrer speed (S_2) for uniform and continuous mixing of mixture of soybean grains with salt and puffing time (S_3) of the soybean grain. The effect of process parameters viz. puffing temperature (S_1), stirrer speed (S_2) and puffing time (S_3) on puffed soynuts quality was analyzed by conducting seventeen experiments using the Box Behnken Design (BBD). The experimental data were analyzed by applying Response Surface Methodology (RSM) using Design Expert 8.0.6. Quadratic models were developed using response surface methodology (RSM) to study the synergy between the process parameters and responses in terms of puffing efficiency, expansion ratio, bulk density, colour (L value), hardness and crispness. The optimized model for each response variable was verified for its significance by analysis of variance (ANOVA) at a 5 % level of significance ($p < 0.05$) using Design Expert 8.0.6 software. To visualize the combined effect of the two variables on the puffing efficiency, expansion ratio, bulk density, colour, hardness, and crispness, response surface and contour plots were generated for the fitted model as a function of the two variables while keeping the other variable constant. The details of the process variables and responses used in the experiments are presented in Table 4.

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Table 4: Quality characteristics of puffed soynuts by varying process parameters

Temperature				Quality characteristics
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	S ₁	S ₂	S ₃	Puffing efficiency (%)	Expansion ratio	Bulk density (kg/m ³)	Colour (L value)	Hardness (N)	Crispness (number of +ve peaks)
1	-1	-1	0	82.05	1.18	635.58	54.20	62.82	17
2	1	-1	0	81.45	1.14	705.88	47.76	69.69	16
3	-1	1	0	73.19	1.08	632.62	56.75	92.57	10
4	1	1	0	87.87	1.19	679.86	53.98	57.13	18
5	-1	0	-1	68.18	1.09	637.00	57.40	92.08	10
6	1	0	-1	89.05	1.16	688.50	54.10	48.05	19
7	-1	0	1	81.38	1.10	638.02	54.68	74.83	15
8	1	0	1	74.43	1.12	689.72	47.52	90.86	10
9	0	-1	-1	96.59	1.23	609.19	54.69	42.56	20
10	0	1	-1	82.58	1.10	604.08	56.20	81.05	14
11	0	-1	1	81.51	1.12	628.77	48.86	72.65	15
12	0	1	1	88.12	1.17	610.15	54.48	52.89	17
13	0	0	0	96.06	1.24	607.69	55.63	46.37	23
14	0	0	0	98.41	1.23	604.84	55.67	37.98	24
15	0	0	0	97.17	1.24	601.82	54.93	41.26	23
16	0	0	0	96.56	1.23	603.71	54.91	43.99	22
17	0	0	0	98.00	1.24	602.84	55.24	43.28	23

S₁ = Puffing temperature, S₂ = Stirrer speed and S₃ = Puffing time

4.3.1 Effect of process parameters on puffing efficiency for the production of puffed soynuts

The puffing efficiency of puffed soynuts is the ratio of the weight of puffed grains to the weight of the total (puffed plus unpuffed) grain. The computed values for the puffing efficiency of puffed soynuts prepared with different combinations of process parameters are presented in Table 4. The puffing efficiency for puffed soynuts ranged from 68.18 % to 98.41 % within the combination of variables studied. The relationship between the puffing efficiency of puffed soynuts was obtained using the following process parameters viz: puffing temperature (S₁), stirrer speed (S₂) and puffing time (S₃).

The regression equation (4.1) represents a second-order polynomial model describing the effect of the process variables, puffing temperature (S_1), stirrer speed (S_2) and puffing time (S_3) on the puffing efficiency for the production of puffed soynuts.

$$PE (\%) = - 3003.23 + 38.33 S_1 - 5.39 S_2 + 126.31 S_3 + 0.08 S_1S_2 - 0.69 S_1S_3 + 1.04 S_2S_3 - 0.13 S_1^2 - 0.14 S_2^2 - 6.46 S_3^2$$

$$(R^2=0.989) \dots\dots (4.1)$$

Where,

S_1 = Puffing temperature, S_2 = Stirrer speed and S_3 = Puffing time

The coefficient of determination ($R^2 = 0.989$) suggested that the model explained 98.97% of the variability in puffing efficiency, indicating an excellent fit to the experimental data. The magnitude of the coefficient of the linear term showed that puffing time (S_3) had the most prominent effect on puffing efficiency, followed by puffing temperature (S_1) and stirrer speed (S_2). The positive coefficients in the case of the first-order term of puffing temperature (S_1) and puffing time (S_3) indicated that these process parameters have a significant direct influence on increasing the puffing efficiency. Whereas the negative coefficients of stirrer speed (S_2) and their quadratic terms suggest that an increase in stirrer speed have a detrimental effect on puffing efficiency. Add linear terms. Add Interaction terms. The presence of quadratic terms (S_1^2 , S_2^2 , S_3^2) suggests that the effect of each parameter is nonlinear, implying that beyond a certain level, increasing these parameters could lead to diminishing returns or even negative effects on puffing efficiency.

Table 5: Analysis of variance (ANOVA) for process parameters showing the effect on puffing efficiency for puffed soynuts

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1448.18	9	160.91	74.54	< 0.0001*
(S_1): Puffing temperature	98.03	1	98.03	45.41	0.0003*
(S_2): Stirrer speed	12.13	1	12.13	5.62	0.0496*
(S_3): Puffing time	15.02	1	15.02	6.96	0.0336*
S_1S_2	58.36	1	58.36	27.03	0.0013*
S_1S_3	193.39	1	193.39	89.58	< 0.0001*
S_2S_3	106.24	1	106.24	49.21	0.0002*
S_1^2	659.98	1	659.98	305.72	< 0.0001*
S_2^2	54.01	1	54.01	25.02	0.0016*
S_3^2	175.75	1	175.75	81.41	< 0.0001*
Residual	15.11	7	2.16		

Source	Sum of Squares	df	Mean Square	F-value	p-value
Lack of Fit	11.3	3	3.77	3.95 ^{NS}	0.109
Pure Error	3.82	4	0.95		
Cor Total	1463.29	16			
R-Squared	0.9897				
Adj R-Squared	0.9764				
Pred R-Squared	0.8724				
Std. Dev.	1.47				
Mean	86.62				
C.V. %	1.7				

*Significant at 5 % level

NS- Non significant

From Table 5, p-value less than 0.05 indicate that the model terms are significant. The Model F-value of 74.54 implies that the model for puffing efficiency is significant ($p < 0.0001$). The comparative effect of each parameter on puffing efficiency for puffed soynuts was observed by the F-values in the ANOVA (Table 5). The lack of fit F-value is not significant for the model obtained. In this case, the coefficients of the linear terms of S_1 , S_2 , S_3 and the quadratic terms of S_1^2 , S_2^2 , S_3^2 and the interaction terms S_1S_2 , S_2S_3 , S_1S_3 are significant model terms at the 5% level of significance. Moreover, the predicted R^2 of 0.8724 was in reasonable agreement with the adjusted R^2 of 0.9764, that is, the difference was less than 0.2. This revealed that the non-significant terms were not included in the model. Therefore, this model can be used to navigate design space.

The 3D surface plots in Figs. 2 through 4.3 illustrates the interaction effects of the independent variables puffing temperature (S_1), stirrer speed (S_2) and puffing time (S_3) on puffing efficiency for puffed soynuts. These response surface methodology (RSM) plots are instrumental in visualizing the nonlinear effects and optimal processing conditions for maximizing yield. Response surface analysis confirmed that the puffing process exhibited nonlinear behavior, with distinct optima for each parameter. It was observed from these figures that the puffing efficiency for puffed soynuts increased with increasing puffing temperature (S_1) up to 150 °C, stirrer speed (S_2) up to 40 rpm, and puffing time (S_3) at 5 min and the puffing efficiency of puffed soynuts decreased at higher levels of these process parameters.

Factor Coding: Actual

Puffing Yield (%)

Design Points:

● Above Surface

○ Below Surface

68.1818 98.4127

X1 = A

X2 = B

Actual Factor

C = 5.00

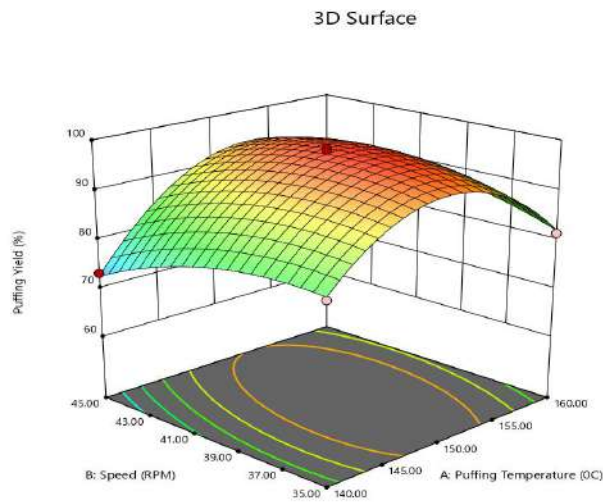


Fig. 2: Effect of puffing temperature and stirrer speed on puffing efficiency of puffed soynuts at constant puffing time

Factor Coding: Actual

Puffing Yield (%)

Design Points:

● Above Surface

○ Below Surface

68.1818 98.4127

X1 = A

X2 = C

Actual Factor

B = 40.00

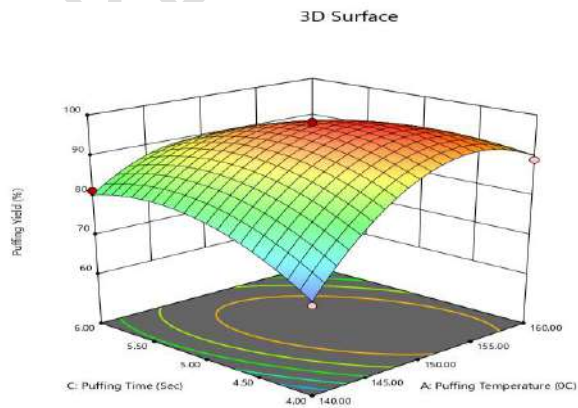


Fig. 3: Effect of puffing temperature and puffing time on puffing efficiency of puffed soynuts at constant stirrer speed

Factor Coding: Actual

Puffing Yield (%)

Design Points:

● Above Surface

○ Below Surface

68.1818  98.4127

X1 = B

X2 = C

Actual Factor

A = 150.00

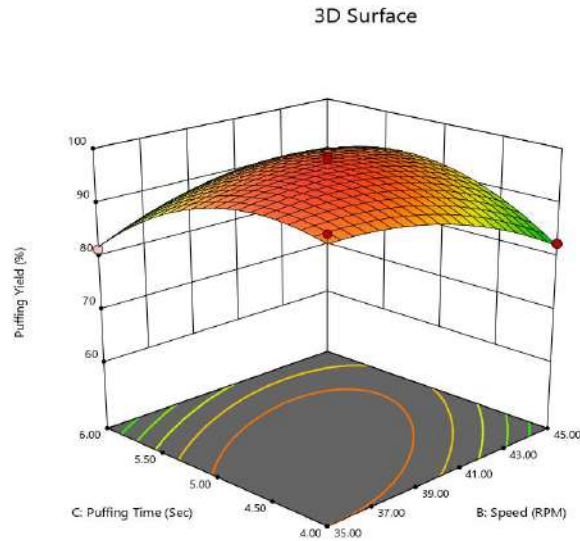


Fig. 4: Effect of stirrer speed and puffing time on puffing efficiency of puffed soynuts of at constant puffing temperature

4.3.2 Effect of process parameter on expansion ratio (ER) for the production of puffed soynuts

The expansion ratio is the ratio of the total puffed volume (cm³) to the volume of the raw kernels. From Table 5, it is observed that the expansion ratio ranged from 1.076 to 1.238. The effects of three independent variables, S₁ (puffing temperature), S₂ (stirrer speed) and S₃ (puffing time), on the expansion ratio of puffed soynuts were analyzed. By applying multiple regression analysis to the experimental results, a second-order polynomial equation was established to estimate the relationship between the expansion ratio and the independent variables S₁, S₂ and S₃ during puffing of soynuts, as given in the following equation:

$$\begin{aligned} ER = & -10.46 + 0.17 S_1 - 0.08 S_2 + 0.34 S_3 + 7.57 E-004 S_1 S_2 - 1.14 E-003 S_1 S_3 + 9.01 E-003 S_2 S_3 \\ & - 6.28 E-004 S_1^2 - 1.02 E-003 S_2^2 - 0.06 S_3^3 \end{aligned} \quad (R^2=0.996) \dots\dots\dots (4.2)$$

Where,

S₁ = Puffing temperature, S₂ = Stirrer speed and S₃= Puffing time

The above given equation represents a mathematical model for ER as a function of three variables S_1 , S_2 and S_3 . ER is the dependent variable, meaning that its value depends on the values of S_1 , S_2 and S_3 . The positive influence of S_1 and S_3 suggests that these factors contribute to increasing the ER and the negative impact of S_2 implies that higher values of S_2 reduce the ER. Furthermore, the coefficient of the linear term effect of puffing time exhibited the most significant effect on the expansion ratio, followed by puffing temperature and stirrer speed. The quadratic coefficients show that the variables have nonlinear effects on ER. The interaction effects highlights the importance of combined factors rather than just their individual contributions. The presence of quadratic terms suggests a nonlinear relationship that is essential for optimizing the levels of S_1 , S_2 and S_3 to achieve the desired ER.

Table 6: Analysis of variance (ANOVA) for process parameters showing the effect on expansion ratio of puffed soynuts

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.055	9	6.14E-03	208.69	< 0.0001*
(S ₁): puffing temperature	2.68E-03	1	2.68E-03	90.96	< 0.0001*
(S ₂): stirrer speed	2.63E-03	1	2.63E-03	89.42	< 0.0001*
(S ₃): puffing time	8.51E-04	1	8.51E-04	28.91	0.001*
S ₁ S ₂	5.73E-03	1	5.73E-03	194.54	< 0.0001*
S ₁ S ₃	5.19E-04	1	5.19E-04	17.63	0.004*
S ₂ S ₃	8.11E-03	1	8.11E-03	275.56	< 0.0001*
S ₁ ²	0.017	1	0.017	563.92	< 0.0001*
S ₂ ²	2.73E-03	1	2.73E-03	92.77	< 0.0001*
S ₃ ²	0.012	1	0.012	416.46	< 0.0001*
Residual	2.06E-04	7	2.94E-05		
Lack of Fit	1.45E-04	3	4.83E-05	3.17 ^{NS}	0.1473
Pure Error	6.11E-05	4	1.53E-05		
Cor Total	0.055	16			
R-Squared	0.9963				
Adj R-Squared	0.9915				
Pred R-Squared	0.9565				
Std. Dev.	5.43E-03				
Mean	1.17				
C.V. %	0.46				

*Significant at 5 % level

NS- Non significant

Where,

expansion ratio, puffing temperature (°C), stirrer speed (rpm), puffing time (min).

Analysis of variables (Table 6) was performed to evaluate the statistical significance and reliability of the model. Moreover, the linear, interaction term, and quadratic coefficients showed significant effects ($p < 0.05$) on the expansion ratio of puffed soynuts. The significant p-value of the model and its F-value are 208.69, indicating the adequacy of the model and implying that the model is significant. There was only a lack of fit and the F value was not significant for the model that could be used to navigate the design space. The coefficient of determination ($R^2 = 0.996$) indicates that the model fits the data very well, as it is close to 1, indicating that the equation explains 99.63% of the variation in ER. The predicted R^2 value of 0.956 was in reasonable agreement with the adjusted R^2 value of 0.991.

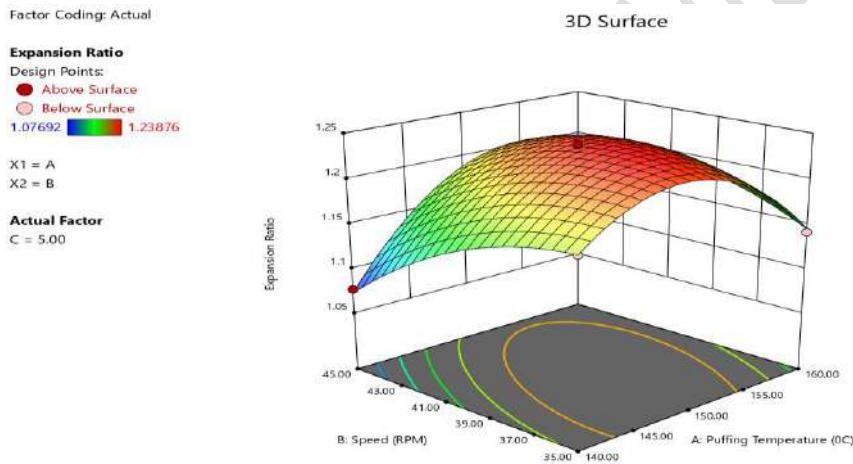


Fig. 5: Effect of puffing temperature and stirrer speed on expansion ratio of puffed soynuts at constant puffing time

Factor Coding: Actual

Expansion Ratio

Design Points:

● Above Surface

○ Below Surface

1.07692  1.23876

X1 = A

X2 = C

Actual Factor

B = 40.00

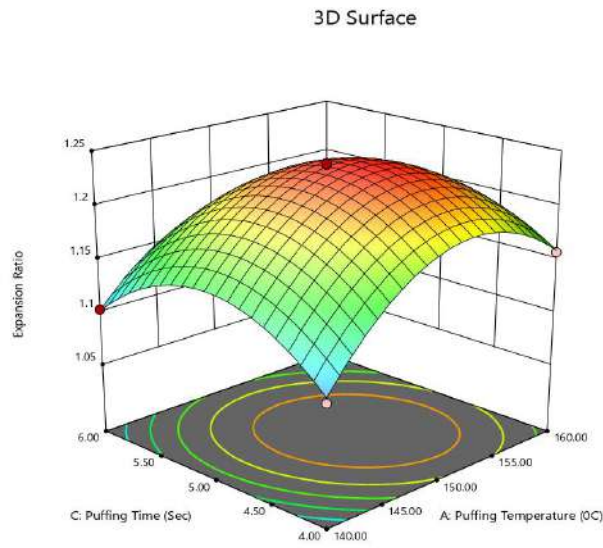


Fig. 6: Effect of puffing temperature and puffing time on expansion ratio of puffed soynuts at constant stirrer speed

Factor Coding: Actual

Expansion Ratio

Design Points:

● Above Surface

○ Below Surface

1.07692  1.23876

X1 = B

X2 = C

Actual Factor

A = 150.00

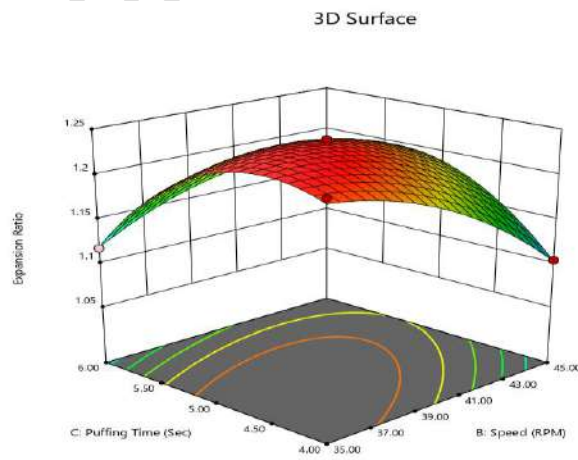


Fig. 7: Effect of stirrer speed and puffing time on expansion ratio of puffed soynuts at constant puffing temperature

To visualize the combined effect of two process parameters (variables) on expansion ratio, the response surface graphs were generated as a function of two variables while keeping the other variable at their central values. Graphical representations of the regression equation are shown through a three-dimensional (3D) response surface plot. As shown in Figs. 5, 6 and 7, it is clear that the expansion ratio of puffed soynuts increased with increasing puffing temperature (S_1) up to 150 °C, stirrer speed (S_2) up to 40 rpm and puffing time (S_3) at 5 min, respectively. Further, the expansion ratio of puffed soynuts decreased at higher levels of these process parameters. The maximum expansion ratio of puffed soynuts was found at the optimum level of process variables, that is, S_1 (150 °C) puffing temperature, S_2 (40 rpm) stirrer speed, and S_3 (5 min) puffing time.

4.3.3 Effect of process parameter on bulk density (BD) for the production of puffed soynuts

The bulk density of puffed soynuts is the ratio of the weight of puffed soynuts to its volume of puffed soynuts. The bulk density of the design matrix and the response values obtained for the combination of the three factors at the three levels are given in Table 3. The responses were analyzed using coded machines to evaluate the significant effects of three factors: puffing temperature (S_1) of puffed soynuts, stirrer speed (S_2) and puffing time (S_3) of puffed soynuts. The higher the expansion volume of puffed soynuts, the lower is the bulk density of puffed soynuts. Bulk density values for puffed soynuts ranged from 601.82 to 705.88 kg/m³, as shown in Table 3. The regression equation for bulk density is as follows:

$$\text{BD (Kg/m}^3\text{)} = 12126.94 - 157.00 S_1 + 4.88 S_2 + 13.76 S_3 - 0.12 S_1 S_2 - 5.28 E003 S_1 S_3 - 0.68 S_2 S_3 + 0.55 S_1^2 + 0.18 S_2^2 + 4.35 S_3^2 \quad (R^2=0.994) \quad \dots(4.3)$$

Where,

S_1 = Puffing temperature, S_2 = Stirrer speed and S_3 = Puffing time

The given regression equation (4.3) models bulk density (BD) in kg/m³ as a function of three independent variables S_1 , S_2 and S_3 . This model incorporates linear, interactive, and quadratic terms, making it a second-order polynomial regression model. The significant negative linear effect of S_1 suggests that BD decreases with increasing S_1 , but the positive quadratic term indicates that beyond a certain threshold, BD might start increasing. The positive contributions of S_2 and S_3 suggest that higher values of these parameters generally enhance the BD. The

interaction effects are negative, which means that increasing the two variables together does not necessarily yield an additive or synergistic improvement in BD. The three linear parameters were significant, of which the puffing temperature was the most influential parameter on bulk density, followed by puffing time and stirrer speed.

Table 7: Analysis of variance (ANOVA) for process parameters showing the effect on bulk density of puffed soynuts

Source	Sum of Squares	df	Mean Square	F-value	P-value
Model	19829.09	9	2203.23	130.72	< 0.0001*
(S ₁): Puffing temperature	6090.6	1	6090.6	361.35	< 0.0001*
(S ₂): Stirrer speed	347.42	1	347.42	20.61	0.0027*
(S ₃): Puffing time	97.32	1	97.32	5.77	0.0473*
S ₁ S ₂	132.87	1	132.87	7.88	0.0262*
S ₁ S ₃	0.011	1	0.011	6.60E-04	0.9802
S ₂ S ₃	45.63	1	45.63	2.71	0.1439
S ₁ ²	12636.36	1	12636.36	749.71	< 0.0001*
S ₂ ²	86.06	1	86.06	5.11	0.0584
S ₃ ²	79.61	1	79.61	4.72	0.0663
Residual	117.98	7	16.85		
Lack of Fit	97.65	3	32.55	6.4 ^{NS}	0.0524
Pure Error	20.33	4	5.08		
Cor Total	19947.07	16			
R-Squared	0.9941				
Adj R-Squared	0.9865				
Pred R-Squared	0.9201				
Std. Dev.	4.11				
Mean	634.13				
C.V. %	0.65				

*Significant at 5 % level

NS- Non significant

Where, bulk density (kg/m³), puffing temperature (°C), stirrer speed (rpm) and puffing time (min).

Table 7 shows that all linear terms, interaction terms S₁S₂ and quadratic term S₁² are significant at (P < 0.05) level of significance. The linear model was found to fit well for the data and the model F value of 130.72 implies that the model is significant. The lack-of-fit test was not significant and the predicted R² value was compatible with the adjusted R² value. The coefficient of determination (R² = 0.994) indicated that the model explained 99.41% of the variability in BD, suggesting an excellent fit.

Factor Coding: Actual

Bulk Density (kg/m3)

Design Points:

● Above Surface

○ Below Surface

601.816  705.875

X1 = A

X2 = B

Actual Factor

C = 5.00

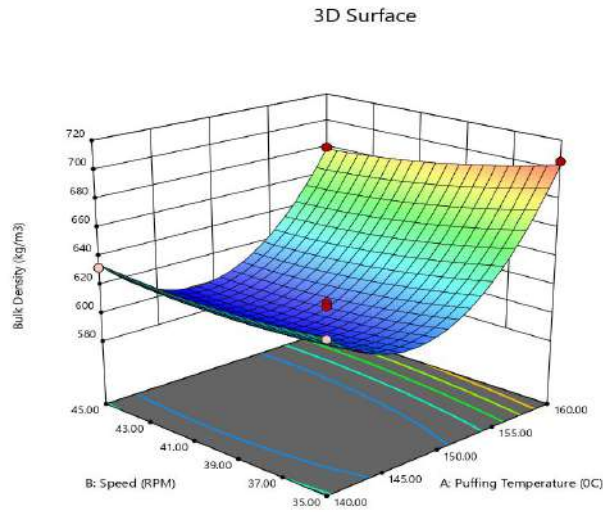


Fig. 8: Effect of puffing temperature and stirrer speed on bulk density of puffed soynuts at constant puffing time

Factor Coding: Actual

Bulk Density (kg/m3)

Design Points:

● Above Surface

○ Below Surface

601.816  705.875

X1 = A

X2 = C

Actual Factor

B = 40.00

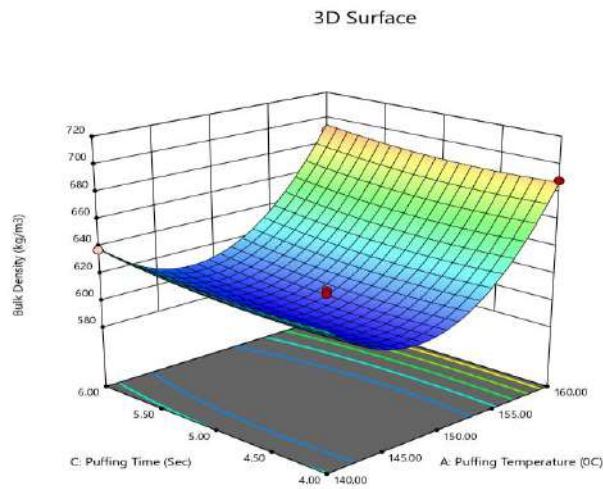


Fig. 9: Effect of puffing temperature and puffing time on bulk density of puffed soynuts at constant stirrer speed

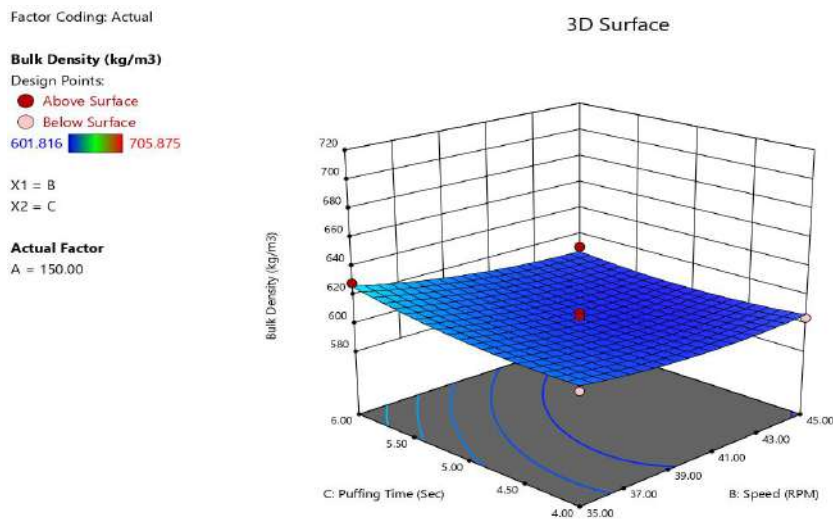


Fig. 10: Effect of stirrer speed and puffing time on bulk density of puffed soynuts at constant puffing temperature

As shown in Figs. 8, 9 and 10, it is clear that the bulk density of puffed soynuts decreases with increasing puffing temperature (S_1) up to 150°C , stirrer speed (S_2) up to 40 rpm and puffing time (S_3) at 5 min, their bulk density value of puffed soybean increased at higher levels of these process parameters. The optimum bulk density of puffed soynuts was found at the following optimum process variables: S_1 (150°C) puffing temperature, S_2 (40 rpm) stirrer speed and S_3 (5 min) puffing time.

It was visually observed that the soybean grains were not properly puffed at lower temperatures 140°C , which may be because the pressure inside the kernel was low, resulting in a less expanded structure and ultimately decreasing the bulk density of puffed soynuts. Similar results were obtained by Subramani et al. (2020), Jadhav (2018), Khedekar (2013) for soybean puff.

4.3.4 Effect of process parameter on colour for the production of puffed soynuts:

The colour of puffed soynuts was determined using a Colour Flex Hunter Lab Colourimeter in terms of L value. The colour (L value) indicates the lightness of the puffed soynuts. The lightness value indicates a measure of colour on the light-dark axis, which in turn denotes that the puffed soynuts turned dark at reduced L value. The data recorded for the average colour of the puffed soynuts after each set of experiments with replications are shown in Table 3 and it ranged between 47.52 to 57.40 within the combinations of variables studied.

By applying multiple regression analysis to the experimental data, a second-order polynomial equation was established to estimate the relation between the response (colour L value) and independent variables (S_1 , S_2 and S_3) during puffing, which is given by the following equation:

$$\text{Colour, L value} = -167.33 + 2.86 S_1 - 0.23 S_2 + 11.48 S_3 + 0.02 S_1 S_2 - 0.10 S_1 S_3 + 0.21 S_2 S_3 - 0.01 S_1^2 - 0.039 S_2^2 - 0.73 S_3^2$$

$$(R^2 = 0.989) \dots\dots (4.4)$$

Where,

S_1 = Puffing temperature, S_2 = Stirrer speed and S_3 = Puffing time

The above regression equation highlights the individual effect of process parameters on the L value of puffed soynuts, which likely represents a measure of brightness or lightness in a puffing process as a function of three independent variables. The coefficients of the regression equation with a positive sign for puffing temperature and puffing time indicate a synergistic effect, whereas the negative sign for the coefficient of stirrer speed represents an antagonistic effect on the color response. The magnitude of the coefficient of linear terms of the model revealed that puffing time was the most influential process variable, followed by puffing temperature and stirrer speed.

Table 8: Analysis of variance (ANOVA) for process parameters showing the effect on colour L value of puffed soynuts

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	139.7	9	15.52	74.94	< 0.0001*
(S_1): Puffing temperature	48.36	1	48.36	233.5	< 0.0001*
(S_2): Stirrer speed	31.6	1	31.6	152.57	< 0.0001*
(S_3): Puffing time	35.49	1	35.49	171.35	< 0.0001*
$S_1 S_2$	3.37	1	3.37	16.26	0.005*
$S_1 S_3$	3.72	1	3.72	17.98	0.0038*

S_2S_3	4.22	1	4.22	20.39	0.0027*
S_1^2	5.26	1	5.26	25.41	0.0015*
S_2^2	4.09	1	4.09	19.74	0.003*
S_3^2	2.26	1	2.26	10.92	0.013*
Residual	1.45	7	0.21		
Lack of Fit	0.91	3	0.3	2.28 ^{NS}	0.2217
Pure Error	0.54	4	0.13		
Cor Total	141.15	16			
R-Squared	0.9897				
Adj R-Squared	0.9765				
Pred R-Squared	0.8904				
Std. Dev.	0.46				
Mean	53.94				
C.V. %	0.84				

*Significant at 5 % level

NS- Non significant

Where, colour L value, puffing temperature (°C), stirrer speed (rpm), puffing time (min)

Whether a quadratic model is significant or not could be determined through ANOVA as seen in Table 8. ANOVA shows that quadratic regression model (Eq.4.4) was highly significant. The colour F- value for model is 74.94 and it is insignificant as p-value < 0.0001..The model adequacy was further confirmed by a satisfactory value of

Factor Coding: Actual

3D Surface

Colour

Design Points:

● Above Surface
○ Below Surface
47.52 57.4

X1 = A

X2 = B

Actual Factor

C = 5.00

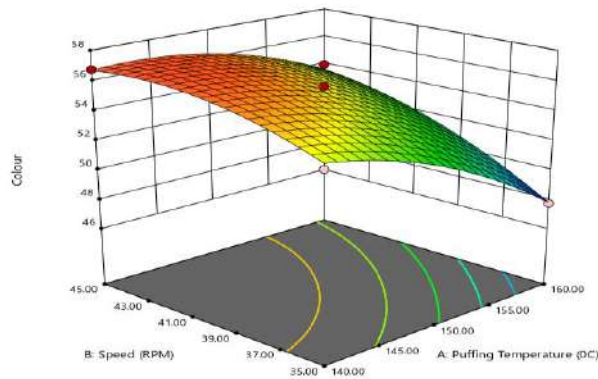


Fig. 11: Effect of puffing temperature and stirrer speed on colour L value of puffed soynuts at constant puffing time

Factor Coding: Actual

Colour

Design Points:

● Above Surface

○ Below Surface

47.52 57.4

X1 = A

X2 = C

Actual Factor

B = 40.00

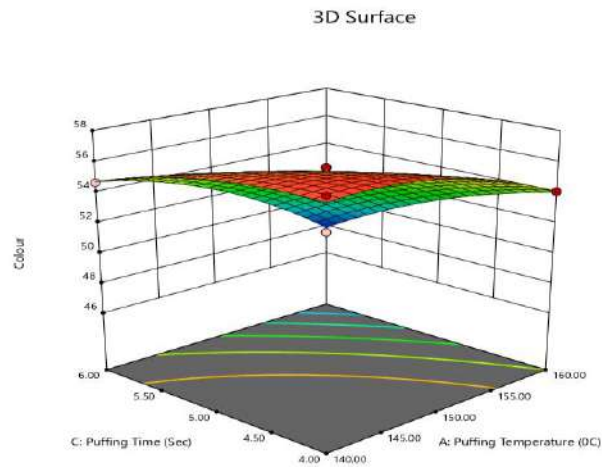


Fig. 12: Effect of puffing temperature and puffing time on colour L value of puffed soynuts at constant stirrer speed

Factor Coding: Actual

Colour

Design Points:

● Above Surface

○ Below Surface

47.52 57.4

X1 = B

X2 = C

Actual Factor

A = 150.00

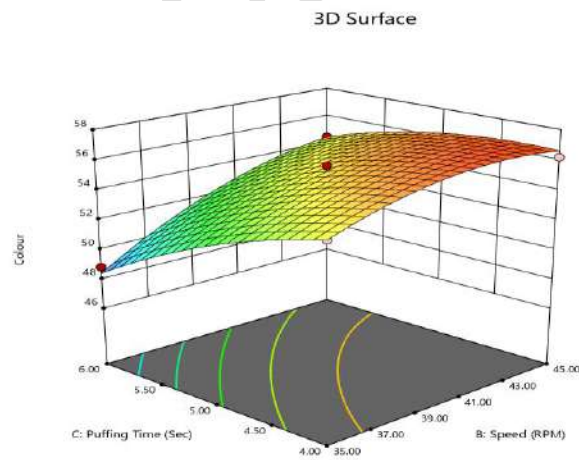


Fig. 13: Effect of stirrer speed and puffing time on colour L value of puffed soynuts at constant puffing temperature

the determination coefficient R^2 , which was calculated to be 0.989, demonstrating strong predictive capability. The value suggests that the model could predict 98.97 % of the

variability in the response. It is adequate for this regression model within the range of experimental variables. The value of the F test for lack of fit is 2.28 which imply that there is non-significant lack of fit at ($P < 0.05$) significance level and the model is acceptable.

The response surfaces and contour plots for L^* value of RTE puffed soynuts were generated for the fitted model as a function of two variables while keeping third variable at its central value which was presented in Figs. 11,12,13. These figures exhibited that, colour value of puffed soybean increased with increase in puffing temperature (S_1) of raw soybean up to 150 °C, stirrer speed (S_2) up to 40 rpm and puffing time (S_3) at 5 min, further colour value of puffed soynuts decreased at higher levels of these process parameters. As puffing temperature increased from 140 °C to 150 °C, colour value of puffed soynuts was increased up to 150 °C and further it decreased and puffed soynuts became darker with increase in puffing temperature up to 160 °C. As per visual observations, at 140 °C puffing temperature soybean grain were not properly puffed however at 160 °C puffing temperature soybean grain were almost spot burned and were not acceptable in terms of colour L value. Kahgyoglu and Kaya (2006) also stated that denaturation of protein inside the grain particles after puffing may be the factor contributing the overall decrease in L value of RTE puffed soynuts. Puffing time (S_3) and puffing temperature (S_1) is a key factor influencing brightness, but excessive temperatures may have diminishing returns, its possibly due to due to thermal degradation. Stirrer speed (S_2) has a small negative impact on brightness, suggesting that too much agitation might cause darkening, possibly due to oxidation or uneven processing. Thus L value is an adequate parameter for the monitoring the color change and thus for controlling the puffing of puffed products (Ozdemir and Devres, 2000).

4.3.5 Effect of process parameter on hardness for the production of puffed soynuts

Hardness is defined as the force required to compress a substance to a given deformation or penetration and is designated as a soft, hard or firm. The hardness value was considered as the mean peak compression force. Hardness of the puffed soynuts was measured for different combinations of process parameters by using TA.XT-2 Texture Analyzer as per the experimental design and presented in Table 3. Hardness value of puffed soynuts varied between 37.98 to 92.57 N within the combination of variable studied.

The quadratic equation describing the effect of the process parameters on hardness of puffed soynuts in terms of actual level of variables are given as:

$$\text{HRD (N)} = 4873.20 - 62.97 S_1 + 25.10 S_2 - 233.36 S_3 - 0.21 S_1 S_2 + 1.50 S_1 S_3 - 2.91 S_2 S_3 + 0.21 S_1^2 + 0.28 S_2^2 + 12.81 S_3^2$$

$$(R^2 = 0.981) \dots\dots (4.5)$$

Where,

S_1 = Puffing temperature, S_2 = Stirrer speed and S_3 = Puffing time

The above equation presents that the regression coefficients (linear, interactive and quadratic) pertaining to process variables along with their respective level of significance. The positive sign of linear coefficient indicated that, with an increase in level of stirrer speed, there was an increase in the hardness value while a negative sign of linear coefficient indicated that hardness value of puffed soy nuts decreased with increase in puffing temperature and puffing time. From the above equation it is clear that, the puffing time was the most influencing parameter on hardness value of puffed soy nuts followed by puffing temperature and stirrer speed.

Table 9: Analysis of variance (ANOVA) for process parameters showing the effect on hardness of puffed soy nuts

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	5867.83	9	651.98	41.52	< 0.0001*
(S ₁): Puffing temperature	400.02	1	400.02	25.47	0.0015*
(S ₂): Stirrer speed	161.3	1	161.3	10.27	0.015*
(S ₃): Puffing time	94.45	1	94.45	6.01	0.044*
S ₁ S ₂	447.53	1	447.53	28.5	0.0011*
S ₁ S ₃	901.8	1	901.8	57.42	0.0001*
S ₂ S ₃	848.32	1	848.32	54.02	0.0002*
S ₁ ²	1869.62	1	1869.62	119.05	< 0.0001*
S ₂ ²	200.76	1	200.76	12.78	0.009*
S ₃ ²	690.68	1	690.68	43.98	0.0003*
Residual	109.93	7	15.7		
Lack of Fit	70.15	3	23.38	2.35 ^{NS}	0.2136
Pure Error	39.78	4	9.95		
Cor Total	5977.76	16			
R-Squared	0.9816				
Adj R-Squared	0.9580				
Pred R-Squared	0.8018				
Std. Dev.	3.96				
Mean	61.77				
C.V. %	6.42				

*Significant at 5 % level NS- Non significant

Where,

hardness (N), puffing temperature (°C), stirrer speed (rpm), puffing time (min).

From the Table 9 model F value as 41.52 implies that the model is significant (p-value < 0.0001). The lack of fit F value (2.35) was non-significant for the model as p-value was 0.2136. Moreover, the predicted coefficient of determination of 0.8018 was in reasonable agreement with the adjusted coefficient of determination of 0.9580; *i.e.*, the difference is less than 0.2. Therefore, this model could be used to navigate the design space.

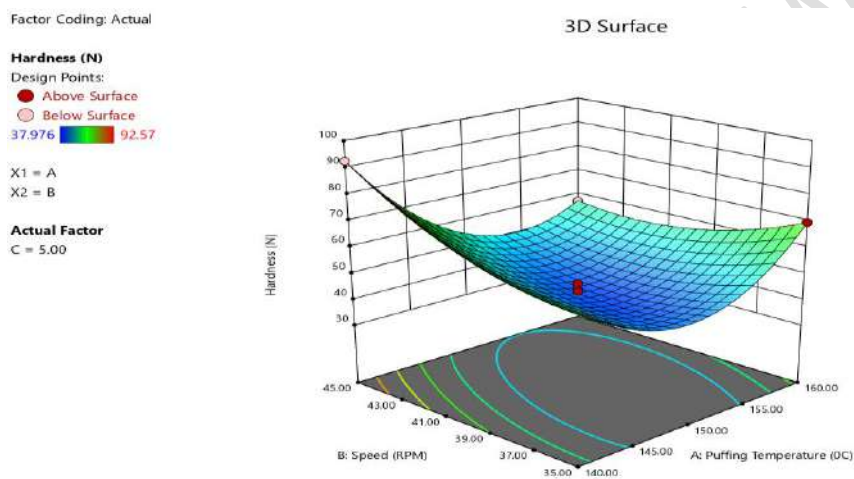


Fig. 14: Effect of puffing temperature and stirrer speed on hardness value of puffed soynuts at constant puffing time

Factor Coding: Actual

Hardness (N)

Design Points:

● Above Surface

○ Below Surface

37.976 92.57

X1 = A

X2 = C

Actual Factor

B = 40.00

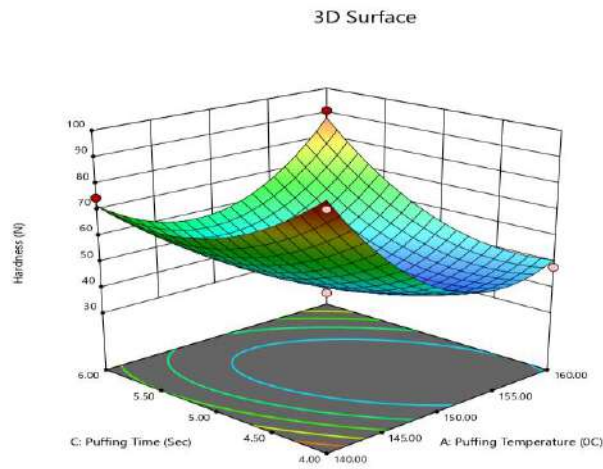


Fig. 15: Effect of Puffing temperature and puffing time on hardness value of puffed soynuts at constant stirrer speed

Factor Coding: Actual

Hardness (N)

Design Points:

● Above Surface

○ Below Surface

37.976 92.57

X1 = B

X2 = C

Actual Factor

A = 150.00

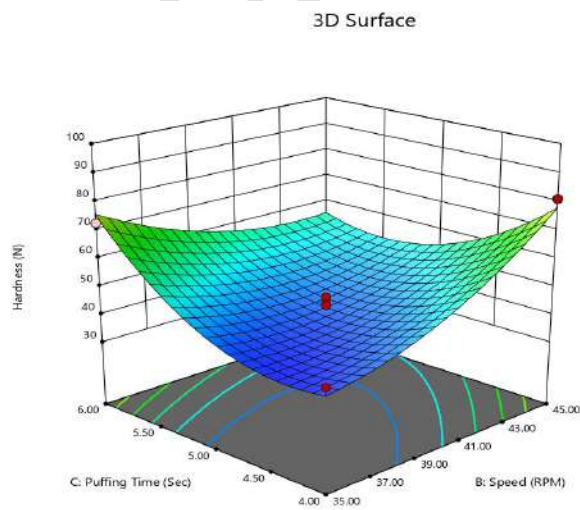


Fig. 16: Effect of stirrer speed and puffing time on hardness value of puffed soynuts at constant puffing temperature

To visualize the combined effect of two variables on hardness, the response surface contour plots (Figs. 14 through 16) were generated for the fitted model as a function of two variables while keeping other one variable at constant value. It was observed that, the hardness of puffed soynuts decreased with an increase in puffing temperature of (S_1) up to 150 °C, stirrer speed (S_2) up to 40 rpm, puffing time (S_3) up to 5 min. Further hardness of puffed soynuts increased at high level of these process parameters. This may be due to the loss and gain in moisture content and exposed to lower temperature during puffing causing the more hard texture, tough and higher temperature brittle. Similar results were observed in case of roasted soynuts quoted by Deshmukh (2016).

4.3.6 Effect of process parameter on crispness for the production of puffed soynuts:

Crispness of the puffed soynuts were measured for different combinations of process parameters by using TA.XT-2 Texture Analyzer as per the experimental design and presented in Table 3. The experimental values of crispness were in the range of 10 to 24 within the combinations of variables studied. The second-order polynomial equation illustrated the relationship of the three variables, which was established to explain crispness in equation 4.6.

$$CSP \text{ (number of +ve peaks)} = -1361.88 + 16.21 S_1 - 1.38 S_2 + 77 S_3 + 0.05 S_1S_2 - 0.35 S_1S_3 + 0.4 S_2S_3 - 0.054 S_1^2 - 0.10 S_2^2 - 4.13 S_3^2$$

$$(R^2=0.989) \dots\dots\dots (5.6)$$

Where, S_1 = Puffing temperature, S_2 = Stirrer speed and S_3 = Puffing time

All linear terms, interaction terms and quadratic terms are significant in above equation. The negative sign of linear regression coefficient viz; stirrer speed revealed that with increase in these process parameters, decreases the crispness value. The positive sign of linear regression coefficient puffing temperature and puffing time revealed that with increase in these process parameter increase the crispness value. The effect of puffing time on crispness value is most influencing factor followed by puffing temperature and stirrer speed.

Table 10: Analysis of variance (ANOVA) for process parameters showing the effect on crispness of puffed soynuts

Source	Sum of Squares	df	Mean Square	F-value	P-value
Model	354.37	9	39.37	73.5	< 0.0001*
(S_1): Puffing temperature	15.13	1	15.13	28.23	0.0011*
(S_2): Stirrer speed	10.13	1	10.13	18.9	0.0034*

(S ₃): Puffing time	4.5	1	4.5	8.4	0.023*
S ₁ S ₂	20.25	1	20.25	37.8	0.0005*
S ₁ S ₃	49	1	49	91.47	< 0.0001*
S ₂ S ₃	16	1	16	29.87	0.0009*
S ₁ ²	121.64	1	121.64	227.07	< 0.0001*
S ₂ ²	23.75	1	23.75	44.33	0.0003*
S ₃ ²	71.64	1	71.64	133.74	< 0.0001*
Residual	3.75	7	0.54		
Lack of Fit	1.75	3	0.58	1.17 ^{NS}	0.4262
Pure Error	2	4	0.5		
Cor Total	358.12	16			
R-Squared	0.9895				
Adj R-Squared	0.9761				
Pred R-Squared	0.9131				
Std. Dev.	0.73				
Mean	17.41				
C.V. %	4.2				

*Significant at 5 % level

NS- Non significant

Where,

crispness (number of +ve peaks), puffing temperature (°C), stirrer speed (rpm), puffing time (min).

Table 10 shows that the all linear term, interaction terms S₁S₂ and quadratic term S₁² are significant at (p < 0.05) level of significance. The linear model was found to fit well for the data and the model F value of 73.50 implies that the model is significant. Lack of fit test was not significant as p value exceeds 5 % level of significance. The lack of fit of the model was not significant, which indicates that the models were correlated well with the measured data. The R² value was calculated by a least square technique and found to be 0.9895 showing good fit of model to the data. Moreover, the predicted R² of 0.9131 was in reasonable agreement with the adjusted R² of 0.9761; *i.e.* the difference is less than 0.2. This revealed that the non-significant terms have not included in the model. Therefore, this model could be used to navigate the design space.

Factor Coding: Actual

Crispness

Design Points:

● Above Surface

○ Below Surface

10  24

X1 = A

X2 = B

Actual Factor

C = 5.00

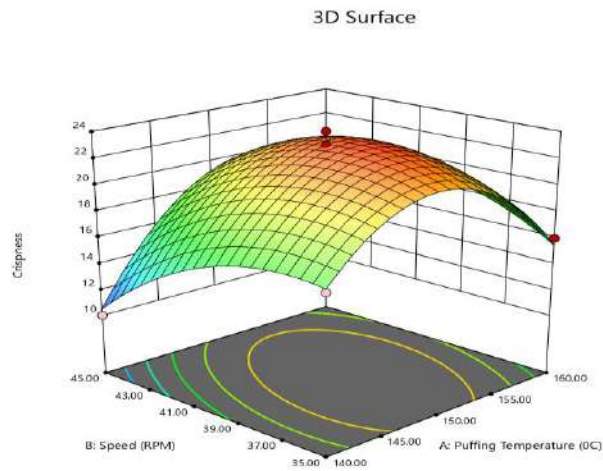


Fig. 17: Effect of puffing temperature and stirrer speed on crispness value of puffed soynuts at constant puffing time

Factor Coding: Actual

Crispness

Design Points:

● Above Surface

○ Below Surface

10  24

X1 = A

X2 = C

Actual Factor

B = 40.00

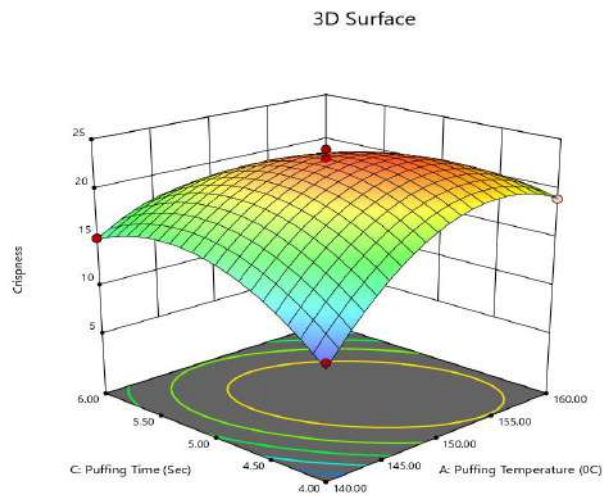


Fig. 18: Effect of puffing temperature and puffing time on crispness value of puffed soynuts at constant stirrer speed

Factor Coding: Actual

Crispness

Design Points:

● Above Surface

○ Below Surface

10  24

X1 = B

X2 = C

Actual Factor

A = 150.00

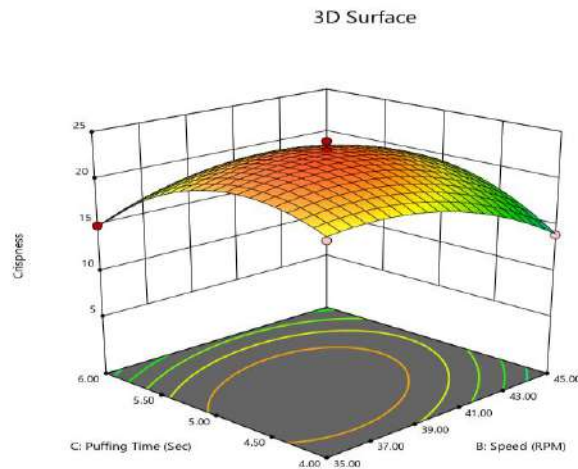


Fig. 19: Effect of stirrer speed and puffing time on crispness value of puffed soynuts at constant puffing temperature

The response surface and contour plots as shown in Figs. 17,18,19 were generated for the fitted model (Eq. 4.6) as a function of two variables while keeping one variable at constant value. It was noted that, the crispness of puffed soynuts was increased with an increase in puffing temperature of (S_1) up to 150 °C, stirrer speed (S_2) up to 40 rpm and puffing time 5 min. Further crispness of puffed soynuts decreases at higher levels of these process parameters.

It was visually observed that, at higher puffing temperature of 160 °C, crispness values of puffed soynuts were decreased. This may be due to the fact that, at higher levels of puffing temperature up to 160 °C soynuts gets over burned and burned and resulting the brittle texture thereby reducing the crispness value of RTE puffed soynuts. Similar results were observed by Jadhav (2018) for crispness value of puffed soynuts.

4.3.7 Optimization and validation of process parameters for the production of puffed soynuts

Optimization of process parameters was done using *Design Expert 8.0.6* software. The optimization of process parameters such as puffing temperature, stirrer speed and puffing time were necessary to obtain better quality of puffed soynuts. Optimization of process parameter for puffed soynuts was performed on the basis of its quality characteristics such as the good quality

puffed soynuts should have maximum puffing efficiency, expansion ratio and optimum range in hardness, colour L value, bulk density and crispness.

Table 11: Constraints of process parameters for the production of puffed soynuts

Independent variable	Goal	Lower limit	Upper limit
Puffing temperature (°C)	in range	140	160
Stirrer speed (rpm)	in range	35	45
Puffing time (min)	in range	4	6
Puffing efficiency (%)	Maximum	68.18	98.41
Expansion ratio	Maximum	1.07	1.24
Bulk density (Kg/m ³)	in range	601.81	705.88
Colour L value	in range	47.52	57.40
Hardness (N)	in range	37.98	41
Crispness (number of +ve peaks)	in range	22	24

The constraints (Lower limit, upper limit and target value) given in Table 11 were used to find out the range of optimum values of process variables S₁ (Puffing temperature), S₂ (Stirrer speed) and S₃ (Puffing time).

4.3.8 Numerical optimization for the production of puffed soynuts

Numerical optimization was carried out by putting the values of independent variables within the experimental range and by setting desirable goals for the each response (Table 11). The simultaneous optimization of the multiple responses was carried out and it gives optimum conditions of process parameters with the predicated values of responses. For more precise values of the responses a solution having maximum desirability (1.00) was selected (Appendix B).

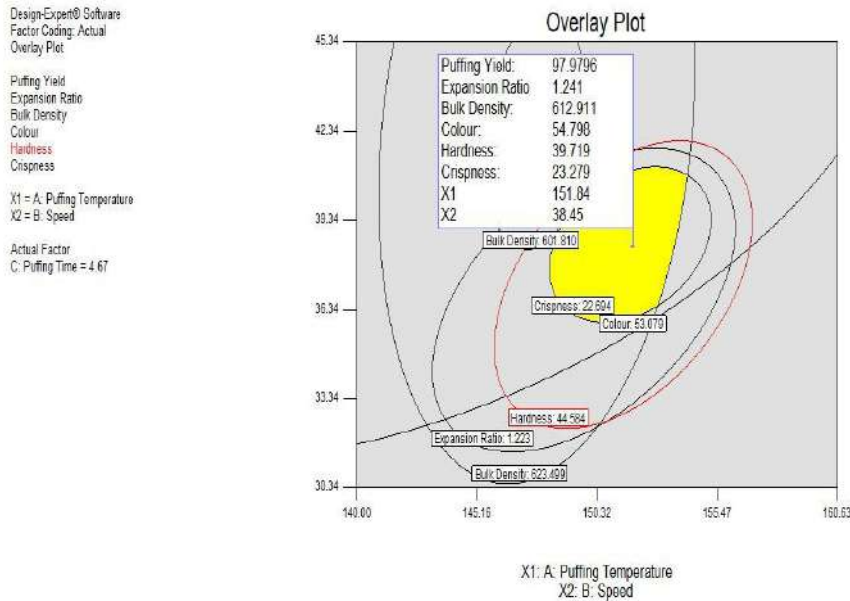
The optimum values of process variables obtained by numerical optimization as follows:

- Puffing temperature (°C) : 151.84 ≈ 150
- Stirrer speed (rpm) : 38.45 ≈ 40
- Puffing time (min) : 4.67 ≈ 5

4.3.9 Graphical optimization for the production of puffed soynuts

The graphical optimization was carried out by superimposition of contours to find the range of process parameters in which the values of responses given by numerical optimization was obtained. It is evident from Fig. 20 (a b and c) that the predicted values of all responses lay well within the optimum intersection zone of process parameters; region that do not fit the optimization criteria are shaded gray and maximum desirability function point presented in yellow zone. The superimposed contours of all responses for puffing temperature (°C) vs stirrer speed (rpm) is shown in Fig.20 (a); puffing temperature (°C) vs puffing time (min) is shown in Fig20 (b) and puffing time (min) vs stirrer speed (rpm) is shown in Fig.20(c).

The superimposed contours of all responses is shown in Fig.20 (a) for puffing temperature (°C) vs stirrer speed (rpm); in Fig. 20 (b) puffing temperature (°C) vs puffing time (min) and in Fig. 20 (c) puffing time (min) vs stirrer speed (rpm).



(a)

Factor Coding: Actual

Overlay Plot

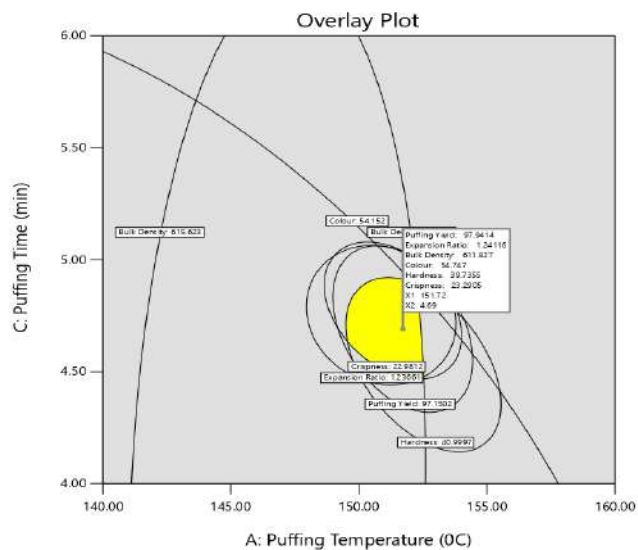
- Puffing Yield
- Expansion Ratio
- Bulk Density
- Colour
- Hardness
- Crispness

X1 = A

X2 = C

Actual Factor

B = 38.36



(b)

Factor Coding: Actual

Overlay Plot

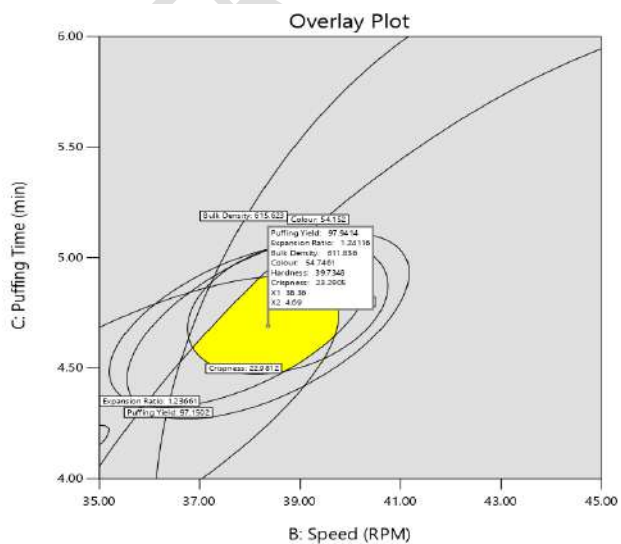
- Puffing Yield
- Expansion Ratio
- Bulk Density
- Colour
- Hardness
- Crispness

X1 = B

X2 = C

Actual Factor

A = 151.72



(c)

Fig. 20 (a, b and c): Overlay plot showing predicted value of quality characteristics of puffed soynuts

The optimum values of responses obtained by graphical optimization as follows:

Puffing efficiency (%)	:	97.97
Expansion ratio	:	1.24
Bulk density (kg/m ³)	:	612.91
Colour L value	:	54.79
Hardness (N)	:	39.71
Crispness (number of +ve peaks)	:	23.27

4.3.10 Validation of model for the production of puffed soynuts:

The predicted optimum values of responses *viz.*, puffing efficiency, expansion ratio, bulk density, colour L value, hardness and crispness were verified by preparing the puffed soynuts using the combination of optimum condition of process variables *i.e.* 150 °C puffing temperature (S₁), 40 rpm of stirrer speed (S₂) and 5 min of puffing time (S₃). Table 12 shows the predicted and experimental values of puffed soybean for puffing yield (%), expansion ratio, bulk density (kg/m³), colour L value (Lightness), hardness (N) and crispness (number of +ve peaks).

Table 12: Predicted and experimental values of responses for the production of puffed soynuts

Responses	Predicted values	Experimental values	CV (%)
Puffing efficiency (%)	98.46	97.24	0.88
Expansion ratio	1.148	1.171	1.403
Bulk density (kg/m ³)	601.91	604.18	0.27
Colour L value	55.27	54.36	1.17
Hardness (N)	42.54	41.75	1.32
Crispness (number of +ve peaks)	23.20	22.40	2.48

From Table 12, it was observed that experimental values and predicted values are very close. The values predicted by the equation of puffing efficiency (%) (Eq.4.1), expansion ratio (Eq. 4.2), bulk density (kg/m³) (Eq.4.3), colour (L value) (Eq.4.4), hardness (N) (Eq.4.5) and crispness (number of +ve peaks) (Eq.4.6) were 98.46, 1.148, 601.91, 55.27, 42.54 and 23.20, respectively. As a general rule, the coefficient of variation (CV) should not be greater than 10%. In this study, the coefficients of variation were less than 10% for all the responses which indicates better precision and reliability of the experiments carried out. There was non-

significant difference between the experimental and predicted values of quality characteristics as indicated by lower values of CV. This indicated the suitability of the corresponding models. Therefore it could be concluded from the discussion that model developed for the puffing efficiency, expansion ratio, bulk density (kg/m^3), colour (L value), hardness (N) and crispness (number of +ve peaks) were adequate to assess the quality of the puffed soynuts.

4.3.11 Standardized flowchart for the production of puffed soynuts

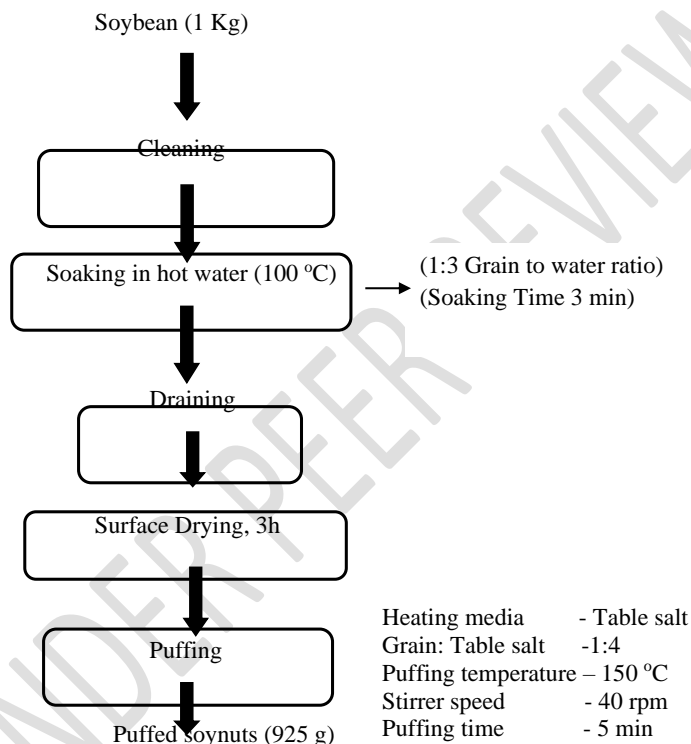


Fig. 21: Process flow chart for production for puffed soynuts prepared from soybean

In Fig. 21 process flow chart for production of puffed soynuts prepared from soybean on batch type semiautomatic multigrain puffing-cum-popping machine is given. The standard process for production of puffed soynuts was adopted as per Nilza, (2022). The puffing efficiency for production of puffed soynuts of this design and developed batch type semiautomatic multigrain puffing-cum-popping machine was found as 98 %. The output quantity of puffed soynuts was obtained as 925 g per kg raw soybean.

Conclusions:

The optimized values of the process parameters for the production of puffed soynuts on design and developed batch-type semi-automatic puffing-cum-popping machine obtained were puffing temperature (S₁) 150 °C, stirrer speed (S₂) 40 rpm and puffing time 5 min. The quantity of puffed soynuts was obtained as 925 g per kg raw soybean. The optimum values of responses obtained by graphical optimization was 97.97 % puffing efficiency (%), 1.24 expansion ratio, 612.91 kg/m³ bulk density, 54.79 colour L value, 39.71 N hardness and 23.27 (number of +ve peaks) crispness. The developed batch-type semiautomatic puffing-cum-popping machine has proven to be well-suited for production of puffed soynuts at small scale-level industries, had a puffing capacity of 80 kg/day.

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Include few line about the futuristic aspect of this research

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