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Optimization of Roasting Conditions on the Functional Properties of Jackfruit Seed Flours

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Abstract: Roasting jackfruit seeds improves jackfruit seed flour's functional properties, which is vital for applications in baking and confectionaries. This study aimed to determine the optimum roasting conditions of jackfruit seeds and evaluate the functional properties of roasted jackfruit seed flours. Response surface methodology (RSM) was employed to optimize the roasting process in the temperature range from 120°C to 170°C and in the duration range from 20 minutes to 120 minutes. The roasting temperature had a significant effect (p<0.05) on water absorption capacity (WAC) and water solubility index (WSI), while roasting time significantly influenced (p<0.05) WAC, oil absorption capacity (OAC), bulk density (BD), WSI and swelling power (SP) of the jackfruit seed flours. Based on the results obtained from RSM, the optimum roasting conditions were 162°C for 20 min. The predicted values were 1.45 g/g, 0.96 g/g, 0.49 g/ml, 9.74 % and 4.35 g/g for WAC, OAC, BD, WSI and SP, respectively, with the overall desirability of 0.693. The optimum conditions obtained from RSM can produce roasted jackfruit seed flours with desirable functional properties for the future development of bakery products.

Keywords: roasting conditions; functional properties; response surface methodology

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1. Introduction

Jackfruit (*Artocarpus heterophyllus*), a member of the Moraceae family and the genus Artocarpus, including evergreen or deciduous trees that produce more yield than any other fruit tree species and yields the largest edible fruit, is among the most underutilized fruits (Ranasinghe *et al.*, 2019). Jackfruit consists of a rind, edible yellow flesh, bulbs and seeds (Madrigal-Aldana *et al.*, 2011). Jackfruit seeds account for 18–25% dry weight of the fruit (Mahanta & Kalita, 2015). Each seed has an intense, sweet flavour and is covered by a golden-yellow fleshy aril (Saxena *et al.*, 2011). Even though jackfruit seeds are abundant in carbohydrates, digestible starch, proteins, and minerals (Singh *et al.*, 1991; Ocloo *et al.*, 2010), they are commonly discarded as agro-industrial waste (John & Narasimham, 1993; Kee & Saw, 2010).

Roasting is one of the processing stages that require heat treatment, primarily aimed at improving the nutritional value, taste, colour, texture, appearance and flavour of edible seeds (Nikzadeh & Sedaghat, 2008; Sharanagat *et al.*, 2018). Temperature and roasting time are the essential parameters that influence favourable characteristics. Roasting of jackfruit seeds alters their olfactory profile (Spada *et al.*, 2017), and it accelerates the Maillard reaction that results in the distinctive cocoa flavour and reduces unwanted smells, like those from aliphatic acids, by utilizing the right combination of temperature and time (Siegmund, 2015). Compared to fermented and roasted cocoa beans, pyrazines are the major odour-active volatile chemicals found in roasted jackfruit seeds (Afoakwa, 2011; Tran *et al.*, 2015). As roasted jackfruit seeds contain high levels of trimethylpyrazine (malty cocoa scent) and 2,3-diethyl-5-methyl-pyrazine (cocoa, green, and roast aroma), are the main compounds for the production of chocolate aroma (Wagner *et al.*, 1999). Recently, the chocolate flavour and volatile components identical to those in cocoa powder, pyrazines, and aldehydes have been observed in dried, acidified or fermented roasted jackfruit seeds (Spada *et al.*, 2020). The chocolate aroma intensity of roasted jackfruit seed flour is comparable to or superior to cocoa powder (Spada *et al.*, 2020). Hence, roasted jackfruit seed flours may be capable of replacing cocoa powder in some food applications.

It is essential to explore the functional properties of roasted jackfruit seed flours to maximise their application (Chowdhury *et al.*, 2012). Functional properties in any food system influence product quality and process efficiency (Akobundu *et al.*, 1982). Functional properties such as bulk density, emulsion behaviour, and foam stability vary substantially for various products and processes. Processing applications, food quality and acceptability, and the ways for the use of ingredients in foods and food formulations are influenced by functional properties (Mahajan & Dua, 2002). In general, protein components of foods contribute to functional properties (Kinsella & Melachouris, 1976). Oil absorption capacity, water absorption index, water solubility index and water absorption capacity of the particles are functional properties used in accessing the types of flours (Hatamian *et al.*, 2020). Soaking, roasting, germination, and fermentation influences the functional properties of flour by altering the protein and starch, as well as their interaction and alignment (Oti & Akobundu, 2008; Odedeji & Oyeleke, 2011; Onuegbu *et al.*, 2013).

Roasting conditions affect the release of aroma from jackfruit seeds and influence the functional properties of jackfruit seed flours, such as water and oil absorption capacity. The ability of flour to bind with oil makes it beneficial in food systems where optimum oil absorption is required (Chandra & Samsher, 2013). Flour with very low or excessive water absorption can negatively affect the quality of food products (Awuchi *et al.*, 2019). Thus, this showed that flours with optimum functional properties are very important in food processing. In this study, roasting of jackfruit seeds can be implemented as one of the solutions to solve the jackfruit waste problems by transforming jackfruit seeds into low-cost cocoa substitutes that provide chocolate flavour or aroma in some food products. This study aims to determine the optimum roasting conditions of jackfruit seeds and evaluate the functional properties of roasted jackfruit seed flours.

2. Materials and Methods

2.1 Preparation of Raw and Roasted Jackfruit Seed Flour

A ripe Tekam Yellow or J33 variety of jackfruit was purchased from a local market in Muar, Johor. The ripe jackfruit had the characteristic of a yellow kernel. The ripe jackfruit was cut open using a knife. The jackfruit seeds were separated manually from the perianths of fruits by hand. The jackfruit seeds were thoroughly washed with running water to remove any components of the fruits. Hands manually removed the outer layers of jackfruit seeds. Each jackfruit seed was cut into tiny slices (thickness of 3.00 ± 0.01 mm) using a commercial slicer. The jackfruit seeds used to make raw jackfruit seed flours was dried in the oven at 60^{o}C for 24 hours, while the jackfruit seeds used to make roasted jackfruit seed flour were roasted in the oven at different roasting conditions (roasting temperature 120–170℃ and roasting time, 20–120 min). The roasting conditions were based on random surface methodology (RSM). Then, a mechanical grinder milled the raw and roasted jackfruit seeds into flour. The raw and roasted jackfruit seed flours were sieved through a 500 μm mesh sieve. All samples were stored in a lidded polypropylene container and kept in the refrigerator (~ 4℃) for further analysis.

2.2 Design of Experiment for Optimization of Roasting Conditions

Roasting temperature and time are very important in producing roasted jackfruit seed flour. A face-centred, central composite design (FCCCD), full factorial in response surface methodology (RSM) based on Design-Expert® 13 (Stat-Ease Inc., US) was used in this study to generate a total of 11 runs, as shown in Table 1. The roasting temperature was set in the range of 120 to 170 ℃, with roasting time ranging between 20 and 120 minutes (Odoemelam, 2005; Eke-Ejiofor *et al.*, 2014; Azeez *et al.*, 2015; Spada *et al.*, 2020; Nabubuya *et al.*, 2022).

Table 1. Optimization design of experiment run obtained from Design-Expert software.

Formulation	Roasting temperature (℃)	Roasting time (min)
1	120	120
2	145	70

Formulation	Roasting temperature (°C)	Roasting time (min)
3	120	70
4	170	20
5	145	120
6	145	20
7	145	70
8	120	20
9	145	70
10	170	70
11	170	120

A central composite design (CCD) consisting of the independent variables X_1 (roasting temperature) and X_2 (roasting time) was employed to allow for the fitting of the second-order model. All experiments were carried out in a randomized order to minimize any effect of extraneous factors on the observed responses.

To approximate a mathematical function Y(Y = *f*(T; t)), second-degree polynomial equations were used as follows:

$$Y_i = B_0 + B_1X_1 + B_2X_2 + B_{12}X_1X_2 + B_{11}X_1^2 + B_{22}X_2^2 \quad (1)$$

where Y_i is the predicted response for water absorption capacity (WAC), oil absorption capacity (OAC), water solubility index (WSI), bulk density (BD) and swelling power (SP); B_0 is the intercept when Y equals zero; B_1 and B_2 are linear terms; B_{12} represents interaction effects; and B_{11} and B_{22} are squared effects, linearly related to roasting temperature, T and roasting time, t.

Numerical optimization was carried out in Design-Expert® 13 (Stat-Ease Inc., US). WAC, OAC, WSI, and SP were maximized during the optimisation, and BD was minimized to yield jackfruit seed flour with optimum functional properties. Roasting conditions were kept in range, and WAC, OAC, BD, WSI, and SP were set as having three essential aspects in the software. The optimized solution was chosen because of a higher overall desirability function value, which varies between 0 and 1 (Montgomery, 2017).

$$D = [d_1(y_1) \times d_2(y_2) \times d_k(y_k)]^{1/k} \quad (2)$$

Where D is the overall desirability, $d_1(y_1)$, $d_2(y_2)$, $d_k(y_k)$ is the individual desirability of each variable, and k is the number of variables.

2.3 Functional Properties of Roasted Jackfruit Seed Flour

2.3.1 Water and Oil Absorption Capacities

The water absorption capacity (WAC) of flour was determined by the centrifugation method of Khan and Saini (2016) and Sosulski (1962). The sample, approximately 3 g, was dispersed in 25 ml of distilled water and placed in the pre-weighed centrifuge tube. The dispersions were stirred occasionally, held for 30 min, followed by centrifugation for 25 min at 4045 rpm. The supernatant was poured into the pre-weighed petri dish and dried in a hot air oven for 25 min at 50°C, and the solids that remained after drying were weighed. Triplicate determinations were carried out, and the WAC was expressed as a gram of water bound per gram of the sample daily. WAC was calculated by using the following Equation 3:

$$\text{WAC} = \frac{\text{Weight of tube with sample after drying (g)} - \text{Weight of tube (g)} - \text{Sample weight (g)}}{\text{Sample weight (g)}} \tag{3}$$

The oil absorption capacity (OAC) of flour was determined based on the method described by Khan and Saini (2016) and Lin *et al.* (1974). The sample, approximately 0.5 g, was mixed with 6 ml of corn oil in a pre-weighed centrifuge tube and stirred with a thin brass wire for 1 min. After a holding period of 30 min, the tubes were centrifuged for 25 min at 4045 rpm. The separated oil was then removed with a pipette, and the tubes were inverted for 25 minutes to drain the oil prior to weighing. Triplicate determinations were carried out, and the OAC was expressed as a gram of oil bound per gram of the sample on a dry basis. OAC was calculated by using the following Equation 4:

$$\text{OAC} = \frac{\text{Weight of tube with sample after removing oil (g)} - \text{Weight of tube (g)} - \text{Sample weight (g)}}{\text{Sample weight (g)}} \tag{4}$$

2.3.2 Bulk density (BD)

The bulk density (BD) of flour was determined using the method described by Nabubuya *et al.* (2022) and Narayana and Rao (1984). A graduated cylinder tube (100 ml capacity) was weighed, and the flour sample was filled with 5 ml of constant tapping until there was no further change in volume. The contents were weighed, and the difference in weight was determined. The BD of the sample was measured in grams per millilitre. BD was calculated by using the following Equation 5:

$$\text{BD (g/ml)} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample after tapping (ml)}} \tag{5}$$

2.3.3 Water solubility index (WSI)

The water solubility index (WSI) of flour was determined as described by Nabubuya *et al.* (2022) and Anderson *et al*. (1969). One gram of the sample was mixed with 10 ml of distilled water in a vortex mixer and then centrifuged at 3000 rpm for 10 min. The supernatant was dried in an oven at 105°C. The WSI was calculated as the percentage of dissolved flour. WSI was calculated by using the following Equation 6:

$$\text{WSI (\%)} = \frac{\text{Weight of dissolved solids in supernatant (g)}}{\text{Weight of flour sample (g)}} \times 100 \tag{6}$$

2.3.4 Swelling power (SP)

The swelling power (SP) of flour was determined by employing the method described by Nabubuya *et al.* (2022) and Leach *et al.* (1959). One gram of the sample was mixed with 10 ml of distilled water in a centrifuge tube and heated at 80°C for 30 min. The mixture was continually shaken during the heating period. After heating, the suspension was centrifuged at 2335 rpm for 15 min. The supernatant was removed, and the pellet was weighed. SP was calculated as a percentage of the fraction of the pellet's weight and the dry sample's weight. SP was calculated by using the following Equation 7:

$$\text{SP (g/g)} = \frac{\text{Weight of the wet mass of flour, pellet (g)}}{\text{Weight of dry sample (g)}} \tag{7}$$

2.4 Validation

Samples were roasted using optimized conditions. The predicted and experimental value of product response was compared, and standard error was calculated by using the following Equation 8:

$$\text{The standard error (\%)} = \frac{\text{Predicted value - Experimental value}}{\text{Predicted value}} \times 100 \tag{8}$$

2.5 Statistical Analysis

The results were expressed as means ± standard deviation to show variations in the various experiments. Differences are considered significant when $p<0.05$. All samples of roasted jackfruit seed flours were analyzed in triplicates; hence, the averages and standard deviation of the means were calculated using Microsoft Excel 365 (Microsoft Corporation, USA). Statistical analyses were made using Response Surface Methodology (RSM), and the results were subjected to analysis of variance (ANOVA) at the alpha level, $\alpha = 0.05$. ANOVA was implemented in all parameters. The means were compared using the least significant difference (LSD) at 0.05 level using Design-Expert® 13 (Stat-Ease Inc., US).

3. Results and Discussions

3.1. Effect of Different Roasting Conditions on Functional Properties of Jackfruit Seed Flour

In this study, an analysis of water absorption capacity (WAC), oil absorption capacity (OAC), bulk density (BD), water solubility index (WSI) and swelling power (SP) of roasted jackfruit seed flour was conducted to study any significant change in functional properties that occurs based on different roasting temperature and time applied. Table 2 shows the response of the results obtained from various roasting conditions that were studied and discussed before fitting into different experimental design models.

Table 2. Experimental data of response parameters water absorption capacity (WAC), oil absorption capacity (OAC), bulk density (BD), water solubility index (WSI) and swelling power (SP) for jackfruit seed flour measurements under different roasting conditions.

Form.	Roasting conditions		Response				
	Temp. (℃)	Time (min)	WAC (g/g)	OAC (g/g)	BD (g/ml)	WSI (%)	SP (g/g)
Raw jackfruit seed flour			1.39±0.02	0.90±0.16	0.62±0.06	16.54±0.13	4.08±0.33
1	120	120	1.78±0.04	0.53±0.15	0.75±0.00	14.78±0.85	3.63±0.29
2	145	70	1.64±0.06	0.75±0.01	0.75±0.00	11.89±0.97	3.32±0.10
3	120	70	1.27±0.02	0.77±0.07	0.84±0.01	13.83±0.31	3.58±0.85
4	170	20	1.49±0.05	0.91±0.09	0.52±0.01	9.48±0.08	4.71±0.30
5	145	120	1.60±0.05	0.66±0.08	0.83±0.01	14.28±0.47	3.10±0.13
6	145	20	1.28±0.03	1.12±0.08	0.46±0.00	9.30±0.38	3.92±0.41
7	145	70	1.61±0.16	0.68±0.02	0.87±0.00	12.68±0.08	3.53±0.04
8	120	20	1.09±0.07	1.00±0.04	0.44±0.01	11.85±2.54	3.77±0.53
9	145	70	1.48±0.05	0.68±0.08	0.92±0.01	13.10±0.10	3.50±0.02
10	170	70	1.58±0.02	0.72±0.06	0.85±0.02	12.01±0.05	3.53±0.07
11	170	120	1.72±0.05	0.58±0.08	0.94±0.01	11.41±0.51	3.60±0.07

[1] Form. = Formulation, Temp. = Temperature

3.1.1 Water absorption capacity (WAC)

WAC of the raw and roasted jackfruit seed flours are provided in Table 2. WAC of jackfruit seed flour was affected by roasting temperature (p<0.05) and roasting time (p<0.01) of jackfruit seed. The observed WAC for raw jackfruit seed flour was 1.39 ± 0.02 g/g, which was lower than the value reported by the previous study (2.34 ± 0.17 g/g) (Verma *et al.*, 2020). The highest and the lowest WAC of the flour, approximately 1.78 ± 0.04 g/g and 1.09 ± 0.07 g/g, were obtained from the jackfruit seeds roasted at 120℃ for 120 min and 20 min, respectively. As shown in Figure 1(a), the WAC increased significantly ($p<0.05$) with the increase in the roasting temperature as well as roasting time. Previous studies reported that the WAC of roasted seed flour increases with the increase in the roasting time of seeds (Yusuf *et al.*, 2008; Hatamian *et al.*, 2020). Roasting causes the gelatinization of starch and increases the level of damaged starch, leading to the formation of a porous structure that absorbs and holds water through capillary action (Sharma *et al.*, 2011; Sharma & Gujral, 2013; Adebiyi *et al.*, 2016; Sharanagat *et al.*, 2019). Roasting also causes the denaturation of proteins, dissociating major proteins into smaller units with more water-binding sites than native or oligomeric proteins (Akubor *et al.*, 2000; Adebiyi *et al.*, 2016).

The analysis of variance (ANOVA) results for the response surface model of WAC showed that the two-factor interaction (2FI) model and model terms (A, B and AB) were significant ($p\leq0.05$). A non-significant lack of fit was obtained. The adjusted R^2 value was 0.7909. The final equation showing the effect of the roasting temperature and roasting time on the WAC is shown in Equation 9:

$$\text{WAC} = +1.50 + 0.1083\text{A} + 0.2067\text{B} - 0.1150\text{AB} \tag{9}$$

3.1.2 Oil absorption capacity (OAC)

OAC measured for raw and roasted jackfruit seed flours are given in Table 2. OAC of jackfruit seed flour was affected by the roasting time ($p<0.01$) of jackfruit seed. The observed OAC for raw jackfruit seed flour was 0.90 ± 0.16 g/g, which was lower than the value reported by the previous study (1.12 ± 0.02 g/g) (Verma *et al.*, 2020). The highest and the lowest OAC of the flour, approximately 1.12 ± 0.08 g/g and 0.53 ± 0.15 g/g, were obtained from jackfruit seeds roasted at 145℃ for 20 min and at 120℃ for 120 min, respectively. As shown in Figure 1(b), the OAC decreased significantly ($p<0.05$) with the increase in the roasting time. A previous study reported that the reduction in OAC of roasted seed flour occurs with increasing roasting time of seeds (Jogihalli *et al.*, 2017). Lower OAC of the roasted seed flour may be attributed to the reduction in apolar amino acids, alteration in their polarity, and denaturation and dissociation of the constituent protein (Obasi *et al.*, 2014; Jogihalli *et al.*, 2017). According to Sharma and Gujral (2013) and Adebiyi *et al.* (2016), OAC is influenced by surface polarity, quantity of apolar amino acids, and composition of amino acids.

The result of ANOVA for OAC showed that the linear model and model term (B) were significant ($p\leq0.05$). A non-significant lack of fit was obtained. The adjusted R^2 value was 0.7906. The final equation showing the effect of the roasting temperature and roasting time on the OAC is shown in Equation 10:

$$\text{OAC} = +0.7636 - 0.0150\text{A} - 0.2100\text{B} \tag{10}$$

3.1.3 Bulk density (BD)

BD of the raw and roasted jackfruit seed flours are provided in Table 2. BD of jackfruit seed flour was affected by the roasting time (p<0.01) of jackfruit seed. The observed BD for raw jackfruit seed flour was 0.62 ± 0.06 g/ml, comparable to the value reported by the previous study (0.61 ± 0.03 g/ml) (Odoemelam, 2005). As shown in Figure 1(c), the highest and the lowest BD, approximately 0.94 ± 0.01 g/ml and 0.44 ± 0.01 g/ml, were obtained from jackfruit seeds roasted at 170℃ for 120 min and at 120℃ for 20 min, respectively. Previous studies reported that the reduction in BD of roasted jackfruit seed flour occurs after roasting jackfruit seeds (Odoemelam, 2005; Eke-Ejiofor *et al.*, 2014; Nabubuya *et al.*, 2022). Roasting causes the loss of integrity between starch-starch and starch-protein matrix and the formation of spaces in the starchy endosperm, leading to the formation of porous structure in starch polymers (Chandrasekhar & Chattopadhyay, 1990; Plaami, 1997; Kumar *et al.*, 2020).

The ANOVA result for BD showed that the quadratic model and model terms (B and B^2) were significant (p≤0.05). A non-significant lack of fit was obtained. The adjusted R^2 value was 0.8753. The final equation showing the effect of the roasting temperature and roasting time on the BD is shown in Equation 11:

$$\text{BD} = +0.8444 + 0.0475\text{A} + 0.1830\text{B} + 0.0255\text{AB} + 0.0051\text{A}^2 - 0.1914\text{B}^2 \tag{11}$$

3.1.4 Water solubility index (WSI)

WSI measured for raw and roasted jackfruit seed flours are given in Table 2. WSI of jackfruit seed flour was affected by roasting temperature (p<0.01) and roasting time (p<0.01) of jackfruit seed. The observed WSI for raw jackfruit seed flour was 16.54 ± 0.13 %, higher than the value reported by the previous study (6.5 ± 0.5 %) (Nabubuya *et al.*, 2022). As shown in Figure 1(d), the highest and the lowest WSI, approximately 16.54 ± 0.13 % and 9.30 ± 0.38 %, were obtained from raw jackfruit seeds and jackfruit seeds roasted at 145℃ for 20 min, respectively. A previous study reported that the roasting time of seeds has a significant effect (p<0.01) on the WSI of roasted seed flour (Jogihalli *et al.*, 2017). Roasting causes the release of soluble polysaccharides from the starch granule and reduces the availability of hydrophilic groups, leading to the formation of insoluble compounds (Ding *et al.*, 2006; Jogihalli *et al.*, 2017).

The result of ANOVA for WSI showed that the linear model and model term (A and B) were significant (p≤0.05). A non-significant lack of fit was obtained. The adjusted R^2 value was 0.7728. The final equation showing the effect of the roasting temperature and roasting time on the WSI is shown in Equation 12:

$$\text{WSI} = +12.25 - 1.27\text{A} + 1.63\text{B} \tag{12}$$

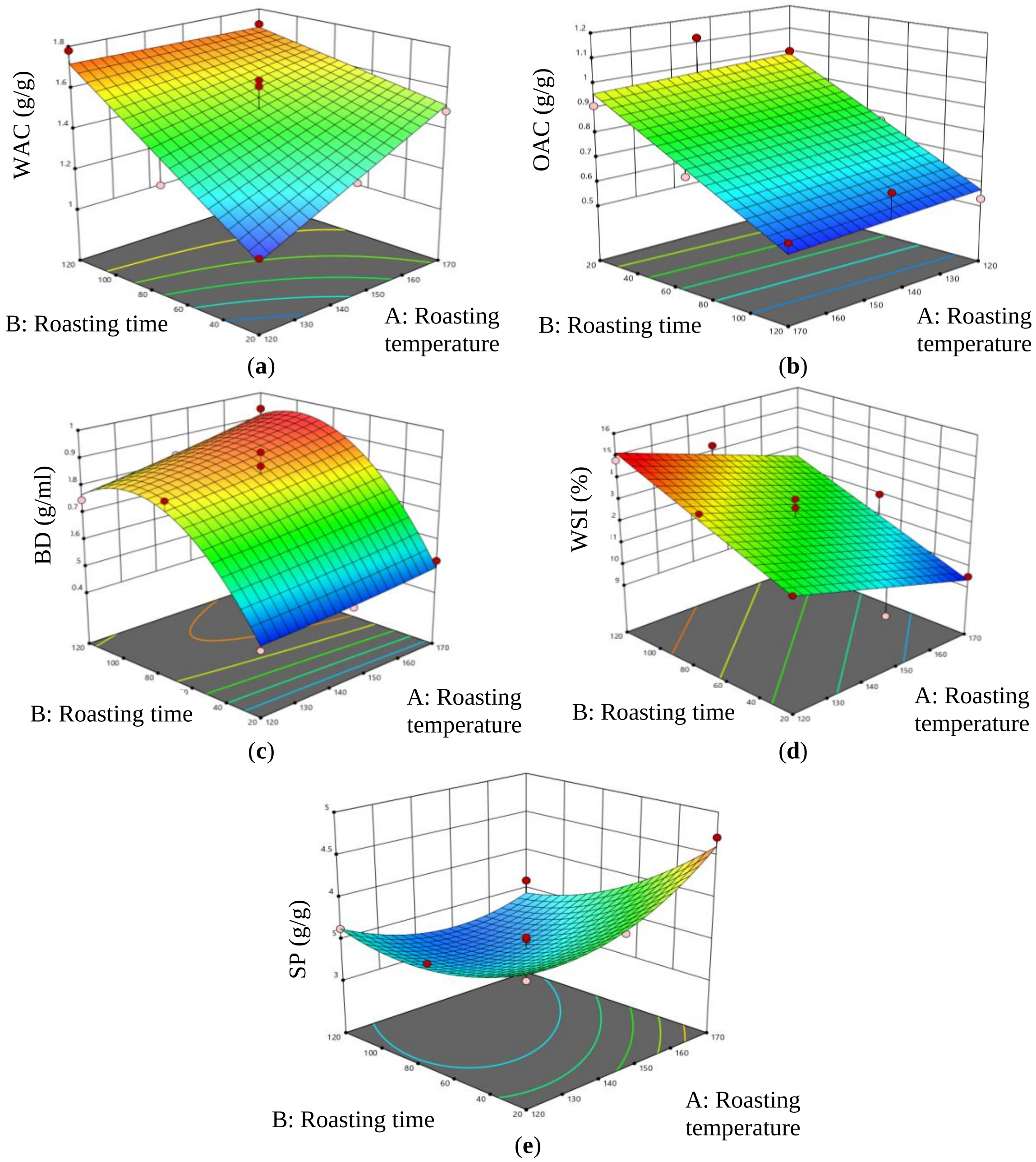

Figure 1. (**a**) Design expert 3D response surface for water absorption capacity (WAC); (**b**) Design expert 3D response surface for oil absorption capacity (OAC); (**c**) Design expert 3D response surface for bulk density (BD); (**d**) Design expert 3D response surface for water solubility index (WSI); (**e**) Design expert 3D response surface for swelling power (SP).

3.1.5 Swelling power (SP)

SP of the raw and roasted jackfruit seed flours are provided in Table 2. SP of jackfruit seed flour was affected by the roasting time ($p<0.01$) of jackfruit seed. The observed SP of raw jackfruit seed flour was 4.08 ± 0.33 g/g, comparable to the value reported by the previous study (4.11 ± 0.06 g/g) (Verma *et al.*, 2020). The highest and the lowest SP, approximately 4.71 ± 0.30 g/g and 3.10 ± 0.13 g/g, were obtained from jackfruit seeds roasted at 170℃ for 20 min and at 145℃ for 20 min, respectively. As shown in Figure 1(e), the SP decreased significantly (p<0.05) with the increase in roasting time. A previous study reported that toasting brown beans significantly reduced their swelling capacity (Obasi *et al.*, 2014). Roasting causes protein denaturation and starch gelatinization and also causes the formation of a protein-amylase complex in native starches and flour, resulting in a reduction in the capability of starch to absorb water and expand (Pomeranz, 2012; Obasi *et al.*, 2014; Jude-Ojei *et al.*, 2017).

The ANOVA result for SP showed that the quadratic model and model term (B) were significant (p≤0.05). A non-significant lack of fit was obtained. The adjusted R^2 value was 0.7797. The final equation showing the effect of the roasting temperature and roasting time on the SP is shown in Equation 13:

$$SP = +3.38 + 0.1433A - 0.3450B - 0.2425AB + 0.2695A^2 + 0.2245B^2 \qquad (13)$$

3.2 Optimization and Validation of Roasting Conditions

Using the desirability approach, a numerical optimization technique was employed to generate the optimum roasting conditions (Chakraborty *et al.*, 2015). This technique was employed to optimize multiple responses or all the dependent variables simultaneously: WAC, OAC, BD, WSI, and SP.

Table 3 shows the setting restrictions and predicted values with individual desirability of the response parameters for optimization. An individual desirability of 1 indicates the expected response to be on target (Raigar & Mishra, 2018). All the geometric means used by all the individual desirability are combined to generate the composite desirability. The roasting conditions and response parameters were set at different goal criteria (range, maximum, and minimum). The temperature and time were kept in range. WAC, OAC, WSI and SP were set at maximum levels while BD was minimized. All variables were set equally by importance 3. After numerical optimization of variables, it was found that optimized oven roasting conditions were at 162℃ for 20 min with a total desirability value of 0.693. A previous study by Raigar and Mishra (2021) reported that a total desirability value of 0.68 for optimized roasting conditions of soybean kernels was acceptable. At this optimal setting, the optimum values of WAC, OAC, BD, WSI and SP of roasted jackfruit seed flour were predicted to be 1.45 g/g, 0.96 g/g, 0.49 g/ml, 9.74 % and 4.35 g/g, respectively. Desirability is a utility function that ranges from 0 (not acceptable) to 1 (ideal), which makes it possible to optimize multiple responses simultaneously via numerical methods (Anderson & Whitcomb, 2016).

Table 3. Optimization criteria for roasting process variables and response parameters for jackfruit seed flour.

Parameters	**Goal**	**Lower limit**	**Upper limit**	**Importance**	**Predicted value at the desirability of = 0.693**
Temperature (℃)	In range	120	170	3	162
Time (min)	In range	20	120	3	20
WAC (g/g)	Maximize	0.625	2.25	3	1.45
OAC (g/g)	Maximize	0.85	1.18	3	0.96
BD (g/ml)	Minimize	0.47	0.68	3	0.49
WSI (%)	Maximize	8.31	8.93	3	9.74
SP (g/g)	Maximize	3.28	4.35	3	4.35

The model is validated by experimenting with the optimum process conditions. Oven roasting experiments (mean of 5 measurements) were conducted at the optimum process condition (162°C and 20 min) to validate the optimized model. Table 4 shows the optimum quality parameters of roasted jackfruit seed obtained experimentally and theoretically in oven roasting. The experimental results were compared with the predicted response values of the responses and validated by the predicted models. The standard error was calculated, and no significant difference was recorded between the actual and the predicted values (test value). This indicated the suitability of the corresponding models.

Table 4. The optimum quality parameters of roasted jackfruit seed were obtained experimentally and theoretically by oven roasting.

Responses	**Predicted value**	**Experimental value ± SD**	**Standard error**
WAC (g/g)	1.45	1.55 ± 0.01	6.90
OAC (g/g)	0.96	0.95 ± 0.01	1.04
BD (g/ml)	0.49	0.50 ± 0.01	2.04
WSI (%)	9.74	10.07 ± 0.20	3.39
SP (g/g)	4.35	4.61 ± 0.04	5.98

4. Conclusions

In this study, both roasting temperature and roasting time were able to cause significant differences in the functional properties of jackfruit seed flour. The roasting temperature had a significant effect (p<0.05) on water absorption capacity (WAC) and water solubility index (WSI), while roasting time significantly influenced (p<0.05) WAC, oil absorption capacity (OAC), bulk density (BD), WSI and swelling power (SP) of the jackfruit seed flours. According to the results from RSM, the optimum roasting conditions were at 162℃ for 20 min, which was achieved to produce the roasted jackfruit seed flours with desirable functional properties, which was helpful for the future development of bakery products.

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