ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(8): 210-216
www.agriculturaljournals.com
Received: 16-06-2026
Accepted: 18-07-2026

Ashwini Handibag
Ph.D. Scholar, College of Agricultural Engineering and Engineering, VNMKV, Parbhani, Maharashtra, India

A Vishnu charan
M.Tech Scholar, College of Agricultural Engineering and Technology, VNMKV, Parbhani, Maharashtra, India

R V Jaybhaye
Head, Department of Agricultural Process Engineering, CAET, VNMKV, Parbhani, Maharashtra, India

Kanifnath Nakade
M.Tech Student, Department of Agricultural Process Engineering, CAET, VNMKV, Parbhani, Maharashtra, India

SU Khodke
Retd. Head, Department of Agricultural Process Engineering, CAET, VNMKV, Parbhani, Maharashtra, India

Corresponding Author:
Ashwini Handibag
Ph.D. Scholar, College of Agricultural Engineering and Engineering, VNMKV, Parbhani, Maharashtra, India

Optimization of Process Parameters for Producing RTE Puffed Groundnut (Kharmure)

Ashwini Handibag, A Vishnu charan, RV Jaybhaye, Kanifnath Nakade and SU Khodke

DOI: https://www.doi.org/10.33545/2664844X.2026.v8.i8c.1773

Abstract
The development of puffed groundnuts was achieved through a High Temperature Short Time (HTST) principle. The investigation into the puffing process focused on how specific parameters namely, Soaking time (ST), Surface drying time (SDT), and Puffing temperature (PT) affect the quality of the final product. Experiments were structured using the Box Behnken Design (BBD) to facilitate this analysis. Through response surface methodology (RSM), both linear and quadratic models were developed to explore the interactions between these parameters and the resulting responses, which included Puffing Yield (PY), Expansion ratio (ER), Crispness (Cr), Hardness (Hd), and colour L-value The optimal conditions for achieving superior product quality were identified as a puffing temperature of 250 °C, a soaking time of 45 minutes, and a surface drying time of 4 hours. Under these conditions, the puffing yield reached 97.23%, the expansion ratio was 1.29, crispness was measured at 22 peaks, hardness was 69 N, and the colour L- value was 50.23.

Keywords: Ready-to-eat (rte) snacks, groundnut, htst puffing process, hardness, yield, crispiness

Introduction

The Ready-To-Eat (RTE) food sector represents a significant component of the food industry. The importance of RTE puffed and popped snacks are an undeniable fact in the era of fast life, rapid urbanization convenience and all a health-conscious society. RTE snacks prepared by puffing and popping of cereals, pulses and millets may provide a myriad of choices for meeting today's recommendations to increase the whole grain Oil-free intake for people of all age groups. Peanuts may be consumed and exported as raw, roasted and salted or processed as Flour, or crushed into edible oil, also for further use in desserts, candies and ice creams (Nepote *et al.*, 2006, Nathalia Mendes Machado *et al.*, 2025) [1]. Proximate analysis of peanut showing rich source of oil (43%) with a high content of unsaturated fatty acids (87%). Peanuts serve as an excellent source of protein, with a content range of 22.02% to 28.99%. (Venkatachalam *et al.*, 2006) [2]. Epidemiological studies indicated that consumption of nuts, as compared to other foodstuffs rich in fat, decreases oxidative stress, improves total cholesterol and high-density lipoprotein levels, thereby decreasing risk of coronary diseases and helps to control weight (Alper *et al.*, 2002) [3]. In addition to oil production, peanuts are transformed into snack foods due to their distinctive taste and rich nutritional content (Jiao *et al.*, 2015) [4]. Among these, dried salted peanuts are particularly favored, with roasting playing a crucial role in the procedure. This step significantly influences the final product's quality, including its crispness, taste, and flavor, as well as its shelf-life (Chen *et al.*, 2010) [5].

Puffed groundnut have availability of protein 23.63%, carbohydrates 14.89% and crude fibre 3.00%. However, puffing reduces moisture content and modifies the internal microstructure of groundnut kernels to create the characteristic crunchy and crispy texture, thereby causing a reduction in the level of aflatoxins-a poison produced by fungus in groundnut kernels (Woodroof J. G., 1983) [6]. The current research aimed to create a puffed groundnuts and to fine-tune the process parameters, specifically Soaking time (ST), Surface drying time (SDT), and Puffing temperature (PT). To achieve this, the study employed Box Behnken Design (BBD) along with response surface methodology (RSM) to apply a linear and second-order polynomial using the least squares method.

Materials and Methods

Preparation of puffed groundnut

The groundnuts are procured from local market of Parbhani. The raw groundnuts were soaked for 45 min, and then soaked groundnut were surface dried for 4 h prior to puffing. Groundnuts were puffed using a multigrain puffing-cum-popping machine at 250 ºC and 3 RPM, developed by the Department of Agricultural Process Engineering, College of Agricultural Engineering and Technology, VNMKV, Parbhani. The High Temperature Short Time (HTST) principle is the basis for its operation. A consistent grain to salt ratio of 1:10 is essential for effective puffing. The machine is equipped with a rotating drum and a panel that digitally controls the temperature.

Quality Evaluation of Puffed Groundnut Within the Experimental range

Puffing yield: The puffing yield of puffed groundnut is a ratio of final number of puffed grains to the number of total grains of puffed groundnut

Puffing yield was calculated by using following formula

$$Puffing\ Yield = \frac{Number\ of\ Puffed\ grains}{Total\ number\ of\ grains \in sample} \times 100$$

Expansion Ratio:

The expansion ratio was determined by measuring the average bulk volume of the product post-puffing and comparing it to its original average bulk volume. (Jadhav *et al.*, 2018) [7]

$$Expansion\ ratio = \frac{Total\ popped\ /\ puffed\ volume(cm^3)}{voulme\ of\ raw\ kernlas(cm^3)}$$

Color:

The L-value, indicating the color of the puffed groundnuts, was measured using a Hunter Lab colorimeter. These color readings are reported as L-values. Measurements were taken two days following the popping experiment (Jadhav, 2018) [7]. The L-value quantifies the lightness on a scale from 0 (black) to 100 (white). It was noted that the 'a' and 'b' values showed minimal variation with different process parameters, so the focus of this study was solely on the L-value (lightness). For each experimental sample, the average of three replicates was calculated (Tavanandi *et al.*, 2021) [8].

Textural Properties: Textural properties of puffed groundnut, specifically hardness and crispness, were assessed using a Stable Micro System TA-XT plus texture analyser from Texture Technologies Corp., UK. The analysis employed a cylindrical probe P75 with a testing force of 0.05N, 50% strain, measuring force in compression mode, a pre-test speed of 0.5 mm/s, and a test speed of 1 mm/s. Hardness was quantified using the average peak compression force, while crispness was determined from the major positive peaks obtained during compression. (Jaybhaye and Srivastav, 2015 and Anon *et al.*, 1998) [9, 10]. Each experiment involved averaging 10 replications for both parameters.

Effects of Process Parameters on the Quality Attributes of Puffed Groundnut

Design-Expert software (Version 10.0, Stat-Ease Inc., Minneapolis, MN, USA) was employed to create response surface graphs and contour plots, these graphs and contour plots are used to assess how process variables influenced the response variables (Jaybhaye and Srivastav, 2015) [9]. The same software facilitated both numerical and graphical optimization of the process parameters, aiming to decide the optimal levels of the independent variables. This optimization sought to enhance popping efficiency and expansion ratio while ensuring the desired bulk density, hardness, color, and crispiness were achieved (Montgomery, 2001; Pawar *et al.*, 2014) [11]. The experimental setup was crafted following the selection of parameter ranges, utilizing the Box Behnken Design (BBD) with three variables, each having three levels. The parameters assessed included soaking time, surface drying time, and puffing temperature, set at intervals of 30 to 60 minutes, to 5 hours, and 240 to 260 °C , respectively. A total of 17 experiments were executed in line with the BBD Design, and the experimental data were analyzed using Response Surface Methodology (RSM) with the aid of Design Expert-version 10.0.

The relationship between the response, Y , and the factors was hypothesized to be represented by a second order polynomial equation structured as follows:

$$Y = \beta_0 + \sum_{j=1}^{k}\beta_i X_j + \sum_{j=1}^{k}\beta_{jj}X_j^2 + \sum_{i=1}^{k}\beta_{ii}X_i^2 + \sum_{j=2}^{k}\beta_{ij}X_iX_j + \varepsilon \ \ldots\ldots 1$$

Where, y represents predicted response, Xi and Xj represents independent variables, β0= regression coefficients for interept, βi= linear coefficient, βii= squared coefficient, βij= interaction coefficient, ε =noise or error.

Table 1: Experimental Levels of Process Variables for Optimization

S. No.	Process variables	Range	Coded levels (Xi)	Levels			Interval variation
				-1	0	+1	
1	Soaking time (min)	30 - 60	X_1	30	45	60	15
2	Surface drying time (h)	3- 5 h	X_2	3	4	5	1
3	Puffing temperature (°C)	240 - 260	X_3	240	250	260	10

Table 2: Design of the experiment (involving 3 factors and 3 levels) and the related values of response quality parameters) wer acquired during the puffing process of groundnut.

Treatments				Quality characteristics				
	X_1	X_2	X_3	Popping yield (%)	Expansion ratio	Hardness (N)	Crispness (+ve peaks)	Color L*
1	-1	-1	0	85.67	1.19	79	13	50.59
2	1	-1	0	86.59	1.28	76	14	49.17
3	-1	1	0	81.42	1.21	81	16	50.42
4	1	1	0	91.62	1.27	76	15	49.54
5	-1	0	-1	56.74	1.12	140	14	32.73
6	1	0	-1	60.43	1.12	123	19	40.45

7	-1	0	1	77.52	1.15	49	21	41.52
8	1	0	1	79.75	1.13	54	13	42.57
9	0	-1	-1	61.38	1.12	127	14	43.78
10	0	1	-1	60.23	1.11	136	17	42.86
11	0	-1	1	82.53	1.12	60	19	47.24
12	0	1	1	81.65	1.16	53	18	48.65
13	0	0	0	96.52	1.27	68	23	50.85
14	0	0	0	96.29	1.28	70	22	50.43
15	0	0	0	96.37	1.31	68	23	48.56
16	0	0	0	97.23	1.28	70	23	50.76
17	0	0	0	97.63	1.29	69	22	50.23

X_1 = Soaking time, X_2=Surface drying time and X_3 = Puffing temperature

Results and Discussion

Impact of Different Process Parameters on Puffing Yield

Table 2 displays the calculated puffing yield values for puffed groundnut produced using various combinations of process parameters. The puffing yield values for puffed groundnut were found to range from 56.74% to 97.63% across the different variable combinations examined. The quadratic equation that illustrates the impact of process parameters on the puffing yield of puffed groundnut, expressed in terms of the actual levels of variables, is provided as follows:

$$PY = +96.80 + 3.13X_1 + 1.15X_2 + 12.33X_3 - 0.8575X_1X_2 - 1.96X_1X_3 - 0.6050X_2X_3 - 6.39X_1^2 - 3.45X_2^2 - 20.60X_3^2 \; (R^2 = 0.998) \ldots .2$$

Where, X_1 = soaking time, X_2 = surface drying time and X_3 = puffing temperature

The effects of the processing variables on the puffing yield of groundnut were evaluated using the ANOVA F-values (Table 3) and the estimated regression coefficients of the actual variables. The developed quadratic model was highly significant (Model F-value=386.77; $p < 0.05$) , indicating that it adequately explained the variation in puffing yield. In addition, the lack-of-fit was non-significant, confirming the suitability and predictive capability of the fitted model within the experimental domain. The positive linear regression coefficients for soaking time (X_1) , surface drying time (X_2) , and puffing temperature (X_3) indicated that increasing these process variables enhanced the puffing yield over the investigated range. As illustrated in Figure 1, the puffing yield increased progressively with increasing soaking time up to 45 min, surface drying time up to 4 h, and puffing temperature up to 250 °C . These findings suggest that adequate hydration, controlled moisture removal, and higher puffing temperature collectively promoted efficient expansion of the groundnut kernels, resulting in improved puffing yield.

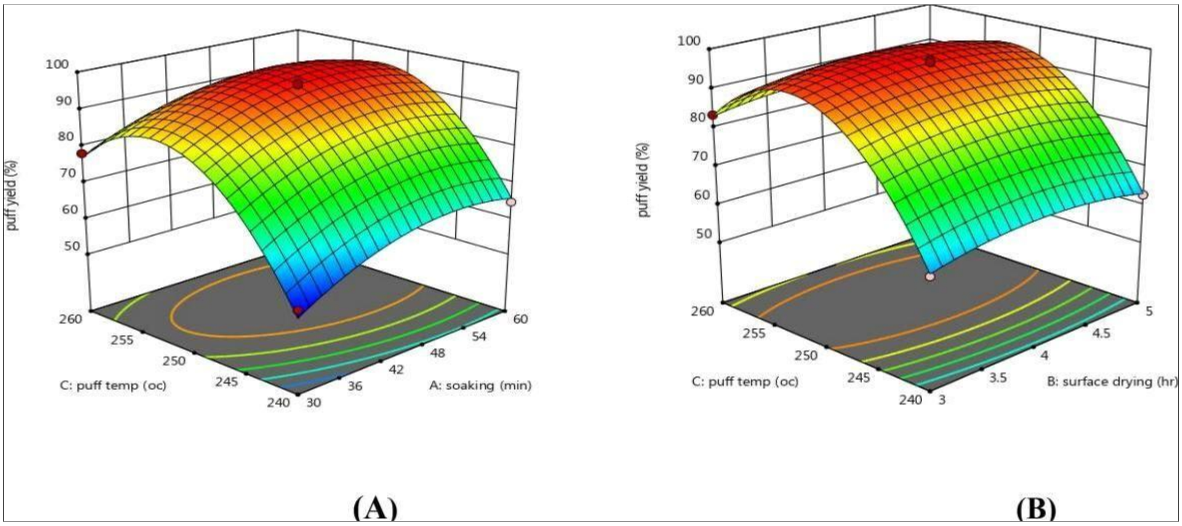


Fig 1: Effect of (A) soaking time (X1) and puffing temperature (X3) at a constant surface drying time (X2), and (B) surface drying time (X2) and puffing temperature (X3) at a constant soaking time (X1) on the puffing yield of puffed groundnut.

Impact of Different Process Parameters on Expansion ratio (ER)

Table 2 displays the calculated expansion ratios for puffed groundnut, which were prepared using various combinations of process parameters. The expansion ratios observed for the puffed groundnut varied from 1.11 to 1.31 across the different variable combinations examined. The quadratic equation that illustrates how the process parameters influence the expansion ratio of puffed groundnut, based on the actual levels of the variables, is provided as follows:

$$ER = 1.29 + 1.11X_1 + 0.96X_2 + 2.16X_3 + 0.02X_1X_2 - 0.05X_1X_3 + 0.05X_2X_3 - 0.03X_1^2 - 0.03X_2^2 - 0.13X_3^2 (R^2 = 0.950) \ldots \ldots 3$$

Where, X_1 = soaking time, X_2 = surface drying time and X_3 = puffing temperature

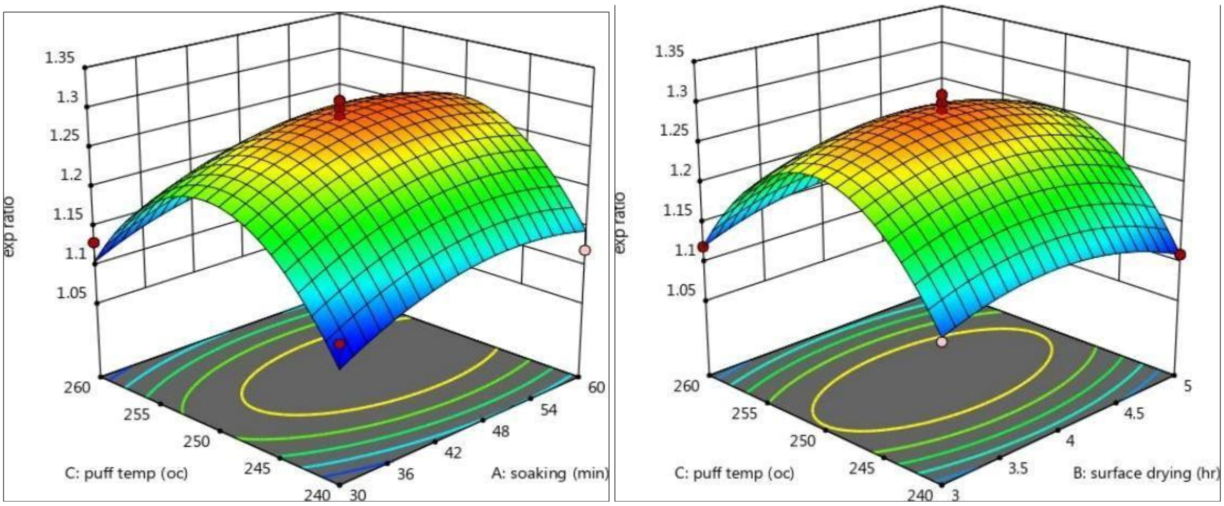
The influence of the processing variables on the expansion ratio of puffed groundnut was evaluated using the ANOVA F-values and the regression coefficients of the actual variables (Table 3).

The developed response surface model was statistically significant (Model F-value=14.81; $p<0.05$) indicating that the selected variables adequately explained the variation in expansion ratio. The positive linear coefficients of soaking time (X_1) , surface drying time (X_2) , and puffing temperature (X_3) demonstrated that increasing these processing parameters enhanced the expansion ratio within the experimental range. However, the negative quadratic coefficients indicated that further increases beyond the optimum levels resulted in a decline in expansion ratio, reflecting the existence of curvature in the response surface. Among the investigated variables, puffing temperature (X_3) had the most pronounced effect on the expansion ratio, followed by soaking time (X_1) and surface drying time (X_2) . As illustrated in Fig. 2, the expansion ratio increased with soaking time up to 45 min, surface drying time up to 4 h, and puffing temperature up to 250 °C . Beyond these optimum conditions, a progressive decline in expansion ratio was observed, which may be attributed to over-processing and structural deterioration of the groundnut kernels, thereby limiting further expansion during puffing.

Table 3: Variance analysis illustrating how process parameters influence the puffing yield, expansion ratio, crispiness, hardness, and L colour value of puffed groundnuts

Source	F-value				
	PY	ER	Cr	Hd	L*
Model	386.77*	14.81*	29.29*	192.58*	15.93*
X_1 -soaking time	38.93	2.54	2.32	18.92	1.91
X_2 -conditioning time	6.2095	1.3047	5.29	6.7568	5.218
X_3 -popping temp	716.27	5.22	9.21	445.27	18.57
X_1X_2	23.09	0.3428	1.18	0.3784	0.0267
X_1X_3	0.5716	0.1523	49.71	45.78	4.07
X_2X_3	0.0195	0.9521	4.71	24.22	0.4962
X_1^2	200.32	3.39	86.34	16.83	16.52
X_2^2	65.99	4.17*	76.31	52.67	14.22
X_3^2	2094.86	113.46	13.90	590.37	88.28
Lack of Fit	4.90^{NS}	5.33^{NS}	5.28^{NS}	4.83^{NS}	6.02^{NS}

PY- puffing yield, ER- expansion ratio, CRP- crispiness, HDS- hardness, L- colour value - significant, and NS- Non-significant



(A) (B)

Fig 2: Effects of (A) soaking time (X1) and puffing temperature (X3) at a constant surface drying time (X2), and (B) surface drying time (X2) and puffing temperature (X3) at a fixed soaking time (X1) on the expansion ratio of puffed groundnut. Impact of Different Process Parameters on crispiness (CR)

Table 2 displays the calculated crispiness values for puffed groundnuts produced using various combinations of process parameters. The crispiness values of the puffed groundnuts were found to vary between 13 and 23 (number of positive peaks) across the different variable combinations examined. The quadratic equation that illustrates how the process parameters influence the crispiness of puffed groundnuts, based on the actual levels of the variables, is provided as follows:

$$CR = 22.60 - 1.37X_1 + 2.75X_2 + 4.88X_3 - 0.50X_1X_2 - 3.25X_1X_3 - 1.00X_2X_3 - 4.18X_1^2 - 3.93X_2^2 - 1.67X_3^2 (R^2 = 0.974) \ldots\ldots 4$$

Where, X_1 = soaking time, X_2 = surface drying time and X_3 = puffing temperature

The effect of the processing variables on the crispiness of puffed groundnut was evaluated using the ANOVA F-values and the regression coefficients of the coded variables (Table 3). The developed model was statistically significant, with a Model F-value of 24.89 ($p<0.05$) , indicating that the selected variables adequately explained the variation in crispiness. The positive linear coefficients of surface drying time (X_2) and puffing temperature (X_3) indicated that increasing these process variables enhanced the crispiness of the product within the experimental range. In contrast, the negative interaction and quadratic coefficients suggested that excessive levels of these variables adversely affected crispiness, reflecting the presence of an optimum processing region. As illustrated in Fig. 3, the crispiness of puffed groundnut increased with soaking time (X_1)

up to 45 min, surface drying time (X_2) up to 4 h, and puffing temperature (X_3) up to 250 °C . Beyond these optimum conditions, particularly with further increases in surface drying time and puffing temperature, the crispiness decreased, which may be attributed to excessive moisture loss and structural changes in the puffed kernels that reduced the desirable crisp texture.

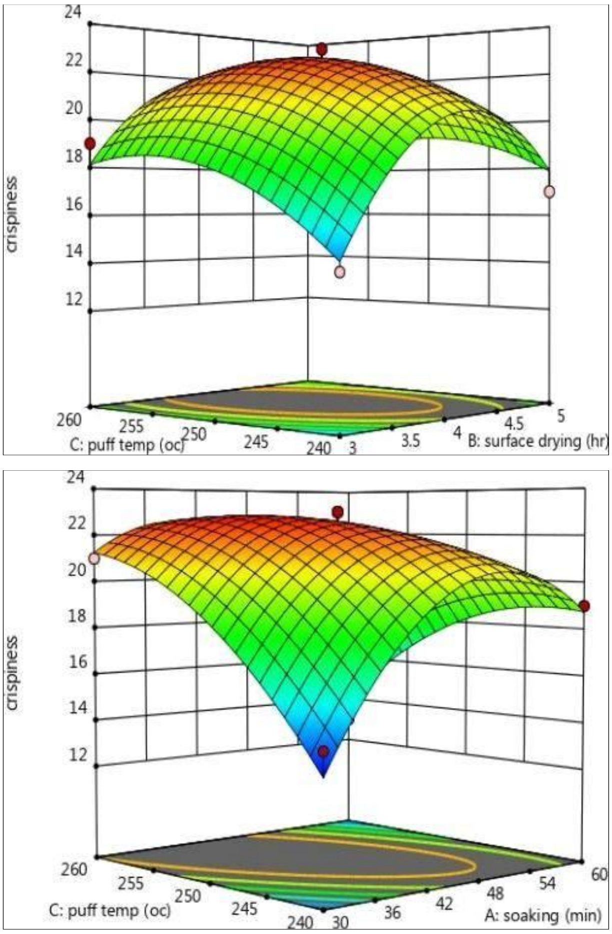


Fig 3: Effect of (A) soaking time and puffing temperature at a constant surface drying time, and (B) surface drying time and puffing temperature at a constant soaking time on the crispness of puffed groundnut.

Impact of Different Process Parameters on Hardness

The hardness of puffed groundnuts was assessed using the TA. XT-2 Texture Analyser, following the experimental design outlined in Table 2, for various process parameter combinations. The hardness ranged from 49 to 140 N across the studied variable combinations. The quadratic equation that illustrates how the process parameters influence the hardness of puffed groundnuts, based on the actual levels of the variables, is provided as follows:

$$HRD = +69.00 - 4.50X_1 - 1.50X_2 - 38.75X_3 - 0.50X_1X_2 + 5.50X_1X_3 - 4.00X_2X_3 + 3.25X_1^2 + 5.75X_2^2 + 19.25X_3^2$$

($R2 = 0.998$) ……. 5

Where, X_1 = soaking time, X_2 = Surface drying time and X_3 = puffing temperature

The effect of the processing variables on the hardness of puffed groundnut was evaluated using the ANOVA F-values and the regression coefficients of the coded variables (Table 3). The developed response surface model was highly significant, with a Model F-value of 192.58 ($p<0.05$) , indicating that the model adequately explained the variation in hardness. The negative linear regression coefficients of soaking time (X_1) , surface drying time (X_2) . , and puffing temperature (X_3) indicated that increasing these processing variables reduced the hardness of puffed groundnut within the experimental range. Among the investigated factors, puffing temperature (X_3) exerted the greatest influence on hardness, followed by soaking time (X_1) and surface drying time (X_2)

As illustrated in Fig. 4, the hardness of puffed groundnut decreased with increasing soaking time up to 45 min, surface drying time up to h, and puffing temperature up to 250 °C . The reduction in hardness under these processing conditions may be attributed to enhanced moisture distribution during soaking, controlled moisture removal during surface drying, and greater expansion of the kernels at higher puffing temperatures, resulting in the formation of a porous structure with a softer texture.

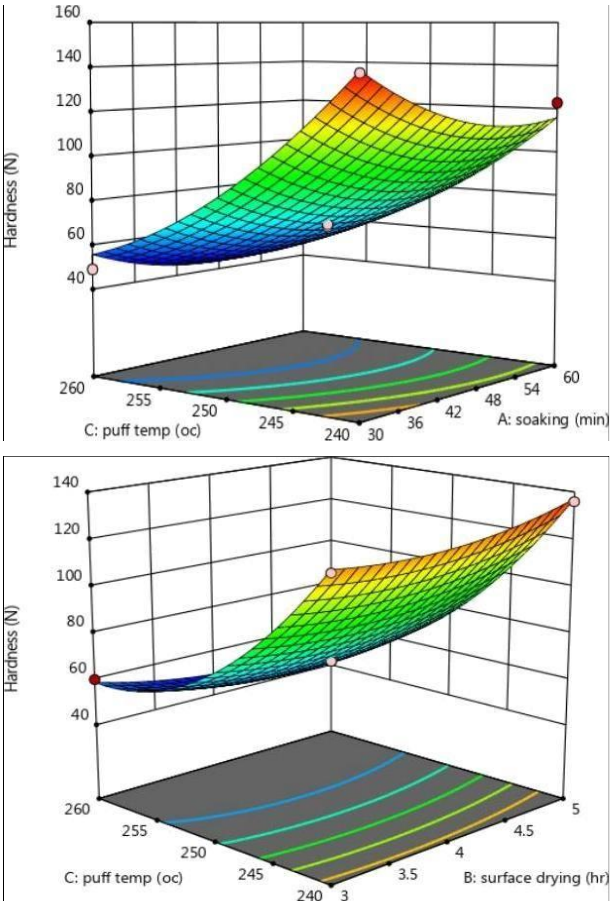


Fig 4: Effect of (A) soaking time and puffing temperature at a constant surface drying time, and (B) surface drying time and puffing temperature at a constant soaking time on the hardness of puffed groundnut.

Impact of Different Process Parameters on color (L- value) of puffed groundnut

The lightness of puffed groundnut, influenced by different process parameters, was measured using a Colour Flex Hunter Lab Colorimeter, represented by the (L- value). This value reflects the brightness of the puffed groundnut. It was found that the L- value of the puffed groundnut varied between 32.73 and 50.85 (Table 2) across the studied variable combinations. The quadratic equation that illustrates how the process parameters affect the L *- value of puffed groundnut, based on the actual levels of the variables, is provided as follows:

$$CLR = 50.17 + 1.61X_1 + 2.87X_2 + 6.52X_3 + 0.131X_1X_2 - 1.67X_1X_3 + 0.58X_2X_3 - 3.28X_1^2 + 3.04X_2^2 - 7.57X_3^2 (R^2 = 0.953) \ldots$$

Where, X_1= soaking time, X_1= surface drying time and X_1 = puffing temperature

The influence of each factor on color (L- value) can be assessed through the F-values from the analysis of variance (Table 3) and the size of the coefficients of the coded variables. The ANOVA results indicate a model with an F value of 15.93 at a 5% significance level. The lack of fit F value is not significant, indicating a good model fit. Positive coefficients for linear terms suggest that an increase in these parameters leads to a rise in the color L- value of puffed groundnut. Conversely, negative coefficients for the quadratic terms imply that an excessive increase in these parameters causes a reduction in the color L*-value of puffed groundnut.

Figure demonstrated that the L colour value of puffed groundnut rose as the soaking time (X1) of raw groundnut extended to 45 minutes, the surface drying time (X2) of soaked groundnut reached 4 hours, and the puffing temperature (X3) was set at 250 °C. Beyond these levels, the L colour value of puffed groundnut began to decline.

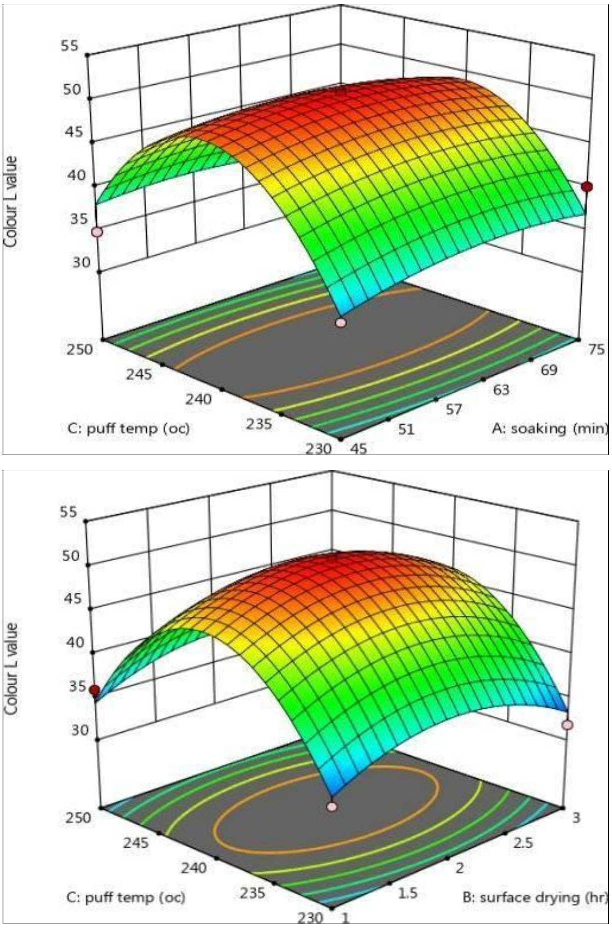


Fig 5: Effect of (A) soaking time (X1) and puffing temperature (X3) at a constant surface drying time (X2), and (B) surface drying time (X2) and puffing temperature (X3) at a constant soaking time (X1) on the L- value of puffed groundnut.

Optimization

Design-Expert software (Version 10.0, Stat-Ease Inc., Minneapolis, MN, USA) was employed to optimize multiple responses simultaneously. The software provided optimal conditions for independent variables along with predicted response values. Figure illustrates the superimposed contours for PY, ER, Hd, Cr (+ve peaks), and the colour L*-value for puffing groundnut grains, based on varying ST, SD, and PT. The optimal process variable values were determined through numerical optimization:

The ideal values for process variables were determined through numerical optimization as follows:

Soaking time (min)	**:**	**45**
Surface drying time (h)	:	4
puffing temperature (°C)	:	250

The ideal values for process variables were determined through graphical optimization as follows:

Puffing yield (%)	**:**	**96.85**
Expansion ratio	:	1.29
Crispiness	:	22
Hardness (N)	:	69.08
Colour L*- value	:	50.22

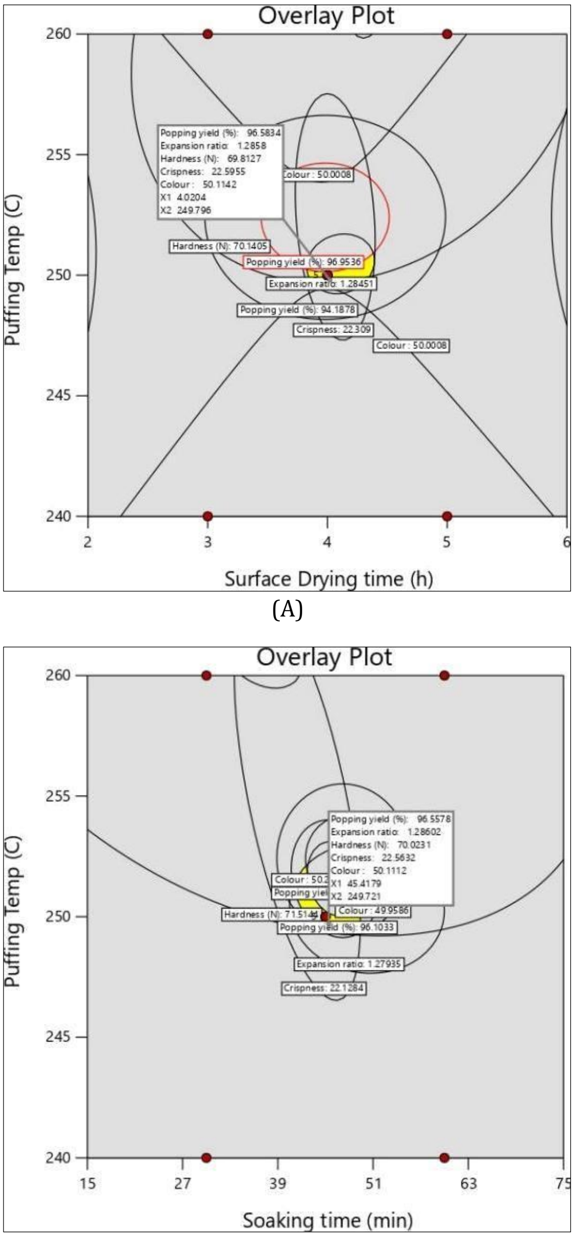


Fig 6: Overlay plot showing predicted values of quality characteristics of puffed groundnut

Conclusion

The design of experiments and optimization employed the BBD and RSM techniques, which effectively demonstrated how process parameters (ST, SD, and PT) influenced the responses (PY, ER, HD, CSP, and L *- value) of puffed groundnut. The ideal puffing conditions for groundnut grains involved heating to 250 °C , , followed by a soaking period of 45 minutes and a surface drying duration of 4 hours. Under these optimal conditions, the puffed groundnut achieved a puffing yield of 97.63%, an expansion ratio of 1.29, crispness with 22 positive peaks, hardness of 69 N, and a color L*- value of 50.23.

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