Optimization of Process Parameters for Soaked Soybean Splits Roasting using Response Surface Methodology

S. Balasubramanian1, Vikash Shukla2, Rongen Singh2

ABSTRACT

Background: Generally, roasting of any food grains or legumes are carried out to improve the palatability and to improve the special characteristics like physical texture, colour and etc.

Methods: This study was carried out to optimize the process parameter for soaked soybean splits in an open type LPG gas assisted soybean roaster using response surface methodology with process variables viz., soaking time and roasting time. The capacity of soybean roaster is 15 kg/batch, rotating drum speed with 24 rpm and power operated with a 0.5 hp electric motor. A central composite rotatable design (CCRD) was used to select variables level i.e. soaking time (60-180 min) and roasting time (4-10 min).

Result: The effect of moisture content on some physical properties of soybean seed and split were determined. The results showed that the roasted soybean splits increased linearly in length, width, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, unit volume and surface area, where in sphericity, aspect ratio and shape factor decreased linearly with the increase in moisture content of soybean splits. The process variable had a significant effect on Hunter color and textural properties. The optimized soaking time and roasting time in the developed roaster is 123.36 2 min and 7.702 min, respectively.

Key words: Geometric properties, Hardness, Response surface methodology, Roasting, Soaking, Soybean.

INTRODUCTION

Soybean [Glycine max (L.) Merr.] is the ‘golden bean’ or ‘miracle bean’. It has come to be recognized as one of the premier agricultural crops today for various reasons. It is a major source of vegetable oil, protein and animal feed (Bisaliah, 1994) and contains protein (43%), fat (20%), carbohydrates (21%), minerals (5%), moisture (8%), fibre (4%) and reasonable amounts of vitamins. Soy based food products are also suitable for diabetic patients as they contain less carbohydrates and low cholesterol and its protein is good to people who are allergic to animal protein. The roasting is a simple and more commonly used household level technology which is more effective for grinding and milling of agriculture materials. It is a thermal time-temperature-dependent process at high temperatures (>150°C) and it leads to the production of high value, better flavor and crispier textured products (Goszkiewicz et al., 2020). Roasting improves the flavor, texture and nutritive value of grains and eliminates most anti-nutritional or toxic effect of legumes (Gopaldas et al., 1985). During roasting, temperature reaches upto 170°C, depending on the equipment used. Response surface methodology (RSM) has been applied in optimizing several types of roasted products and the technique is suitable for determining optimum roasting conditions in hazelnut (Sena et al., 2001; Ozdemir and Devres, 2000); chashew nut (Hebar and Ramesh, 2005); sesame seed (Kahyaoglu and Kaya, 2006); coffee (Mendes et al., 2001), robusta coffee, peanut (Slade and Levine, 2006), pistachio nut (Nikzadeh and Sedaghat, 2008; Kahyaoglu, 2008) and maize beverage. Moreover, some compounds such as fatty acids, peptides, free amino acids and vitamins are altered during the roasting process (Roche et al., 2010; Guo et al., 2019). Starch gelatinization and protein denaturation are the most critical changes in grains and legumes during the roasting process (Kavitha and Parimalavalli, 2014). As the soaking time increases, the amount of water absorbed increases with an increase in temperature. Pan and Tangratanavalee (2003) studied the water absorption of soybeans and reported that the increase in moisture is directly related to the changes in textural and grinding characteristics of soybean. Thus, the soaking process changes the textural characteristics of soybean and facilitates the extraction of soy protein. Ozdemir and Devres (2000) analyzed hazelnut roasting using RSM to find out the effect of process variables on color development during roasting established prediction models and reported that roasting temperature had main effect on its color development. Developed prediction models satisfactorily described color (L, a, b values) development as a function of roasting temperature and exposure time of whole-kernel,
ground-state and cut-kernel measurements. Shakerardekani et al. (2011) studied the effect of hot air roasting temperatures (90-190°C) and times (5-65 min) on hardness, moisture content and colour attributes (L, a, b values and yellowness index) of both whole-kernel and ground-state using response surface methodology (RSM).

MATERIALS AND METHODS

Soybean seeds were obtained from the local market of Coimbatore and were subjected to dehulling by TNAU dhal mill. The initial moisture content of sample (12% wb) was determined (Ranganna, 1986). The samples were cleaned by using cleaner-cum-grader to remove foreign materials, broken, cracked and damaged grains. The sound grains were sealed in polyethylene bags and stored at room temperature (30±2°C). To determine the dimension and different physical properties of soybean seed and splits, approximately 2±0.5g (screened for uniformity of size) of sample was weighed using an digital electronic balance (Precisa 310 M, Adair Dutt Pvt. Ltd, Calcutta) having a least count of 0.001g and soaked for 4 h in 10 ml tap water (Fig 1). The study was carried out at ICAR-Central Institute of Agricultural Engineering Regional centre, Coimbatore during the year 2014-15.

Description of roaster

Soybean roaster developed at ICAR-Central Institute of Agricultural Engineering Regional Centre, Coimbatore was used for the study. It consists of the following components.

Rotating drum with baffles

It is fabricated with 10 mm thick stainless steel, having a dimension of 600 mm diameter and 100 mm height. Both ends of rotating drum are fitted with 1 mm thick stainless steel guard of 125 mm height. It is mounted on a vertical shaft (MS, 30 mm diameter). Three numbers of stationary baffles with different dimensions were fastioned using a separate frame touching the drum surface so as to keep uniformity in mixing of soaked soybean splits in the rotating drum. The baffles were arranged 60 mm away and arranged parallel to each other in a zigzag manner.

Heating source

Liquid petroleum gas (LPG) is used as heating source. A burner of 67 mm in length and positioned just below drum, provided with a gas flow regulator to control heating rate of rotating drum.

Power drive mechanism

It is powered by a 0.5 hp motor, gear box (1:60) arrangement.

Study parameters

The primary factors which influence the machine capacity, power requirement and efficiency were identified as viz., (i) Roasting temperature (ii) Residential time.

Preparation of soaked soybean splits

The soaked soybean splits were dried (4 h) in cabinet dryer (85±5°C) in order to remove the surface moisture. The soaked dried sample (5 kg) was roasted in rotating drum roaster with constant (135±5°C) roasting temperature. The roasted sample (Fig 2) were packed in low density poly ethylene bags (75 μ) and stored under ambient condition in plastic container till further use.

Experimental design

Response surface methodology (RSM) was adopted in experimental design and analysis (Khuri and Cornell, 1987; Balasubramanian et al. 2014) and multiple regression analysis was used to fit the model, represented by an equation, to the experimental data. Maximization and minimization of the polynomials thus fitted was done by numeric techniques, using the numerical optimization technique given in the software package (Design expert, 9.0.3.1, Minneapolis, MN, USA).

RSM was used to optimize roasting condition of soybean roaster having prominent parameters viz., soaking time (X1) and roasting time (X2). After preliminary laboratory tests, upper and lower levels for these variables were established. A CCRD was used for variable as soaking time (60-180 min), roasting time (4-10) (Table 1). The RSM, was performed using two-factors (X1 and X2) with three levels central composite design. The responses studied are length, width, thickness, bulk density, L-value, a-value, b-value, hardness and rupture energy of roasted soybean splits. Since the functional relationship between the responses and factors are unknown, first order or second order polynomial expressions for a selected experimental region (60-180 min and 4-10 min) were used to estimate the actual response surfaces (Balasubramanian et al., 2014).

For the analysis of experimental design by response surface, it was assumed that n-numerical functions, fi (k=1, 2, ..., n), Yi in terms of ‘m’ independent processing factors Xi (i=1, 2, ..., m) existed for each response variable. Yi = fi (X1, X2, ..., Xm), in this case, n = 2, m = 3. Full second-order experimental design and analysis (Khuri and Cornell, 1987; Balasubramanian et al., 2014).

| Table 1: Coded levels of independent variables used in developing experimental design for soybean splits roasting. |
|---------------------------------------------------------------|
| **Independent variables** | **Symbols** | **Levels** |
| | Uncoded | Coded | Uncoded | Coded |
| Soaking Time (min) | T1 | X1 | 35.1472 | -1.4142 |
| | 60 | -1 | 120 | 0 |
| | 180 | 1 | 204 853 | 1.1442 |
| Roasting Time (min) | T2 | X2 | 2.75736 | -1.4142 |
| | 4 | -1 | 7 | 0 |
| | 10 | 1 | 11.2426 | 1.1442 |
order equation was fitted in each response to describe it mathematically and to study the effect of variables. The equation is

\[ Y_k = \beta_0 + \sum_{i=1}^m \beta_i X_i + \sum_{i=1}^m \sum_{j=i+1}^m \beta_{ij} X_i X_j + \sum_{i=1}^{m-1} \beta_i X_i^2 \]

Where,
- \( Y_k \): Response variable
- \( \beta_0 \): Value of fitted response at centre point of design i.e. (0,0)
- \( \beta_i, \beta_{ij} \): Linear, quadratic and interactive regression coefficients
- \( X_i, X_j \): Coded independent variable

In order to select best fit, analysis of variance (ANOVA), partial F test for individual parameters and analysis of residuals were performed following the Enter - method (Guerrero et al., 1996). The backward method together with a partial F-test was used to find the production equation.

The partial F-test between a proposed reduced model and a full second-order model was calculated as follows

\[ F = \frac{[SSE_{reduced} - SSE_{full}] - df_{reduced} - df_{full}}{MSE_{full}} \]

where,
- SSE: Sum of square of error.
- MSE: Mean square error.
- \( d_f \): Degree of freedom.

Either full or simplest reduced model that was not significantly different from full model at the 5% level was selected as the final model for each response variable (Muego- Gnanasekharan and Resurreccion, 1992).

**Determination of responses**

The dimension measurements (L, W, T) and bulk density for roasted soybean splits were measured and calculated (Balasubramanian et al. 2010, 2012, 2015). The colour of roasted sample was measured using a hunter colourlab (Labscan XE Hunterlab) and care was taken to remove the poor quality roasted soybean splits. The colour readings were expressed in terms of L-value, a-value and b-value (Moss and Otten, 1989; Driscoll and Madamba, 1994; Kahyaoglu, 2008). The colour measurement was carried out by randomly selected five samples from each designed treatment. Hardness and rupture energy of roasted soybean splits were measured using texture analyzer (TA.HD plus Texture Analyser, Stable Micro System, UK) using its test settings viz., Test mode (compression), pre-test speed (1 mm/s), test speed (0.5 mm/s), post test speed (5 mm/s), type of mode strain, strain (50%), testing force (0.05 N). A kernel was placed horizontally on the plate and compression was applied using a cylindrical probe (P75). The maximum peak of compression (N) in the force-time curves indicates the hardness value (Kahyaoglu and Kaya 2006). For all the response studies, average values of five replications are reported and taken for RSM analysis.

**RESULTS AND DISCUSSION**

**Variation of moisture content**

In the soybean soaking study, moisture content showed an increasing trend with respect to soaking time. During soaking, volumetric changes/expansion in samples was similar with respect to water uptake. The increasing trend of moisture content for soybean splits (12 - 34.4%) during 4 h soaking are given in Table 2.

**Table 2: Regression equations for geometrical properties of soybean splits.**

| Geometric properties | Soybean splits | Range | \( mx+c \) | \( R^2 \) |
|----------------------|---------------|-------|------------|--------|
| Length (mm)          |               | 5.98 - 11.42 | 0.0598x + 5.8264 | 0.984 |
| Width (mm)           |               | 4.28 - 6.30 | 0.0199x + 4.446 | 0.967 |
| Thickness (mm)       |               | 2.36 - 3.62 | 0.0088x + 2.4185 | 0.971 |
| AMD (mm)             |               | 4.20 - 7.11 | 0.03x + 4.2409 | 0.995 |
| GMD (mm)             |               | 3.92 - 6.38 | 0.0235x + 4.0038 | 0.997 |
| SMD (mm)             |               | 7.05 - 11.66 | 0.0459x + 7.1698 | 0.996 |
| EOD (mm)             |               | 5.06 - 8.36 | 0.0331x + 5.1382 | 0.996 |
| Sphericity (%)       |               | 0.65 - 0.55 | -0.0016x + 0.6709 | 0.896 |
| Aspect ratio         |               | 0.71 - 0.52 | -0.0023x + 0.7454 | 0.912 |
| Shape factor         |               | 1.09 - 0.98 | -0.0011x + 1.1152 | 0.898 |
| Surface area (mm²)   |               | 54.85-159.02 | 1.0361x + 51.968 | 0.995 |
| Unit volume (mm³)    |               | 35.86-169.25 | 1.2553x + 29.309 | 0.993 |

X: moisture content, % wb.

**Fig 1:** Dimension changes occurring in length, width and thickness of soybean split during soaking.
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Response surface methodology

Diagnostic checking of the fitted models

The actual values of test variables and experimental results viz., length, width, thickness, bulk density, L-value, a-value, b-value, hardness and rupture energy were found to be ranged as 7.7-11.30, 3.92-4.86, 1.31-1.66, 0.554-0.710, 43.08-58.79, 9.02-14.74, 28.26-35.39, 200.79-379.39, 157.10-442.25, respectively (Table 3). All main, linear, quadratic and interactive effects were calculated for each model. The correlation coefficients for the responses, i.e. length, width, thickness, bulk density, L-value, a-value, b-value, hardness and rupture energy were 0.959, 0.960, 0.941, 0.957, 0.990, 0.931, 0.979, 0.998, 0.998 respectively, indicating that all the values were equal to or more than 93%. The calculated F-values were more than Table F-value indicating the adequacy of the models. All nine responses were considered adequate to describe the effect of variables on the quality of roasted soybean splits samples (Table 3, 4 and 5).

Effect of variables on geometrical properties (length, width, thickness) and bulk density

Length is much influenced by roasting of soybean split. Both soaking time and roasting time had a significant (p≤0.01) negative effect on length at quadratic level. The length of soybean splits varies from 7.7 to 11.30 mm while soaked for 180 min and roasted for 10 min; soaked for 120 min and roasted for 7 min (Fig 3a). Both the soaking and roasting time had a significant positive effect on length as reported
### Table 3: Central composite design arrangement and responses.

| Experiment | Soaking time (min) | Roasting time (min) | Length (mm) | Width (mm) | Thickness (mm) | Bulk density (g/cm³) | L | a | b | Hardness (N) | Rupture Energy (N-s) |
|------------|-------------------|---------------------|-------------|------------|---------------|---------------------|---|---|---|-------------|---------------------|
| 1          | 120               | 11.2426             | 8.08        | 4.32       | 1.43          | 0.554               | 43.08 | 13.43 | 28.26 | 200.79      | 193.85              |
| 2          | 204.853           | 7                   | 8.48        | 3.92       | 1.49          | 0.550               | 50.57 | 13.25 | 23.64 | 288.11      | 250.35              |
| 3          | 120               | 7                   | 10.22       | 4.44       | 1.58          | 0.710               | 50.71 | 12.79 | 33.23 | 377.40      | 442.25              |
| 4          | 60                | 4                   | 7.93        | 4.86       | 1.63          | 0.610               | 56.21 | 12.02 | 35.33 | 244.28      | 157.10              |
| 5          | 120               | 7                   | 11.30       | 4.51       | 1.66          | 0.658               | 50.84 | 14.17 | 33.66 | 374.64      | 439.55              |
| 6          | 120               | 7                   | 11.13       | 4.53       | 1.62          | 0.694               | 49.47 | 13.66 | 32.67 | 379.39      | 425.40              |
| 7          | 180               | 10                  | 7.70        | 4.03       | 1.63          | 0.572               | 43.66 | 13.75 | 30.65 | 202.63      | 189.00              |
| 8          | 35.1472           | 7                   | 8.40        | 4.45       | 1.55          | 0.578               | 52.19 | 14.74 | 32.38 | 304.88      | 219.20              |
| 9          | 180               | 4                   | 9.90        | 4.22       | 1.35          | 0.590               | 56.39 | 11.00 | 34.34 | 288.06      | 247.45              |
| 10         | 60                | 10                  | 9.35        | 4.09       | 1.31          | 0.556               | 46.90 | 13.33 | 29.62 | 285.40      | 238.60              |
| 11         | 120               | 7                   | 11.13       | 4.53       | 1.62          | 0.694               | 49.47 | 13.66 | 32.67 | 379.39      | 425.40              |
| 12         | 120               | 7                   | 11.13       | 4.53       | 1.62          | 0.694               | 49.47 | 13.66 | 32.67 | 379.39      | 425.40              |
| 13         | 120               | 2.75736             | 9.13        | 4.69       | 1.56          | 0.599               | 58.79 | 9.02  | 35.39 | 242.27      | 179.10              |

### Table 4: Estimated coefficients of fitted quadratic equation for different responses.

| Factors | Length (mm) | Width (mm) | Thickness (mm) | Bulk Density (g/cm³) | L | a | b | Hardness (N) | Rupture Energy (N-s) |
|---------|-------------|------------|----------------|----------------------|---|---|---|-------------|---------------------|
| β₀      | -3.77742    | +5.21925   | +1.79129       | +0.24946             | +7.1229 | +37.58287 | +378.04 | -832.72677 |
| β₁      | +0.11754    | +0.00299*  | -0.00213511    | +0.00356             | -0.03179 | -0.00841 | -7.84   | +8.14126*  |
| β₂      | +2.28093    | -0.13864*  | -0.00141032    | +0.07209*            | -1.86458** | +2.05997* | -12.87** | +216.81360 |
| β₃      | -0.00503*   | +0.00081*  | +0.00005**     | -0.00005            | -0.00200 | +0.00280* | -31.64** | -0.19437** |
| β₄      | -0.00034**  | -0.00005*  | -0.00002**     | +0.00017*           | +0.00005* | -0.00004 | -41.75** | -0.02751** |
| R²      | 0.959       | 0.960      | 0.941          | 0.957                | 0.999    | 0.998    | 0.998    | 0.998       |

*Significant at 5% level, **Significant at 1% level.

### Table 5: Analysis of variance of different models.

| Response               | Sources of variance | Sum of squares | d.f. | Mean square | F-value |
|------------------------|---------------------|----------------|------|-------------|---------|
| Length                 | Model               | 21.12          | 5    | 4.22        | 33.11   |
|                        | Residual            | 0.89           | 7    | 0.13        |         |
|                        | Cor.Total           | 22.01          | 12   |             |         |
| Width                  | Model               | 0.83           | 5    | 0.17        | 33.90   |
|                        | Residual            | 0.034          | 7    | 0.004897    |         |
|                        | Cor.Total           | 0.86           | 12   |             |         |
| Thickness              | Model               | 0.15           | 5    | 0.029       | 22.13   |
|                        | Residual            | 0.009248       | 7    | 0.001321    |         |
|                        | Cor.Total           | 0.16           | 12   |             |         |
| Bulk density           | Model               | 0.043          | 5    | 0.008578    | 31.35   |
|                        | Residual            | 0.001916       | 7    | 0.0002736   |         |
|                        | Cor.Total           | 0.045          | 12   |             |         |
| L                      | Model               | 254.51         | 5    | 50.90       | 148.46  |
|                        | Residual            | 2.40           | 7    | 0.34        |         |
|                        | Cor.Total           | 256.91         | 12   |             |         |
| a                      | Model               | 25.56          | 5    | 5.11        | 19.02   |
|                        | Residual            | 1.88           | 7    | 0.27        |         |
|                        | Cor.Total           | 27.45          | 12   |             |         |
| b                      | Model               | 50.28          | 5    | 10.06       | 64.78   |
|                        | Residual            | 1.09           | 7    | 0.16        |         |
|                        | Cor.Total           | 51.36          | 12   |             |         |
| Hardness               | Model               | 56481.79       | 5    | 11296.36    | 767.14  |
|                        | Residual            | 103.08         | 7    | 14.73       |         |
|                        | Cor.Total           | 56584.87       | 12   |             |         |
| Rupture energy         | Model               | 160400         | 5    | 32075.96    | 730.66  |
|                        | Residual            | 307.30         | 7    | 43.90       |         |
|                        | Cor.Total           | 160700         | 12   |             |         |
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Fig 3: Response surface plot for effect process variables on geometrical properties viz., (a) length (b) width (c) thickness and (d) bulk density.

by Otegbayo et al., (2001). Width is slightly influenced by roasting of soybean splits. The soaking time had shown significant ($p<0.05$) negative effect and roasting time showed non-significant on width at quadratic level. Fig 3b represents the effect of soaking time and roasting time on width. The soaking time and roasting time had a significant ($p<0.05$) negative effect on the thickness at quadratic level. The thickness of soybean splits varies from 1.31 to 1.66 mm while soaking for 60 min and 10 min roasting time, 120 min soaking time and 7 min roasting time (Fig 3c). The increase in thickness is a result of increasing soaking time and decreasing roasting time. The soaking time and roasting time had a significant ($p<0.01$) negative effect on bulk density at quadratic level. The bulk density of soybean splits varies from 0.554 to 0.710 g/cm$^3$ while soaking for 120 min and 11.24 min roasting time; 120 min soaking time and 7 min roasting time. Fig 1d represents the effect of soaking time and roasting time on bulk density (g/cm$^3$).

Effect of variable on colors
The observed colour (L-value,) values of roasted soybean with different soaking time and roasting time combination are presented in Table 3. The L-value varied between 43.08 and 58.79, within combination of variable studied. It revealed that soaking time had positive effect ($p<0.05$) on L-value at quadratic level. The roasting time had a non-significant on L-value at quadratic level. Yadav et al. 2014 found that increased lightness of pearl millet based pasta as a function of barley flour and whey protein concentration, (Yadav et al., 2014) also found increased brightness of wheat pasta incorporated with barley and oat bran. The a-value varied between 9.02 and 14.74 within combination of variable studied. Table 4 revealed that soaking time had non-significant and roasting time had a significant ($p<0.05$) negative effect on a-value at quadratic level (Fig 4a). The b-value varied between 28.26 and 35.39 within combination of variable studied (Fig 4b). Table 2 revealed that soaking time had non-significant and roasting time had a significant ($p<0.01$) negative effect on b-value at quadratic level (Fig 4c). Colour of roasted soybean splits is an important quality factor for consumers. During roasting of nuts, brown pigments generally increase as browning and caramelisation reactions where in progress (Sena et al. 2001).

Effect of variables on hardness and rupture energy
Hardness is an important parameter that needs to be controlled during roasting of soybean. Table 4 represents that both soaking and roasting time had a significant ($p<0.01$)
negative effect on hardness at quadratic level. The hardness value of soybean during roasting varies from 200.79 to 379.39 N while soaking time 120 for roasting time 11.2426 roasted and soaking time 120 min for roasting time 7 min. Fig 5a represents the effect of soaking time and roasting time on hardness (force). Soaking time and roasting time had a significant (p<0.01) negative effect on hardness at quadratic level. It is evident that hardness increases when soaking time is kept constant but roasting time is decreased. Similar result obtained by Shakerardekani et al. (2011) for roasting of pistachio kernels. This finding is concurrent with Nikzade and Sedaghat (2008) who observed a similar reverse relationship between roasting temperature and hardness of pistachio nuts. The decrease in hardness with the increase of roasting time had also been reported by Kahyaoglu and Kaya (2006) for sesame seeds.

Table 4 represents soaking time had a significant (p<0.01) negative effect on rupture energy on quadratic level and roasting time had a significant (p<0.01) negative effect on rupture energy on quadratic level. The rupture energy value of roasted soybean were found varied from 157.10 J to 442.25 J while roasted at soaking time 60 for 4 min.
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Table 6: Constraints, criteria for optimization, solution along with predicted and actual response values.

| Constraints              | Goal          | Lower limit | Upper limit | Predicted values | Actual response values |
|--------------------------|---------------|-------------|-------------|-------------------|------------------------|
| Soaking time (min)       | is in range   | 60          | 180         | 123.362           | -                      |
| Roasting time (min)      | is in range   | 4           | 10          | 7.702             | -                      |
| Length (mm)              | is in range   | 7.7         | 11.3        | 10.841            | 10.81 ± 0.005          |
| Width (mm)               | is in range   | 3.92        | 4.86        | 4.455             | 4.44 ± 0.002           |
| Thickness (mm)           | maximize      | 1.31        | 1.66        | 1.611             | 1.62 ± 0.03            |
| Bulk Density             | maximize      | 0.55        | 0.71        | 0.683             | 0.68 ± 0.001           |
| L                        | minimize      | 43.08       | 58.79       | 48.671            | 48.68 ± 0.06           |
| a                        | maximize      | 9.02        | 14.74       | 13.810            | 13.81 ± 0.002          |
| b                        | is in range   | 28.26       | 35.39       | 32.392            | 32.39 ± 0.007          |
| Hardness (N)             | is in range   | 200.793     | 379.385     | 369.702           | 369.5 ± 0.8            |
| Rupture Energy (N-s)     | maximize      | 157.1       | 442.25      | 425.962           | 425.96 ± 1.2           |

roasting time and at soaking time 120 min for 7 min roasting time. Fig 5b represents the effect of soaking time and roasting time on rupture energy.

Optimization of independent variable levels

Optimization of variable level was done by selecting the response viz. length, width, thickness, bulk density, L-value, a-value and b-value, hardness, rupture energy. On the basis that responses had direct effect on the quality and acceptability of roasted soybean splits as shown by their respective $R^2$ value. Graphical as well as numerical optimization was done. Table 6 showed the criteria used, upper and lower limit, predicted and actual value of responses. Numerical optimization was carried out for the level of ingredients to obtain best product. The desired goals for each factor and response were chosen and different time and temperature were assigned to each goal to adjust the shape of its particular desirability function. Among the solutions obtained, solution with maximum desirability was selected as optimum ingredients composition. The observed experimental values and predicted values by model equations are presented in Table 5. Closeness between experimental and predicted values of quality parameters indicated the suitability of corresponding models. Fig 6 depicts overlay plot showing optimum level of ingredients and corresponding response values i.e., soaking time 123.362 min and roasting time as 7.702 min.

CONCLUSION

The open type LPG gas assisted soybean roaster is suitable for roasting of soaked soybean splits. Optimization of process variable using response surface methodology results showed that the roasted soybean splits increased linearly in length, width, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, unit volume and surface area, where in sphericity, aspect ratio and shape factor decreased linearly with increase in moisture content of soybean splits. Also, showed a significant effect on color and textural property of roasted soybean splits. The optimized soaking time and roasting time of the soybean roaster are 123.362 min and 7.702 min, respectively.
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