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Optimization of Process Technology for Puffing Of Bengal Gram

Kanifnath Nakade[1]*, Smita Khodke[1], Akshay Petkar[2], Pavan Paulzagade[3]
1 M.Tech scholar 1 Associate Professor and head Department of Agriculture Process Engineering, CAET, VNMKV Parbhani 2M.Tech scholar 3 M.Tech scholar*
Corresponding Author: K.T. Nakade

Abstract
Puffed bengal gram were developed with high temperature short time (HTST) puffing process. The effect of process parameters viz. Soaking time (ST), Surface drying time (SD), Puffing temperature (PT) on the product quality was investigated by conducting experiments using Box Behnken Design (BBD). Linear and quadratic models were developed using response surface methodology (RSM) to study the synergy between process parameters and responses in terms of puffing yield (PY), expansion ratio (ER), crispness (Csp), hardness (HRD) and colour L value. The optimal product quality were obtained at the optimal process condition as Puffing temperature at 240 °C followed by Soaking time 60 min and Surface drying time 2 h having puffing yield (86.19 %), expansion ratio (1.72), crispness (19 + peaks), hardness (57 N) and colour L* value(50.11).*

Key Words: *Bengal gram, Hardness, Yield*

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I. Introduction

Chickpeas (Cicer arietinum L.) are the second largest cultivated legume in the world (Varshney *et al.*, 2013) and are available as small-seeded desi (brown-coloured with a wrinkled seed-coat) and bold-seeded Kabuli (cream-coloured with a smooth seed-coat). Chickpea is a staple food forming an indigenous source of protein for large Indian vegetarian population. It is rich in fibre, protein, vitamins (thiamine and niacin), minerals (Ca, Mg, Zn, K, Fe, and P), carbohydrate and antioxidants (Williams and Singh, 1987). Chickpeas are processed in a variety of ways e.g. puffing, roasting, splitting, frying, canning, and boiling. Roasting is a dry heat method of cooking, generally practiced at150-400 ^{o}C, where in food is cooked by convicting heat throughforced air or by radiating heat (Singh, Varshney, & Agarwal, 2016). Itis a high temperature and short time process accompanying variouschemical reactions.Puffed chickpea, also known as poor's nut in India, is afavourite crispy and savoury snack consumed to satisfyone's craving without sabotaging the diet. Puffed chickpea is alsoused for preparation of *sattu*, which is consumed as ahealthy drink or made into balls to be eaten with curry.Puffing is a high-temperature short-time heattreatment, which induces characteristic aroma, colourand texture in the food grain when carried out undercontrolled condition. It involves dehydration andmany thermal and chemical reactions which enhancethe overall sensory quality of the grain (Saklar *et al*.,2001). Present study was undertaken to develop puffed product from bengal gram and optimize the process parameters using Soaking time (ST), Surface drying time (SD) and Puffing temperature (PT). For this purpose, Box Behnken Design (BBD) and response surface methodology (RSM) were used to fit a liner and second order polynomial by a least square technique.

II. Materials And Methods

Preparation of puffed bengal gram

The bengal gram grain was purchased from local market. The soaking was carried out at 60 min, surface drying was carried out at 2 h and puffing was carried out by using multigrain popping and puffing (HTST) machine at 240 ^{o}C and 3 RPM. This machine has rotating drum and digital temperature controlled panel. The following quality characteristics are optimized by using RSM.

Puffing yield:

$$\text{Puffing yield} = \frac{\text{Number of puffed grain}}{\text{Total number of grains in sample}} \times 100$$

Expansion Ratio:

The expansion ratio (ER) for all the samples was determined in terms of ratio of average bulk volume (vp) of puffed product during puffing to the average initial bulk volume (Chandrasekhar and Chattopadhyay, 1990).

$$\text{Expansion ratio} = \frac{\text{puffed volume (cm3)}}{\text{Volume of raw kernels (cm3)}}$$

Color:

Color (L* value) of the puffed bengal gram was determined by using Hunter Lab colorimeter. Color measurements were conducted after 2 days of production of products. Before testing the sample, the instrument was calibrated with standard black and white tiles supplied with the instrument. The color readings were expressed in terms of L* value. The L* value represents the light-dark spectrum with range of 0 (black) to 100 (white).

Textural Measurement (Hardness and Crispness)

The texture characteristics of puffed bengal gram in terms of hardness and crispness were measured using a Stable Micro System TA-XT2 texture analyser (Texture Technologies Corp., UK), fitted with a 2.5 mm diameter circular punch. The studies were conducted at a pre test speed of 0.5 mm/s, test speed of 1 mm/s, distance of 50% strain, and load cell of 5.0 kg. Hardness value was considered as mean peak compression force and expressed in grams and crispness was measured in terms of major positive peaks (Cruzycelis, *et al.*, 1996; Anon., 1998) with the help of Texture Analyser. For measurement of crispness a macro was developed which counts number of major peaks represented in the force-time deformation curve during compression (Nath and Chattopadhyay, 2007). The compression force at which product offers maximum resistance at the highest peak of graph was taken as the hardness value for that sample. Average of 10 replications was taken for both the parameters in each individual experiment.

Experimental Design for puffed groundnut

In the present study, the process variables considered were soaking time (45 to 75 min), surface drying time (1 to 3 h) and puffing temperature (230 to 250 °C). The experimental design was applied after selection of the ranges. Seventeen experiments were performed according to a Box Behnken Design (BBD) with three variables and three levels of each parameter. Table 1 gives the levels of variables in coded and actual units, and Table 2 indicates the treatment combinations of variable levels used in the BBD. The central point in the design was repeated five times to calculate the reproducibility of the method (Montgomery, 2001). In Table 1, the coded levels of process variables are fixed as given below (Myers, 1971). The HTST puffing experiments were conducted according to the BBD design (Table 1) and RSM were applied to the experimental data using a commercial statistical package, *Design Expert - version 10.0* (Stat Ease, 2002). The relative effect of the process variables (Soaking time (ST), Surface drying time (SD) and Puffing temperature (PT) on the responses was studied and the puffing process was optimized in order to get best quality puffed bengal gram based ready-to-eat snacks. The responses studied were final puffing yield (PY) (%), Expansion ratio (ER), Hardness (HD), crispness (CSP, no. of +ve peaks) and colour L* value. A second order polynomial equation of the following form was assumed to relate the response, Y and the factors, such as:

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_i X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{j=2}^{k} \beta_{ij} X_i X_j + \varepsilon \qquad \text{….. 1}$$

Where, y = predicted response, β0= a constant, βi= linear coefficient, βii= squared coefficient, βij= interaction coefficient, Xi and Xj=the independent variables, ε =noise or error.

Table I: Levels, codes and intervals of variation for puffing process

Sr. No.	Name of process variable	Range	Code (Xi)	LEVELS			Interval variation
				-1	0	+1	
1	Soaking time (min)	45 – 75	X_1	45	60	75	15
2	Surface drying time (h)	1– 3 h	X_2	1	2	3	1
3	Puffing temperature (°C)	230 – 250	X_3	230	240	250	10

Table II: Experimental design (3 factors, 3 levels) and corresponding values of responses (quality parameters) obtained during puffing of bengal gram

Treatments				Quality characteristics				
	X_1	X_2	X_3	Popping yield (%)	Expansion ratio	Hardness (N)	Crispiness (+ve peaks)	Color L*
1	-1	-1	0	72.61	1.46	108	14	45.1
2	1	-1	0	75.2	1.55	104	13	44.48
3	-1	1	0	74.81	1.51	105	17	48.81
4	1	1	0	74.41	1.73	97	14	41.75
5	-1	0	-1	65.17	1.4	135	13	36.68
6	1	0	-1	70.58	1.62	114	13	38.35
7	-1	0	1	78.9	1.66	71	17	34.56
8	1	0	1	75.16	1.61	69	11	35.23
9	0	-1	-1	68.13	1.41	101	14	33.69
10	0	1	-1	69.81	1.59	100	13	31.77
11	0	-1	1	77.23	1.65	56	15	35.91

12	0	1	1	76.12	1.62	44	16	36.39
13	0	0	0	86.25	1.7	57	20	51.45
14	0	0	0	85.91	1.73	58	19	51.84
15	0	0	0	86.4	1.71	55	20	50.63
16	0	0	0	86.81	1.72	56	19	50.96
17	0	0	0	86.19	1.72	57	19	50.11

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

Data Analysis and Optimization

Regression analysis and analysis of variance (ANOVA) were conducted for fitting the models Represented by Eq. (1) and to examine the statistical significance of the model terms. The adequacy of the models were determined by using model analysis, lack-of fit test and R^2 (coefficient of determination) analysis as outlined by (Lee *et al.*, 2000) and (Weng *et al.*, 2001). The lack of fit is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression or variations in the models cannot be accounted for by random error (Montgomery, 2001). If there is a significant lack of fit, as indicated by a low probability value, the response predictor is discarded. The R^2 is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit (Haber and Runyon, 1977). Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the prediction of the model. Response surfaces and contour plots were generated with the help of commercial statistical package, *DesignExpert - version 10.*0 (Stat Ease, 2002). The numerical and graphical optimization was also performed by the same software.

Numerical Optimization

Numerical optimization technique of the Design-Expert software was used for simultaneous Optimization of the multiple responses. The desired goals for each factor and response were chosen. The goals may apply to either factors or responses. The possible goals are: maximize, minimize, target, within range and none (for responses only). All the independents factors were kept within range while the responses were either maximized or minimized. In order to search a solution optimizing multiple responses, the goals are combined into an overall composite function D(x), called the desirability function (Myers and Montgomery, 2002). Desirability is an objective function that ranges from zero outside of the limits to one at the goal. It reflects the desirable ranges for each response. The desirable ranges are from zero to one (least to most desirable), respectively. 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 (Stat Ease, 2002).

III. Result And Discussion

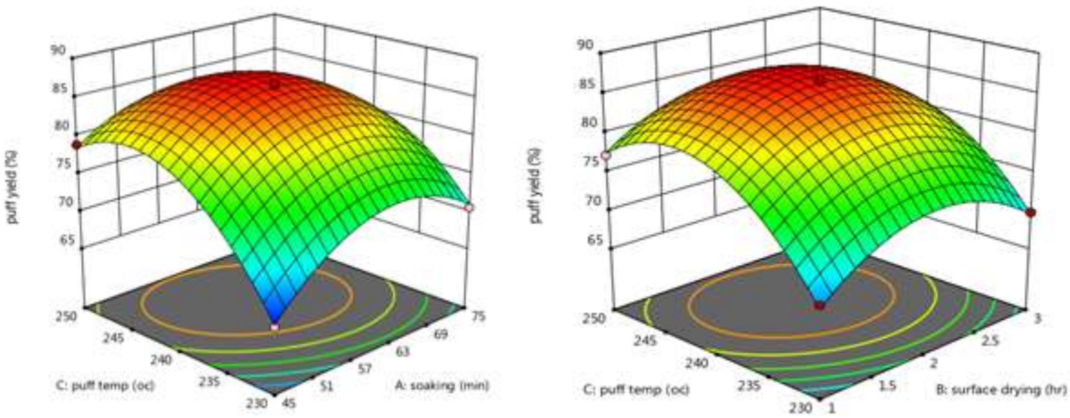
Effect of Various Process Parameters on puffing yield

The computed values for puffing yield of puffed bengal gram prepared with different combination of process parameters are presented in Table 2. It was observed that the values of puffing yield of puffed bengal gram were ranged 65.17 % to 86.81% within the combination of variable studied. A second-order polynomial equation was used to fit the experimental data. The R^2 value was calculated by a least square technique and found to be 0.998 showing good fit of model to the data. The quadratic equation describing the effect of the process parameters on puffing yield of puffed Bengal gram in terms of actual level of variables are given as:

$PY = +86.31 + 3.34X_1 + 1.24X_2 + 11.22X_3 - 0.74X_1X_2 - 2.29X_1X_3 - 0.69X_2X_3 - 6.21X_1^2 - 5.84X_2^2 - 7.65X_3^2$ ($R^2 = 0.998$) …… 2

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

The comparative effect of each parameter on puffing yield of puffed Bengal gram was observed by the F-values in the ANOVA (Table 3) and also by the magnitude of coefficients of the actual variables. Model F 379.74 value implies that model is significant at 5 % level. The lack of fit was non-significant showing good model fit. The positive coefficients in case of first order term of soaking time (X_1), surface drying time (X_2) and puffing temperatures (X_3) indicated that increase in puffing yield with increase of these parameters while negative coefficients of their quadratic term suggested that excessive increase of these parameters resulted in decrease of puffing yield. It was observed that puffing temperature (X_3) had maximum influence on puffing yield followed by soaking time (X_1) and surface drying time (X_2).Through Fig. 1 it was clear that, puffing yield of puffed bengal gram increased with increase in soaking time (X_1) of raw bengal gram up to 60 min, surface drying of soaked bengal gram (X_2) up to 2 hr and puffing temperature (X_3) at 240 ^oC respectively, further puffing yield value of puffed bengal gram decreased at higher levels of these process parameters.



(A) (B)

Fig 1:- Effect of (X_1) and (X_3) at constant (X_2) (A) and effect of (X_2) and (X_3) at constant (X_1) (B) on puffing yield of puffed bengal gram

Effect of process parameter on expansion ratio (ER)

The computed values for expansion ratio of puffed bengal gram prepared with different combination of process parameters are presented in Table 2. It was observed that the values of expansion ratio of puffed bengal gram were ranged 1.40 to 1.73 within the combination of variable studied. A second-order polynomial equation was used to fit the experimental data. The R^2 value was calculated by a least square technique and found to be 0.980 showing good fit of model to the data.

The quadratic equation describing the effect of the process parameters on expansion ratio of puffed bengal gram in terms of actual level of variables are given as:

$$ER = 1.71 + 1.66X_1 + 1.04X_2 + 2.17X_3 + 0.03X_1X_2 - 0.06X_1X_3 - 0.05X_2X_3 - 0.07X_1^2 - 0.07X_2^2 - 0.06X_3^2 \quad (R^2 = 0.980) \ldots\ldots 3$$

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

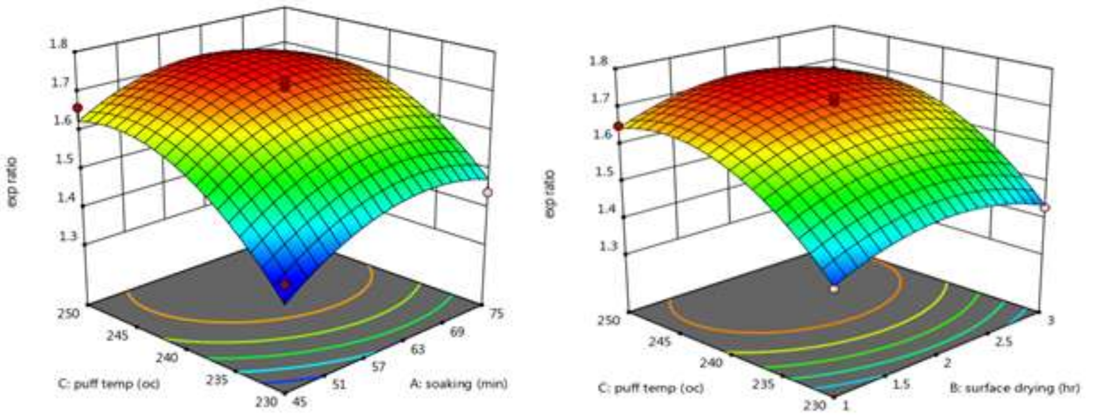
The comparative effect of each factor of each parameter on the expansion ratio could be observed by the F value in the ANOVA and also by the magnitude of coefficients of the actual variable as shown in the Table 3. Model F value 33.39 implies that the model is significant at 5 % level. The lack of fit F value was non-significant showing good model fit.

The positive coefficients in case of first order term of soaking time (X_1), surface drying time (X_2) and puffing temperature (X_3) indicated that increase in expansion ratio with increase of these parameters while negative coefficients of their quadratic term suggested that excessive increase of these parameters resulted in decrease of expansion ratio. It was observed that puffing temperature (X_3) had maximum influence on expansion ratio followed by soaking time (X_1) and surface drying time (X_2). Through Fig. 2 it was clear that, expansion ratio of puffed bengal gram increased with increase in soaking time (X_1) of raw bengal gram up to 60 min, surface drying of soaked bengal gram (X_2) up to 2 hr and puffing temperature (X_3) at 240 ^oC respectively, further puffing yield value of puffed bengal gram decreased at higher levels of these process parameters.

Table III:- Analysis of variance showing the effect of process parameters on puffing yield, expansion ratio, crispiness, hardness and colour L* value of puffed bengal gram

Source	F-value				
	PY	ER	CRP	HDS	L*
Model	379.74*	33.39*	23.95*	218.00*	15.20 *
X_1-soaking time	12.10	36.03	7.50	36.40	12.65
X_2-conditioning time	7.13	19.85	3.33	15.72	26.34
X_3-popping temp	518.21	54.02	20.83	131.27	55.87
X_1X_2	9.72	6.75	1.67	0.9508	1.81
X_1X_3	91.04	29.13	15.00	21.45	0.043
X_2X_3	8.46	17.62	1.67	7.19	0.251
X_1	706.78	35.13	61.07	187.76	2.64
X_2	625.1	40.16	26.68	155.13	9.85
X_3	1071.03	30.43	61.07	38.47	114.53
Lack of Fit	3.59^{NS}	4.07^{NS}	3.33^{NS}	6.22^{NS}	4.86^{NS}

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



(A) (B)

Fig 2:- Effect of (X_1) and (X_3) at constant (X_2) (A) and effect of (X_2) and (X_3) at constant (X_1) (B) on expansion ratio of puffed bengal gram

Effect of process parameter on crispiness (CR)

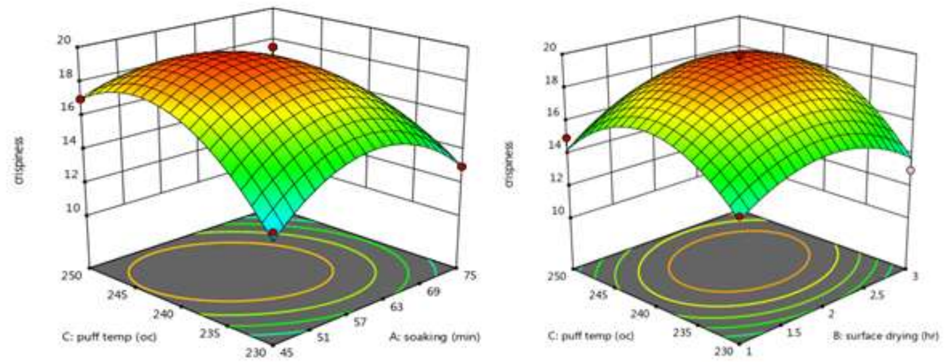
The computed values for crispiness of puffed bengal gram prepared with different combination of process parameters are presented in Table 2. It was observed that the values of crispiness of puffed bengal gram were ranged 11 to 20 within the combination of variable studied. A second-order polynomial equation was used to fit the experimental data. The R^2 value was calculated by a least square technique and found to be 0.970 showing good fit of model to the data.

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

$CR = 19.40 - 1.25X_1 + 0.95X_2 + 2.75X_3 - 0.50X_1X_2 - 1.50X_1X_3 + 0.50X_2X_3 - 2.95X_1^2 - 1.95X_2^2 - 2.95X_3$ $(R^2 = 0.970)$…………… 4

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

The comparative effect of each factor on crispiness was observed by the F-values in the analysis of variance (Table 3) and also by the magnitude of coefficients of the coded variables. The ANOVA data shows a model with F value of 23.95. The lack of fit F value was non-significant showing good model fit. The positive coefficients in case of first order terms i.e. surface drying time (X_2) and puffing temperature (X_3) indicated that increase in crispiness with increase of these parameters, while negative coefficients of their interaction and quadratic term suggested that excessive increase of these parameters resulted in decrease of crispiness of puffed bengal gram. The negative coefficient in case of first order terms i.e. soaking time (X_1) indicated that decrease in crispiness value with increase in the soaking time. Through Fig.3 it was clear that, crispiness of puffed bengal gram increased with increase in soaking time (X_1) of raw bengal gram up to 60 min, surface drying of soaked bengal gram (X_2) up to 2 hr and puffing temperature (X_3) at 240 ^oC respectively, further crispiness value of puffed bengal gram decreased at higher levels of these process parameters.



(A) (B)

Fig 3:- Effect of (X_1) and (X_3) at constant (X_2) (A) and effect of (X_2) and (X_3) at constant (X_1) (B) on crispiness of puffed bengal gram

Effect of process parameter on Hardness

Hardness of the puffed bengal gram was measured for different combinations of process parameters by using TA.XT-2 Texture Analyser as per the experimental design and presented in Table 2. It varied between 44 to 135 N within the combination of variable studied. Second order polynomial model was fitted adequately to the observed data with high coefficient of correlation (R^2 = 0.998). This indicated that all the observed variation could be satisfactorily explained by the model.

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

$$HRD = + 56.60 - 4.37X_1 - 2.87X_2 - 26.25X_3 - 1.00X_1X_2 + 4.75X_1X_3 - 2.75X_2X_3 + 34.45X_1^2 + 12.45X_2^2 + 6.20X_3^2 \quad (R^2 = 0.998) \ldots\ldots\ 5$$

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

The comparative effect of each factor on hardness could be observed by the F-values in the analysis of variance (Table 3) and also by the magnitude of coefficients of the coded variables. The ANOVA data shows a model F value of 218.00 which is significant at 5 % level. The lack of fit F value is non-significant showing good fit of model.

The negative coefficient of the first order terms in the equation with actual variables indicated that, the hardness of puffed bengal gram decreased with increase in soaking time (X_1) of raw bengal gram, surface drying time (X_2) of soaked bengal gram and puffing temperature (X_3). Through Fig. 4 revealed that, the hardness of puffed bengal gram was decreased with an increase in soaking time of raw bengal gram (X_1) up to 60 min surface drying of soaked bengal gram (X_2) up to 3 hr, it is also clear that, hardness of puffed bengal gram was decreased with an increase in levels of puffing temperature (X_3). Further hardness of puffed bengal gram increased at higher levels of these process parameters.

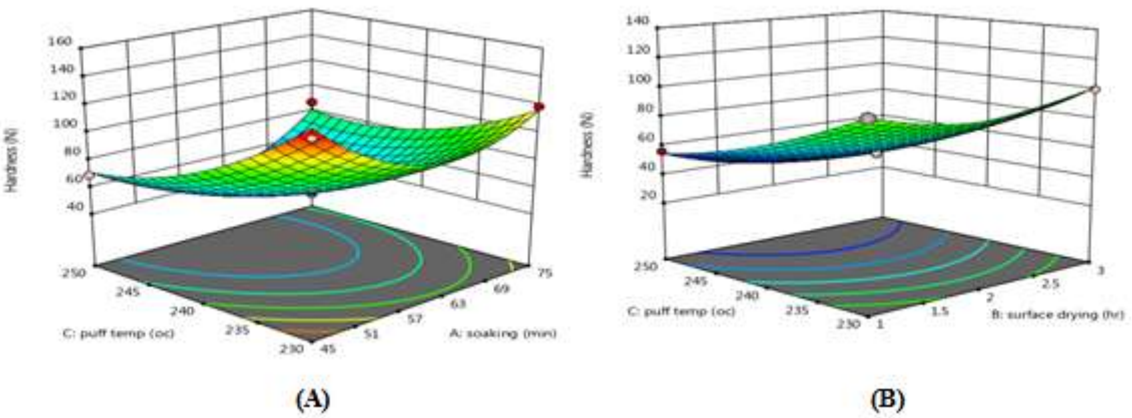


Fig 4:- Effect of (X_1) and (X_3) at constant (X_2) (A) and effect of (X_2) and (X_3) at constant (X_1) (B) on hardness of puffed bengal gram

Effect of process parameter on color (L* value) of puffed bengal gram

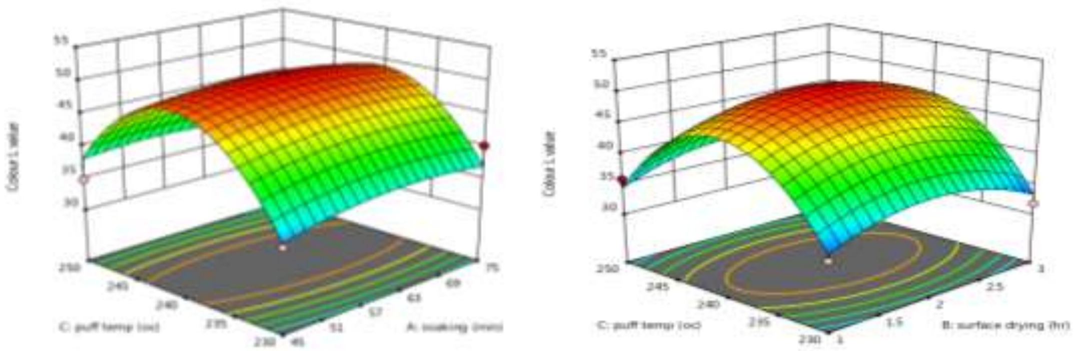
The colour of puffed bengal gram prepared by varying various process parameters was determined by Colour Flex Hunter Lab Colorimeter in terms of (L* value). Colour (L* value) indicates the lightness of puffed bengal gram. The measured values for colour (L* values) of puffed bengal gram prepared with different combination of process parameters are presented in Table 2. It was observed that the values of colour (L*value) of puffed bengal gram were ranged 31.77 to 51.84 within the combination of variable studied. The lightness value indicates a measure of colour in light-dark axis, which in turn denotes that the sample turned dark at reduced (L*value). The R^2 value was computed by a least square technique and found to be 0.950, showing good fit of model to the data.The quadratic equation describing the effect of the process parameters on L* value of puffed bengal gram in terms of coded level of variables is given as:

$$CLR = +50.71 - 1.6X_1 - 4.1X_2 + 9.5X_3 - 1.6X_1X_2 - 0.91X_1X_3 + 0.23X_2X_3 - 1.60X_1^2 - 4.08X_2^2 - 12.60X_3^2 \quad (R^2 = 0.950) \ldots\ldots\ 6$$

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

The comparative effect of each factor on colour (L* value) could be observed by the F-values in the analysis of variance (Table 3) and also by the magnitude of coefficients of the coded variables. The ANOVA data shows a model with F value of 15.20 which is significant at 5 % level. The lack of fit F value is non-significant showing good fit of model.

The positive coefficients in case of linear term (X_3) indicated that increase in colour L*value of puffed bengal gram with increase of these parameter, while negative terms (X_1 and X_2) of their quadratic term suggested that excessive increase of these parameters resulted in decrease of colour L*value of puffed bengal gram. It was observed that puffing temperature (X_3) had maximum influence on lightness followed by surface drying time (X_2) and soaking time (X_1) of bengal gram.Through Fig. 5 exhibited that, colour L*value of puffed bengal gram increased with increase in soaking time (X_1) of raw bengal gram up to 60 min, surface drying of soaked bengal gram (X_2) up to 2 hr and puffing temperature (X3) at 240 ^{o}C respectively, further colour L* value of puffed bengal gram decreased at higher levels of these parameters. As puffing temperature increased from 230 ^{o}C to 250 ^{o}C, lightness of puffed bengal gram was increased and further it decreased as puffing temperature increased up to 250 ^{o}C.



(A) **(B)**

Fig 4:- Effect of (X_1) and (X_3) at constant (X_2) (A) and effect of (X_2) and (X_3) at constant (X_1) (B) on colour L* value of puffed bengal gram

Optimization

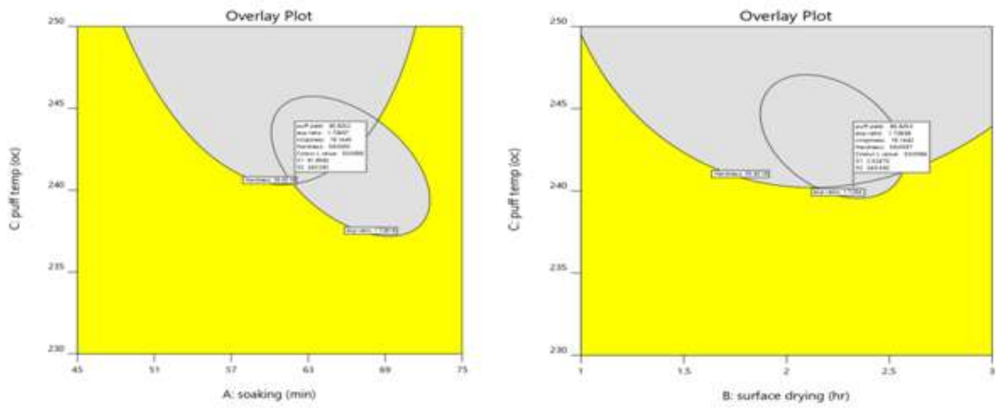
To perform this operation, Design-Expert program (Version 10.0) of the STAT-EASE software (Stat Ease, 2002), was used for simultaneous optimization of the multiple responses. The software generated optimum conditions of independent variables with the predicted values of responses. In Fig 6 shows the superimposed contours for PY, ER, HD, CSP (+ve peaks) and colour L* value for puffing of bengal gram grains based at varying ST, SD and PT. The optimum values of process variables obtained by numerical optimization as follows:

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

Soaking time (min)	:	60
Surface drying time (h)	:	2
puffing temperature (^{o}C)	:	240

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

Puffing yield (%)	:	85.82
Expansion ratio	:	1.72
Crispiness	:	19
Hardness (N)	:	56.01
Colour L* value	:	50.11



(a) **(b)**

Fig. 6 (a and b) Overlay plot showing predicted values of quality characteristics of puffed bengal gram

IV. Conclusions

The optimization technique of BBD and RSM were used in design of experiments and optimization successfully exhibited the effect of process parameters (ST, SD and PT) on the responses (PY, ER, HD, CSP and L* value) of the puffed bengal gram. The optimal puffing of bengal gram grains at 240 °C followed by soaking time 60 min and surface drying time 2 h. The puffed bengal gram product at the optimal process condition having puffing yield (86.19 %), expansion ratio (1.72), crispness (19 + peaks), hardness (57 N) and colour L* value (50.11).

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