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ORIGINAL ARTICLE

Effect of roasting conditions on the browning intensity and structural changes in jackfruit (*Artocarpus hetrophyllus*) seeds

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Abstract Central composite rotatable design (CCRD) was used to optimize the settings for the roasting conditions of jackfruit (*Artocapus hetrophyllus*) seed (JFS). The response variables studied were; color attributes *L**, *a**, and *b**, browning intensity, and fracturability. The colors *L**, *a**, *b** and browning intensity were well predicted by a second-order polynomial model. Fracturability was predicted by a first-order polynomial. The determination coefficients for colors *L**, *a**, *b**, browning intensity, and fracturability were 0.81, 0.96, 0.93, 0.92, and 0.74 respectively. The fitted models were checked for adequacy using analysis of variance (ANOVA). The optimum roasting conditions were established at a temperature of 153.36 °C, 34.36 min, and pH of 6.34 with composite desirability value of 0.95. Micro-structural studies of both raw and roasted JFS at different roasting levels (i.e., low, medium, and high) were also investigated using scanning electron microscope (SEM). JFS starch granules fell in the B-type category with semi-oval to bell-shaped granules (5–9 μm in diameter). In addition, Fourier Transform Infrared analysis was carried out on both raw and roasted JFS. The IR spectra was in the 4000–1000 cm^{-1} region which is described by five main modes; O-H, C-H, C=O, (C-H) CH_3, and C-O.

Keywords Jackfruit cultivar (J31) · Roasting · Browning intensity · Fracturability · FTIR

Introduction

Efficiency is a key factor necessary in the industrial design and development of a new product (Montgomery 1999). Some of the objectives of product design may include; determination of factors influencing the responses; setting the influential factors in order to obtain the response (s) closer to the desired target values; minimizing variability in the response (s); and establishing the position of the influential factors, in order to minimize the effect of some uncontrollable variables on the response (s). Response surface methodology is a useful framework used in modeling and optimization of process designs. RSM is a vital tool in product and process development. It is used to design and optimize the connection between dependent and independent variables. RSM is usually employed to map out the response surface over an area of interest. In addition, it's used to optimize the dependent variables, and to select experimental factors to attain targeted specification or customer's requirement (Box and Draper 1987; Khuri and Cornell 1996; Myers and Montgomery 1995).

During roasting process, color and textural attributes of nuts and seeds are significantly altered. These changes are mostly associated with non-enzymatic browning which occur in food (Buckholz et al. 1980; Mayer 1985; Perren and Escher 1996a,b). Temperature and water activity are factors responsible for non-enzymatic browning. Browning of nuts and seeds has been a bottleneck for the industries producing dehydrated foods. Thus, the browning mechanism and its control are crucial in obtaining the desired colored products. In order to achieve this, optimization of the roasting conditions is necessary to achieve a desirable browning.

Jackfruit is an indigenous fruit widely consumed in the Southeast of Asia. The unique flavors of ripe jackfruit have been exploited in several Asian cuisines and food industries. The seeds are usually eaten raw, boiled, or roasted. Some have

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been produced into flour and composite flour blends (Morton, 1987). Despite the increased knowledge on the browning of several nuts, there has been little or no report on the color development and structural changes in jackfruit seeds during roasting.

This study was aimed at investigating the effect of roasting temperature, roasting time and pH on the color and textural attributes of jackfruit seed (JFS). Also the microstructure and Fourier Transform Infrared analysis of roasted jackfruit seed (JFS) were investigated.

Materials and methods

Materials

Jackfruit cultivar (J31) was purchased from a commercial market in Negeri Sembilan, Malaysia. Fully ripe fruits were cut opened to remove the seeds. The seeds were sliced into tiny slices (3 cm x 1.5 cm x 0.5 cm) using a food processor (Model, Panasonic). The JFS slices were soaked in varying acidic medium to obtain pH in the range of 1–3.5 according to the central composite design. Roasting conditions (i.e., temperature, 120–160 °C and roasting time, 20–70 min) were based on the central composite design.

Color measurement of the roasted Jackfruit seeds

The color of ground roasted JFS was measured using the Hunter Lab Color Measuring System with Minolta Chroma Meter (CR- 300, Osaka, Japan). Calibration was first done with the black and white glass standards. The color parameters of the roasted jackfruit seeds measured were lightness (*L*), redness (+a), greenness (−a), yellowness (+b) and blueness (−b). The browning intensity (BI) was calculated from the values of colors *L**, *a**, and *b** using Eq. 1 (Maskan 2001).

$$\begin{aligned} &\mathrm{BI} = [100(x-0.31)]/0.17 \\ &\text{Where, } x = (a + 1.75L)/5.64L + a - 3.012b \end{aligned} \tag{1}$$

Textural analysis

The textural analysis of roasted JFS in terms of fracturability was determined using Texture Analyzer TA-XT2i (Stable Micro System Ltd., Surrey, UK). Samples were compressed to about 50 % using a 36 mm cylindrical probe (SMS P/36R). Calibration was done with a 20 kg load cell. Roasted JFS slices were placed in a cylindrical cup (43 mm x 55 mm) and compression was done at a pretested rate of 3 mm/sec. Samples were later compressed to 5 mm at 1 mm/sec with a contact force of 5 g and post tested at 5 mm/sec. Fracturability was obtained from the force time curves (Bourne 1982) in Newton as the first peak of first compression.

Microstructural analysis

A scanning electron microscope Joel JSM 6400 with EDX (JEOL-USA, Inc., Peabody, MA, USA) was used to investigate the appearance and surface structure of the roasted JFS at different levels of roasting. Sample preparation was done on steel plates covered with carbon and dried in a CPD 030 critical point dryer (Bal-tec AG, Balzers, Liechtenstein). Coating was done using the SCD 005 Bal-tec sputter coater (Bal-tec AG, Balzers, Liechtenstein) and observed at 15 KV and x1000 magnification. Desired micrographs were selected and image analysis was done to determine the effect of roasting conditions on the structural changes in JFS starches.

Fourier transform infrared analysis (FTIR*)*

The FTIR spectra of raw and roasted JFS samples were recorded using the Universal attenuated total reflectance (ATR) single reflectance cell. Diamond crystal/ KRS −5 were used as the contact crystal on a Perkin Elmer Spectrum 100 FT-IR spectrophotometer with CsI detector (Shelton, CT, USA). 32 scans were recorded at a resolution of 4 cm^{-1}, co-added and Fourier transformed. Prepared samples were placed on the diamond crystal and compressed with a steel cylinder to a force of 100 and the scan was read over a range of 4000 to 1000 cm^{-1} (mid-infrared region). The surrounding spectrum was recorded in air (blank) and deducted from the sample values.

Experimental design and data analysis

The main and combined effects of three independent variables; roasting temperature ($x_{1,}$ 130–150 °C), roasting time ($x_{2,}$ 30–60 min), and pH variation ($x_{3,}$ 4.55–5.95) on color *L**, *a**, *b**, browning index (BI), and fracturability were investigated. The experimental domains were established by means of preliminary experiments. A second order central composite design with three factors was assigned to the experimental data to produce 20 experimental runs with six centre point. The centre points were used to check the reproducibility of the design (Montgomery, et al. 2001). The ranges of the three independent factors studied are given in Table 1. Regression analysis and ANOVA were conducted to: (1) Determine regression coefficients and the statistically significant model terms; (2) Fit the mathematical models to experimental data, aiming at a reduced region and a high composite desirability for the response variables; (3) Determine the optimum roasting conditions for jackfruit seeds. Response variables were evaluated for each treatment and the data subjected to multivariate regression analysis using the least-squares technology (Myers 1971) to predict the linear, quadratic and interactive effects

Table 1 Central Composite Design with experimental values of the response variables

Run #	Block	Independent Variables			Dependent Variables				
		Roasting Temperature (°C)	Roasting Time (min.)	pH level	L*	a	b	BI	Fracturability
1	1	150 (+1)	60 (+1)	4.55 (−1)	83.56	5.99	18.98	30.59	5167.14
2	1	130 (−1)	60 (+1)	5.95 (+1)	76.26	5.50	18.29	32.35	3496.89
3	1	130 (−1)	30 (−1)	4.55 (−1)	78.66	2.13	9.20	14.12	3458.69
4	1	140 (0)	45 (0)	5.25 (0)	78.30	3.06	11.14	18.24	3543.41
5	1	140 (0)	45 (0)	5.25 (0)	76.18	3.22	9.57	16.47	3793.84
6	1	150 (+1)	30 (−1)	5.95 (+1)	77.23	3.76	11.18	18.82	3470.06
7	3	156.33 (+1.63)	45 (0)	5.25 (0)	81.65	5.00	12.97	22.35	3260.41
8	3	140 (0)	20.51 (−1.63)	5.25 (0)	77.46	2.38	8.87	14.12	1508.93
9	3	140 (0)	45 (0)	4.11 (−1.63)	79.67	3.66	16.03	25.88	3366.17
10	3	123.67 (−1.63)	45 (0)	5.25 (0)	76.70	3.14	10.60	17.65	1525.64
11	3	140 (0)	45 (0)	5.25 (0)	77.66	2.93	11.01	17.65	3677.68
12	3	140 (0)	45 (0)	6.41 (+1.63)	76.07	3.53	15.04	25.29	4311.57
13	3	140 (0)	45 (0)	5.25 (0)	76.27	3.11	11.67	19.41	3575.11
14	3	140 (0)	69.51 (+1.63)	5.25 (0)	78.06	4.98	15.53	26.47	5278.58
15	2	150 (+1)	30 (−1)	4.55 (−1)	80.79	3.58	13.14	20.59	3125.63
16	2	140 (0)	45 (0)	5.25 (0)	78.70	3.10	10.35	17.06	3744.54
17	2	140 (0)	45 (0)	5.25 (0)	78.27	2.83	10.96	17.65	3635.26
18	2	130 (−1)	30 (−1)	5.95 (+1)	78.90	3.75	11.18	18.24	2269.61
19	2	130 (−1)	60 (+1)	4.55 (−1)	76.03	3.11	13.54	22.35	3758.41
20	2	150 (+1)	60 (+1)	5.95 (+1)	83.00	4.55	16.32	25.88	5247.91

on the dependent variables. The proposed model for the dependent variables was predicted as;

$$Yi = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \tag{2}$$

Only the significant terms were included in the final reduced models for all response variables. Model adequacies were checked using R-square, R-square adjusted, and lack-of-fit test. The significance of the model terms for the color attributes and fracturability was determined by the F-ratio at P-value of 0.05. Minitab V. 15 statistical package (Minitab Inc. Pennsylvania, USA) was used to perform the experimental design matrix, data, analysis, and optimization procedure.

The interactive effect of the factors on the dependent variables was visualized by generating 3D response surface plots (Montgomery et al. 2001; Lasekan et al. 2011). Optimization of response variables was also done using multiple response optimizers to determine the optimum value of each response variable. Validation was done by comparing the experimental values to the fitted values predicted by the model.

Results and discussion

Model fitting

Multivariate regression analyses was performed using the response surface to: (1) Determine the regression coefficients and models that are statistically significant, (2) Fit the mathematical models to the experimental data, aiming at a targeted region and a high composite desirability for the response variables, and (3) Determine the optimum roasting conditions for JFS. Table 1, shows the correlation between the three independent variables and the dependent variables analyzed. Analysis of variance was then used to analyze the results obtained in order to access the adequacy of fitness of the first-order, interactive and second order polynomial models to the experimental data (Table 2). The adjusted models, with its corresponding probability value and lack of fit test were presented in Table 2. Only significant ($P \leq 0.05$) effects were included in the final reduced models. Results have shown that colors *L**, *a**, *b**, and browning intensity (BI) were all predicted by second-order effect. Conversely, fracturability was predicted by first –order effect. The signs and magnitude of the regression coefficients is an indication of how the color parameters and fracturability were influenced by the independent variables (Lasekan and Abdulkarim 2012). A positive

Table 2 Adjusted models, R sq., R sq. (Adjusted), probability value, and lack of fit for response variables studied

Responses	Model	R^2	R^2 (Adjusted)	Regression (P value)	Lack of fit (P value)
Colour L	$279.260b_0 - 2.540 \times_1 - 1.597\times_2 + 0.008\times_1^2 + 0.012\times_1\times_2$	0.813	0.726	0.000	0.848
Colour a	$23.1879b_0 - 0.6487 \times_1 - 0.0608\, x_2 + 8.1495\times_3 + 0.0043\, x_1^2 + 0.0012 \times_2^2 + 0.05045 \times_3^2 - 0.0941 \times_1 x_3$	0.957	0.918	0.000	0.101
Colour b	$-47.1122b_0 + 1.1487 \times_1 - 0.0787\, x_2 - 11.5065 \times_3 + 0.0027 \times_2^2 + 3.8033 \times_3^2 - 0.2027 \times_1 x_3$	0.931	0.899	0.000	0.210
Browning Intensity	$-111.093b_0 + 2.055 \times_1 - 0.093\, x_2 - 11.226 \times_3 + 0.004\, x_2^2 + 6.042 \times_3^2 - 0.368 \times_1 \times_3$	0.92	0.885	0.000	0.064
Fracturability	$-6486.72b_0 + 51.45 \times_1 + 57.51\, x_2 + 55.55 \times_3$	0.73	0.640	0.001	0.007

^{x1} temperature (°C); ^{x2} time (min); ^{x3} pH

sign indicates increase in response as independent variable decreases and vice versa.

The R-square value of colors *L**, *a**, *b**, BI and fracturability were 0.81, 0.96, 093, 0.92, and 0.74 respectively. For a model to be considered to have a good fit, the R-square should not be less than 0.80 (Joglekar and May 1987). Apart from fracturability, the R-square values for other response variables were above 0.80 with a non-significant lack-of-fit as shown in Table 2. Myers and Montgomery (2002) stated that a model having a significant lack-of-fit is not a good indicator

Table 3 ANOVA and regression coefficient of the first and second-degree polynomial regression models

Variables	Main Effects			Quadratic Effect			Interaction Effect		
	χ_1	χ_2	χ_3	χ_1^2	χ_2^2	χ_3^2	$\chi_1\chi_2$	$\chi_1\chi_3$	$\chi_2\chi_3$
Colour L									
P value	0.016 ^{a}	0.001^a	–	0.031 ^{a}	–	–	0.001 ^{a}	–	–
F ratio	7.66	16.62	–	5.82	–	–	17.12	–	–
Colour a									
P value	0.022 ^{a}	0.094^b	0.013 ^{a}	0.000 ^{a}	0.006 ^{a}	0.012 ^{a}	–	0.000 ^{a}	–
F ratio	7.31	3.42	9.03	27.58	11.88	9.32	–	40.08	–
Colour b									
P value	0.001^a	0.470 ^{b}	0.211 ^{b}	–	0.035 ^{a}	0.000 ^{a}	–	0.001 ^{a}	–
F ratio	20.61	0.55	1.73	–	5.54	51.16	–	17.87	–
BI									
P value	0.001 ^{a}	0.642 ^{b}	0.499 ^{b}	–	0.063 ^{b}	0.00 ^{a}	–	0.001 ^{a}	–
F ratio	19.31	0.23	0.48	–	4.12	37.80	–	17.23	–
Fracturability									
P value	0.008 ^{a}	0.000 ^{a}	0.819 ^{b}	–	–	–	–	–	–
F ratio	9.56	26.86	0.05	–	–	–	–	–	–

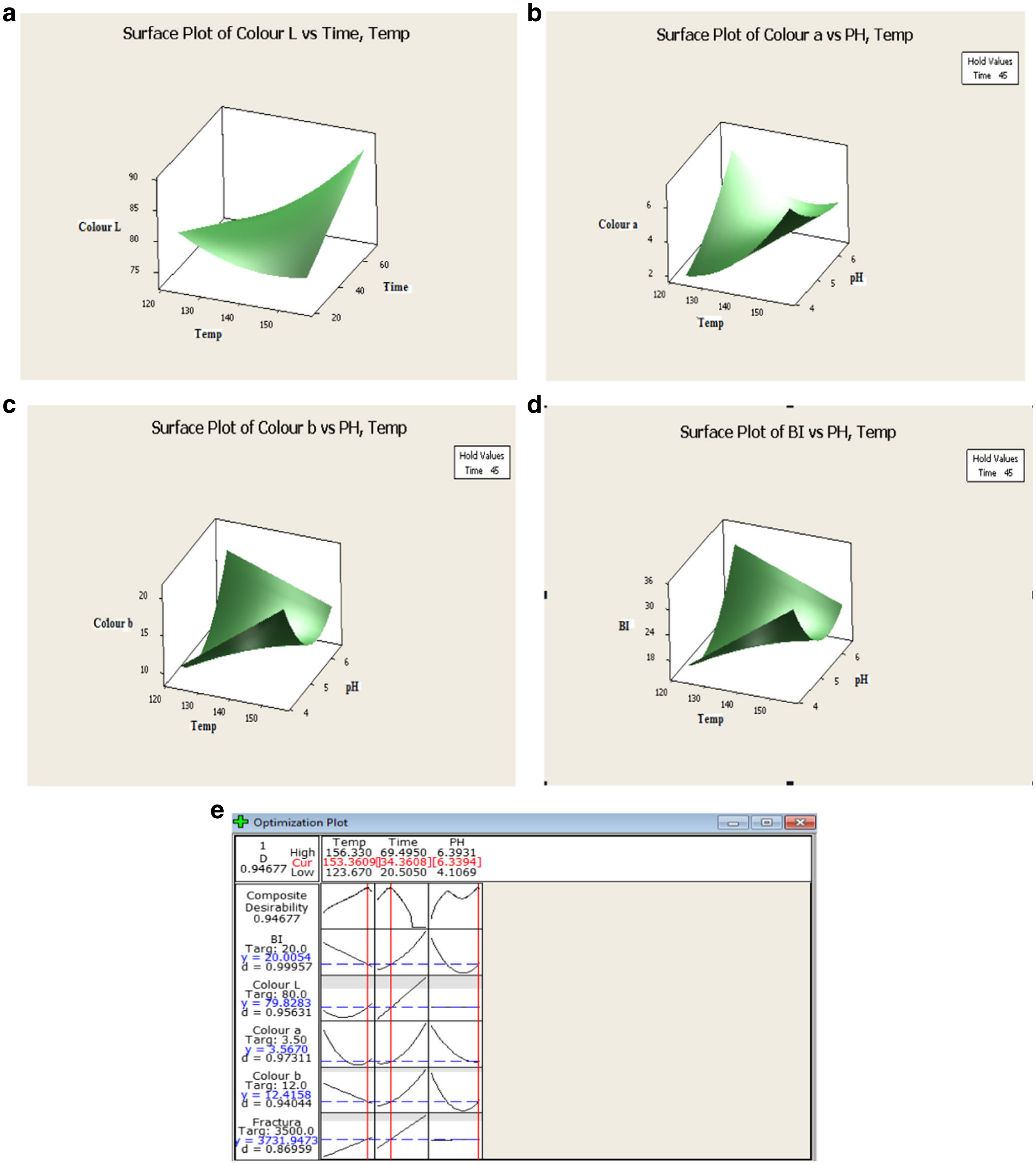
^{a} Significant ($P<0.05$)

^{b} Not significant ($P>0.05$)

^{a} Significant ($P<0.05$)

^{b} Not significant ($P>0.05$)

of the response variable and, therefore should not be used for prediction. The significance of each effect in the final adjusted models was further determined by the F ratio and P values (Table 3). All response variables with the exception of fracturability had a significant interaction effect. As shown in Table 3, color *L** was significantly ($P \leq 0.05$) influenced by the linear effect of temperature and time, followed by the quadratic effect of roasting temperature and interactive effect of temperature and time. Color *a** was significantly ($P \leq 0.05$) influenced by the quadratic effect of all the variables studied, followed by the linear and interactive effects of temperature and pH. Color *b** however, was significantly ($P \leq 0.05$)



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  1            Temp      Time      PH
  D     High  156.330   69.4950   6.3931
0.94677 Cur  153.3609[]34.3608][6.3394]
        Low   123.670   20.5050   4.1069

Composite
Desirability
0.94677

BI
Targ: 20.0
y = 20.0054
d = 0.99957

Colour L
Targ: 80.0
y = 79.8283
d = 0.95631

Colour a
Targ: 3.50
y = 3.5670
d = 0.97311

Colour b
Targ: 12.0
y = 12.4158
d = 0.94044

Fractura
Targ: 3500.0
y = 3731.9473
d = 0.86959
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Fig. 1 **a**, **b**, **c**, **d**; Response surface plots for colour L, a, b, and BI respectively; E: Numerical multiple response optimizer

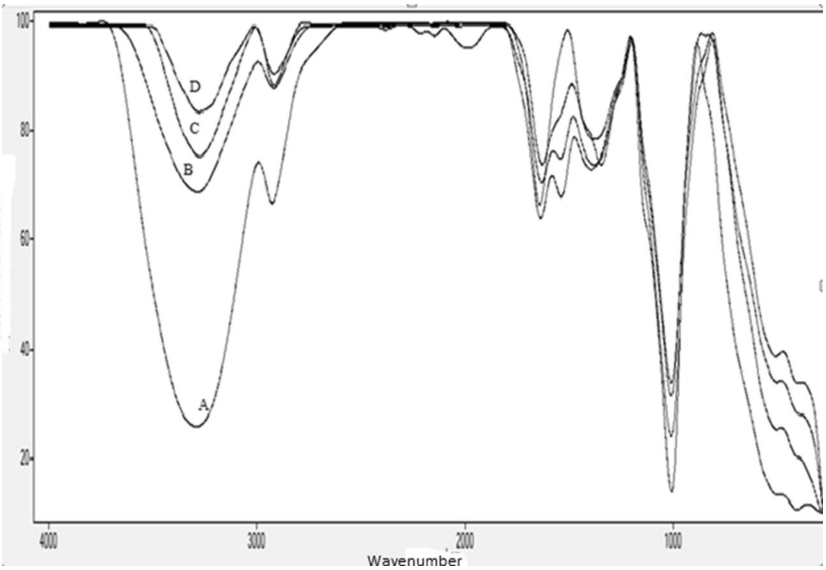

Fig. 2 **a**: FT-IR spectra for Raw jackfruit seed; **b**: FT-IR spectra for jackfruit seed roasted at 130 °C for 30 min; **c**: FT-IR spectra for jackfruit seed roasted at 140 °C for 45 min; **d**: FT-IR spectra for jackfruit seed roasted at 150 °C for 60 min

influenced by the quadratic effect of roasting time and pH, followed by the main effect of temperature and interactive effect of roasting temperature and pH. For browning intensity, only the linear effect of roasting temperature, quadratic effect of pH and interactive effect of both were significant. Fracturability however was only significantly affected by the linear effect of all the variables studied.

Visualization of the significant interactive effects was aided by a 3D surface plot for the variable values obtained during the roasting of jackfruit seed as shown in Fig. 1. It was observed that the color *L** decreased with increase in temperature, but strangely it was found to increase with roasting time. This is a different trend from the convectional order of process. Moss and Otten (1989) reported that color *L** decreased

Table 4 Experimental and Predicted values of the response variables studied

Browning										Fit					
Colour L* Y1	Fit L Y0	Y1-Y0	Colour a Y2	Fit a Y0	Y2-Y0	Colour b Y3	Fit b Y0	Y3-Y0	Index Y4	Fit bi Y0	Y4-Y0	Fracturability Y5	fracturability Y0	Y5-Y0
81.96	81.021	0.939	5.99	4.793	1.197	18.98	18.33	0.65	35.29	20.882	14.408	3167.14	2678.549	488.591
76.26	75.91	0.35	5.5	4.58	0.92	18.29	16.712	1.578	35.29	22.648	12.642	3496.89	2788.082	708.808
78.66	79.536	−0.876	2.13	2.906	−0.776	9.2	8.804	0.396	11.76	20.882	−9.122	3458.69	3984.219	−525.529
78.3	77.296	1.004	3.06	3.712	−0.652	11.14	11.127	0.013	17.65	19.119	−1.469	3543.41	3667.791	−124.381
76.18	77.296	−1.116	3.22	3.712	−0.492	9.57	11.127	−1.557	17.65	19.119	−1.469	3793.84	3667.791	126.049
77.23	77.532	−0.302	3.76	3.956	−0.196	11.18	10.57	0.61	17.65	22.648	−4.998	5470.06	5220.312	249.748
80.65	81.963	−1.313	5	3.575	1.425	12.97	12.509	0.461	23.53	19.119	4.411	3260.41	4127.708	−867.298
77.46	77.539	−0.079	2.38	3.059	−0.679	8.87	8.683	0.187	11.76	19.119	−7.359	2345.76	3667.791	−1322.03
79.67	77.483	2.187	3.66	3.642	0.018	16.03	16.037	−0.007	23.53	24.734	−1.204	4366.17	3118.438	1247.732
80.45	79.426	1.024	3.14	2.543	0.597	10.6	9.746	0.854	17.65	19.119	−1.469	2447.14	3207.873	−760.733
77.66	77.483	0.177	2.93	3.059	−0.129	11.01	11.127	−0.117	17.65	19.119	−1.469	3677.68	3667.791	9.889
76.07	77.483	−1.413	3.53	4.324	−0.794	15.04	16.158	−1.118	23.53	27.617	−4.087	4311.57	4217.143	94.427
76.27	77.483	−1.213	3.11	3.059	0.051	11.67	11.127	0.543	17.65	19.119	−1.469	4057.11	3667.791	389.319
78.06	77.428	0.632	4.98	3.059	1.921	15.53	16.841	−1.311	23.53	19.119	4.411	5278.58	3667.791	1610.789
80.79	79.052	1.738	3.58	4.313	−0.733	13.14	13.334	−0.194	17.65	20.882	−3.232	1525.63	2678.549	−1152.92
78.7	78.816	−0.116	3.1	3.232	−0.132	10.35	11.127	−0.777	17.65	19.119	−1.469	3744.54	3667.791	76.749
78.27	78.816	−0.546	2.83	3.232	−0.402	10.96	11.127	−0.167	17.65	19.119	−1.469	4135.26	3667.791	467.469
81.46	81.056	0.404	3.75	4.1	−0.35	11.18	11.716	−0.536	17.65	22.648	−4.998	2269.61	2788.082	−518.472
76.03	77.43	−1.4	3.11	2.426	0.684	13.54	13.8	−0.26	23.53	20.882	2.648	3758.41	3984.219	−225.809
82.46	82.541	−0.081	4.55	3.476	1.074	16.32	15.566	0.754	29.41	22.648	6.762	5247.91	5220.312	27.598

^{Y0} predicted values for all responses; $^{Y1\text{-}Y5}$ experimented values for all responses gradually as the roasting time of peanut was increased. However, colors a^*, b^*, and BI were all increased with temperature, roasting time and pH. The rate and extent of browning increased with pH (Wolfrom and Rooney, 1953) and changes in pH may also lead to changes in the mechanism of reaction, hence, the formation of different volatiles and colored products (Westphal, et al. 1988). The composite desirability (D) for the response variables analyzed (Fig. 2) was 0.95 with the individual desirability (d) of 0.96, 0.97, 0.94, 0.99, and 0.87 for colors L^*, a^*, b^*, BI, and fracturability respectively. The optimum roasting conditions obtained for jackfruit seed were Temperature (153.36 °C), Time (34.36 min), and pH (6.34).

Model verification

The equations generated were checked for adequacy by comparing the experimental values with the fitted values predicted using two-sample *T*-test. The experimental and predicted values of all response variables are presented in Table 4. The results showed no significant ($P \geq 0.05$) difference between the values. It was observed that there was little difference between the two values, indicating that the experimental response variables were in agreement with the predicted values for all response variables except fracturability.

Spectra of jackfruit seed

The mid-infrared spectrum is categorized into four regions where the character of a group frequency is determined. The regions include; the X–H stretching (4000–2500 cm^{-1}), the triple-bond (2500–2000 cm^{-1}), the double-bond (2000–1500 cm^{-1}) and the fingerprint (1500–600 cm^{-1}) regions. Figure 2 shows the FTIR spectra of the raw and roasted jackfruit seeds at different roasting conditions (i.e., low, medium, and high). The IR spectra of the samples were in the 4000–1000 cm^{-1} region which is described by five main modes. The band's absorbance in starches has been assigned to the vibrational modes by many authors (Demiate, et al. 2000; Goodfellow and Wilson 1990; Kizil et al. 2002; Van Soet et al., 1995). The peaks at 3290–3276 cm^{-1} could be attributable to hydroxyl group (O-H bond stretching) with a very strong but broad band. This spectrum represents a typical behavioral pattern of starches. As expected, the main absorption band at 3290.33 cm^{-1} decreased to a lower value (3276.44 cm^{-1}) as roasting conditions increased,

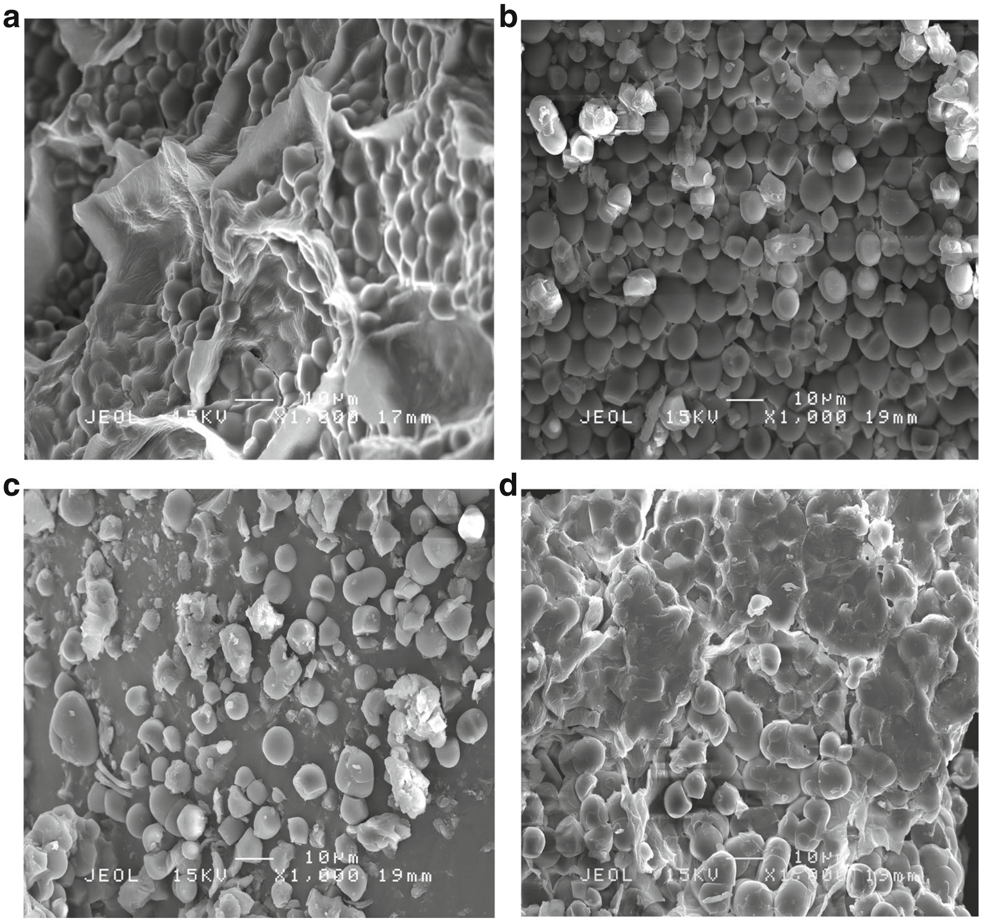

Fig. 3 **a**: SEM for Raw jackfruit seed; **b**: SEM for jackfruit seed roasted at 130 °C for 30 min; SEM for jackfruit seed roasted at 140 °C for 45 min; D: SEM for jackfruit seed roasted at 150 °C for 60 min

indicating a reinforcement of hydrogen bonds with covalent bonds (ether linkage) (Pavlovic and Brandão, 2003). The peaks at 2927–2917 cm^{-1} were assigned to the C-H bond asymmetric stretching, while the peaks at 1641–1629 cm^{-1} can be attributed to the C=O stretching of the carbonyl group. Starch degradation mechanism involves two main processes which include; water elimination and de-polymerization, which dependents on the polysaccharide crystallinity. Starch degradation was slightly noticed in the spectrum of sample with low roasting conditions (120 °C for 30 min) which gradually progressed as water evaporated during increase in thermal treatment. This can be observed in the IR spectrum of sample with high roasting conditions (150 °C for 60 min) at absorption band 1538.40 cm^{-1} (attributed to the C=C aromatic rings). This behavior suggests that water loss from starch could lead to an increase in crystallinity of its structure. The peaks found at 1394–1345 cm^{-1} were assigned to the bending modes of C-H and CH_3 vibrational deformation. The peaks at 1009–1007 cm^{-1} can be assigned to C-O bond stretch of alcohols, ethers, carboxylic acid, and esters. Previous studies have attributed bands in the 1200–800 cm^{-1} region (finger print region) to changes in polymer conformation and hydration of processed starches (Bello-Perez et al. 2005; Goodfellow and Wilson 1990; van Soest, et al. 1995). There were little changes in conformation (differ only in absorbance intensity) as observed in the peaks at 1007.74, 1009.15, 1009.21, and 1009.99 cm^{-1}.

Microstructural analysis of jackfruit seed

The scanning electron microscopy (SEM) analysis of both raw and roasted jackfruit seeds are showed in Fig. 3. The results showed granules with semi-oval and bell-shapes predominating. Similar observations have been reported by other authors for jackfruit seed starches (Tulyathan et al. 2002). The surfaces of the granules are almost smooth like that of potato starches but differ in shapes and sizes. It was observed in the raw seeds that the starch granules were surrounded by cellular comportments. As roasting temperature and time were increased, the swelling and gelatinization of the granules exerted pressure on the cell walls, thus causing the cell walls to rupture. This can be observed from the micrograph of seeds roasted at high temperature (d). The starch granules showed characteristic flatten surface. This is an indication of the effect of dry heat treatment on the microstructure of seeds. The size range of starch granules analyzed by SEM was between 5 to 9 μm. This is in agreement with previous studies for jackfruit seed starches, with a range of 7 to 11 μm (Bobbio et al. 1978), average granule size of 7.75 μm (Tongdang 2008), and 6–11 μm for soft and 6–13 μm for hard variety of jackfruit seed (Tulyathan et al. 2002). Corn starch granules are angular-shaped with average size ranging from 1 to 7 μm for small granules and 15 to 20 μm for large granules. Wheat endosperm is reported to contain two types of starch granules, large A- and small B- type (Baum and Bailey 1987). The A-type granules are disc – like or lenticular shaped with diameter ranging from 10 to 35 μm. Whereas, B- type starch granules have roughly spherical or polygonal shape with diameter ranging from 1–10 μm (Baum and Bailey 1987). Jackfruit seed starch granules falls in the category of B – type starch granules with average size ranging from 5 to 9 μm.

Conclusion

This study revealed that RSM was able to predict models for colors *L**, *a**, *b**, and BI adequately as shown from the high determination coefficients 0.81, 0.96, 0.93, and 0.92 respectively. The optimum roasting conditions obtained were at temperature (153.36 °C), time (34.36 min), and pH (6.34) with high composite desirability (D) value of 0.95. Texture analysis of roasted JFS was not well predicted by the first-order polynomial model. Microstructural analysis of both raw and roasted JFS showed a B-type starch granule with semi-oval to round and bell-shapes. The FTIR spectra of the raw and roasted JFS were in the 4000–1000 cm^{-1} (mid-infrared region) and described by five main modes. The products of degradation were acids, alkane, carbonyl, esters, ethers, carboxylic acids, and aromatic compounds.

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