The effect of processing parameters on the functional and pasting properties of breadfruit (*Artocarpus Altilis*) "elubo" flour

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Summary

Breadfruit (*Artocarpus altilis*) *elubo* was produced using various processing parameters. A second order Box-Benhken Response Surface Design was adopted in designing the experiment which generated 17 runs on selected process parameters, including parboiling temperature (30, 50 and 60 °C), parboiling time (90, 120 and 150 min), and steeping time (6, 12 and 18 hrs) on the functional and pasting properties (bulk density, water absorption capacity, swelling power, solubility, dispersibility, and pasting characteristics) of the *elubo*. At high parboiling temperature and time there was an increase in bulk density, water absorption, and swelling power of the BE, while the increase in parboiling temperature and steeping time led to a decrease in peak and final viscosity. The generated models were adequately explained as their adjusted regression coefficients (Adjusted R^2) were between 0.56 and 0.99, this revealed that R^2 gave a good ($50<R^2>75\%$) explanation of the model. BE can be produced at an optimum condition of 60 °C, 133 min, and 10 hrs for parboiling temperature, time and steeping time, respectively, based on the desirability concept of 0.80.

Keywords: Breadfruit, elubo, optimization, response surface methodology

Introduction

Breadfruit (*Artocarpus altilis*) is a carbohydrate food resource and staple diet in many tropical developing countries of the world. The tree fruits primarily between May and August, producing 50 to 200 pieces of fruit in a year. The mature fruit is round or ovoid, 15-20 cm in diameter and weighing 2-10 kg on average (Graham et al., 1981). Total yearly production in Nigeria is about 10 million metric tonnes with improved agricultural practice (Bakare et al., 2012). The fruit has been described as an important staple food of high economic value (Soetjipto and Lubis, 1981). Breadfruit is highly nutritious, cheap, and readily available in overwhelming abundance during its season, it has found limited applications in the food industry (Omobuwajo, 2003).

The bread fruit pulps are made into various dishes; it can be processed into flour and used in bread and biscuit making (Amusa et al., 2002). Breadfruit has also been reported to be rich in fat, ash, fibre, and protein (Ragone, 1997). Despite the importance of this fruit, its production is faced with several problems, including short shelf life and poor yield due to diseases (Olaoye et al., 2007). The fruit is utilized in Nigeria within 5 days of harvesting because of its short shelf life.

One way to minimize post-harvest losses and increase the utilization of breadfruit is through processing into flour, which would provide a more stable storage form, as well as enhance the versatility of the fruit. The current usage of breadfruit is attaining greater industrial importance, particularly in food application such as bakery products, flour confectionaries, and related products (Olatunji and Akinrele, 1978), while its starch is of potential value as adhesive in packaging, and also in textile and pharmaceutical industries (Bakare et al., 2012).

In Nigeria, particularly the south western region, root and tuber crops such as yam and cassava are usually processed into flour known as "*elubo*" using traditional methods of parboiling in water or soaking followed by drying. This is to overcome the high perishability of the fresh forms of fruit and the seasonal nature of their production. The traditional flour, "*elubo*", is used to make a cooked paste meal known as "*amala*". The use of flours from yam and cassava for "*elubo*" has been reported by several authors (Oyewole and Odunfa, 1988; Akissoe et al., 2001; Mestres et al., 2004; Babajide et al., 2006; Nwabueze and Odunsi, 2007). However, information on the production of breadfruit *"elubo"* is limited. In view of the need for

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commercial production of breadfruit "*elubo*", an understanding of the effect of processing parameters, such as parboiling temperature, time, and steeping time, on the properties of breadfruit "*elubo*" is required for quality control purposes. Therefore, this study was conducted to determine the effect of processing parameters on the functional properties of breadfruit "*elubo"*.

Materials and methods

Materials

Unripe matured breadfruit was purchased in Ilobi market, Ogun state. Equipment used includes a cabinet dryer, a laboratory milling machine, a mechanical sieve, a digital weighing balance, a stirrer, a knife, a bucket, and a stainless steel perforated tray.

Production of breadfruit flour ("Elubo")

The method described by Babajide et al. (2006) for the production of yam flour *elubo* was adopted, with variations in parboiling time, parboiling temperature, and steeping time. The pieces of fruit were washed in clean water to remove the adhering latex and dirt, peeled manually, and chopped. The chopped breadfruit was parboiled in water at (30, 50, and 60 °C) for (90, 120, and 150 min). The parboiled breadfruit was steeped for (6, 12, and 18 hrs). The steeped breadfruit was drained and dried in the cabinet dryer at 60 °C for 2 days. The dried breadfruit was milled using a laboratory milling machine (Fritsch, D-55743, Idar-oberstein-Germany). The milled sample was sieved (using a 250 µm screen) and stored in air-tight polyethylene bags.

Experimental design

Response surface methodology (RSM) is a statistical method for determining and simultaneously solving multivariate equations. It uses an experimental design to fit a first or second order polynomial by least significant techniques. An equation is used to describe how the test variables affect the response and to determine the interrelationship among the test variables in the response. A Box-Behnken design (Box and Behnken, 1960) was used for the design of the experiment with three independent variables; Parboiling temperature (X_1), parboiling time (X_2), and steeping time (X_3), using a commercial statistical package, Design Expert version 6.0.2 (Stat Ease Inc., Minneapolis, MN, USA). The levels of each variable were established based on a series of preliminary experiments and coded as −1, 0, and 1 (Table 1), resulting in a total of 17 experimental runs to investigate the effect of these process variables on the response. A second order polynomial model was fitted to measure dependent variables (Y), such as bulk density (Y_1), water absorption capacity (Y_2), dispersibility (Y_3), swelling power (Y_4), solubility (Y_5), and pasting properties (Y_6). The following equation was used:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_{12} + \beta_{22} X_{22} + \beta_{33} X_{32} + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \quad (1)$$

where β_0, β_1- β_3, β_{11}-, $\beta_{33,}$ and β_{12}-, β_{23} are regression coefficients for interception, linear, quadratic, and interaction coefficients, respectively, X_1-X_3 are coded independent variables, and Y is the response.

Determination of functional properties of breadfruit ("Elubo")

Bulk Density

This was determined by the method of Wang and Kinsella (1976). 10g of breadfruit flour was weighed into a 50 ml graduated measuring cylinder. The breadfruit flour was packed by gently tapping the cylinder on the bench top. The volume of the breadfruit flour was recorded.

$$\text{Bulk density}\left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{Weight of breadfruit flour}}{\text{Volume of breadfruit flour after tapping}} \quad (2)$$

Table 1. Experimental Process Variables and their level for breadfruit elubo using Box-Behnken Design (BBD)

Process variables	Symbol	Coded variable levels		
		-1	0	+1
Parboiling temperature (°C)	X_1	45	30	60
Parboiling time (min)	X_2	120	90	150
Steeping time (Hrs)	X_3	6	12	18

Swelling power and solubility index

Swelling power and solubility were determined as described by Takashi and Siebel (1988). 1g of the flour was mixed with 10 ml of distilled water in a centrifuge tube, and heated at 80 °C for 30 min while shaking continuously. The tube was removed from the bath, wiped dry, cooled to room temperature, and centrifuged for 15 min at 2200 rpm. The supernatant was evaporated and the dried residue was weighed to determine the solubility. Solubility was determined using the formula:

$$\text{Solubility \%} = \frac{\text{Weight of dried sample in supernatant}}{\text{Weight of original sample}} \times 100 \quad (3)$$

The swollen sample (paste) obtained from decanting the supernatant was also weighed to determine the swelling power. Swelling power was calculated using the formula.

$$\text{Swelling power} = \frac{\text{weight of wet mass of sediment}}{\text{Weight of dry matter in the gel}} \quad (4)$$

Dispersibility

This was determined by the method described by Kulkarni et al. (1991). 10g of breadfruit flour was suspended in a 100 ml measuring cylinder and distilled water was added to reach a volume of 100 ml. The setup was stirred vigorously and allowed to settle for 3 hr. The volume of settled particles was recorded and subtracted from 100. The difference was taken as dispersibility percentage.

$$\text{\% Dispersibility} = \frac{100 - \text{V}}{100} \times 100 \quad (5)$$

Water absorption capacity

1g of each of the flour samples was mixed with 10 ml of distilled water in a centrifuge tube and allowed to stand at room temperature (30 +2 °C) for 1 h. It was then centrifuged at 2000 rpm for 30 min and the volume of water or the sediment water was measured. Water absorption capacity was then calculated as volume (ml) of water absorbed per gram of flour. This method is as described by Beuchat (1977) for the determination of water and oil absorption capacities.

The determination of pasting properties of breadfruit (“Elubo”)

Pasting properties were determined with a Rapid Visco Analyzer (RVA TECMASTER, Perten Instrument), using the method reported by Adebowale et al. (2005). Three grams (3 g) of sample were weighed into a dried empty canister and then 25 ml of distilled water was dispensed into the canister containing the sample. The suspension was thoroughly and properly mixed, so that no lumps remained, and the canister was fitted into the rapid visco analyzer. A paddle was then placed into the canister and the test proceeded immediately, automatically plotting the characteristic curve. Parameters estimated were peak viscosity, setback viscosity, final viscosity, trough, breakdown viscosity, pasting temperature, and time to reach peak time.

Statistical analysis

All analyses were carried out in triplicates. An ANOVA test was carried out using Design Expert 7.0.0 (Stat-Ease Inc., Minneapolis, USA) to determine the significance at 5% levels.

Results and discussion

The effect of the processing parameters on bulk density

The effect of the processing parameters on bulk density is shown in a 3-D surface plot (Fig. 1). The bulk density of the bread fruit *“elubo”* increased as steeping time and pasting temperature increased. From Table 2, the model for bulk density (R^2 = 0.98) had positive quadratic terms (parboiling temperature, time, and steeping time). There were negative linear terms (parboiling temperature) and positive linear terms (parboiling time and steeping time). The bulk density was significantly ($p<0.05$) affected by parboiling temperature and steeping time (X_1 and X_3). Bulk density is a measure of heaviness of a flour sample. It is directly proportional to starch content of flour (Oti and Akobundu, 2007) and increases with the increase in starch content (Bhattachrya and Prakash, 1994). The increase in bulk density at high parboiling temperature and steeping time may be due to the starch particles becoming looser during steeping.

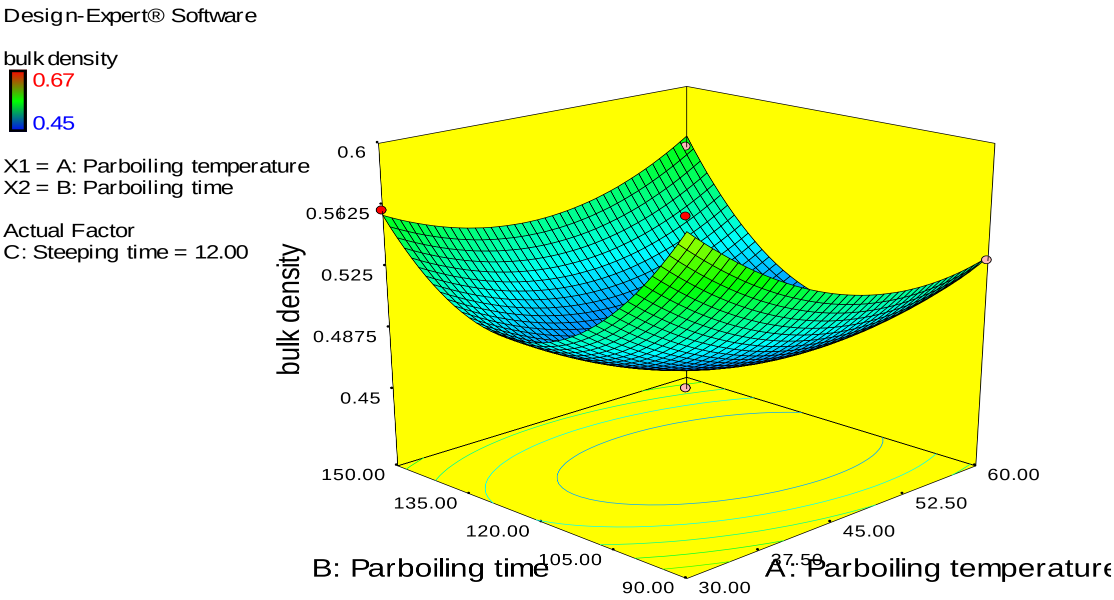

Fig. 1. Response surface plot for bulk density (g/cm^3) of breadfruit elubo

Table 2. Regression Coefficient tables for different responses using coded factors for functional properties

Parameters	Bulk density (g/cm^3)	Swelling power (%)	Solubility (%)	Dispersibility (%)	Water absorption capacity (g/g)
B_o	0.47	8.73	9.28	50.60	5.51
X_1	-0.01*	0.08	-0.15	-2.51*	0.34*
X_2	0.0	-0.08	-0.11	0.14	-0.15
X_3	0.05*	0.73*	-1.18*	-1.46*	0.08
X_1^2	0.03*	-0.06	-0.15	7.64*	0.69*
X_2^2	0.07*	-0.29*	-0.46	6.80*	-0.17
X^2_3	0.07*	-0.70	-0.19	12.76*	-0.04
X_1X_2	0.02*	0.14	0.12	0.01	0.29
X_1X_3	0.01	0.07	-0.38	-0.83	-0.41
X_2X_3	0.03	-0.13	-0.02	1.09	0.02
R^2	0.98	0.98	0.84	0.99	0.80
f. value	37.34	34.31	4.18	51.18	3.14
PRESS	6.54	2.55	18.87	297.77	5.39

*Values are significant at the 5% level. *X_1, X_2 and X_3 are parboiling temperature, parboiling time, and steeping time.

The effect of processing parameters on water absorption capacity

From Fig. 2, the water absorption capacity of BE increases as parboiling temperature, time, and steeping time increase. As showed in table 2, the regression model for water absorption capacity was R^2 = 0.80. There were significant positive quadratic and linear effects on the parboiling temperature. The water absorption capacity was significantly ($p<0.05$) affected by X_1 (parboiling temperature). Water absorption capacity is a necessary functional property that predicts the ability of flour to associate with water, under the conditions where water is limiting. Desikachar (1980) indicated that a high water absorption capacity of flours increases their viscosity (consistency) when mixed with water, resulting in a thick paste, but does not allow free-flow of the meal.

The effect of processing parameters on swelling power

At a constant parboiling temperature, the increase in steeping time and parboiling time increases the swelling power of the breadfruit flour *elubo*. However, from Fig. 3, high parboiling temperature was observed to cause a significant increase in swelling power. As shown in Table 2, the regression model for swelling power (R^2 = 0.98) shows significant negative quadratic effects on parboiling time and a positive linear effect on steeping time. The swelling power was significantly ($p<0.05$) affected by X_3 and X_2 (steeping time and quadratic effect on parboiling time). Fetuga et al. (2014) reported that the difference in swelling power of starchy materials can be attributed to starch content, presence of impurities, such as protein and lipids, as well as pre-treatment and processing parameters. Parboiling increases the swelling power of breadfruit elubo, this is similar to the report of Fetuga et al. (2014) for sweet potato flour *elubo*. Since parboiling is a process associated with increasing temperature compared to soaking in cold water, the trend for swelling power in this study is also in agreement with Yadav et al. (2006). The high swelling capacity of the BE might be due to weak internal bonding between starch granules.

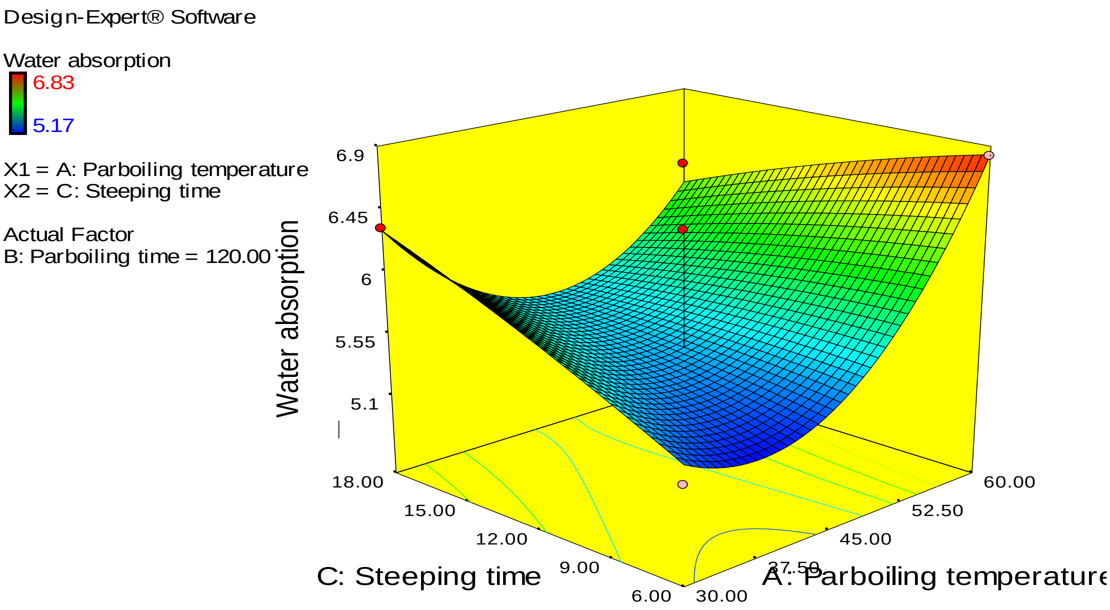

Fig. 2. Response surface plot for water absorption capacity (g/g) of breadfruit elubo

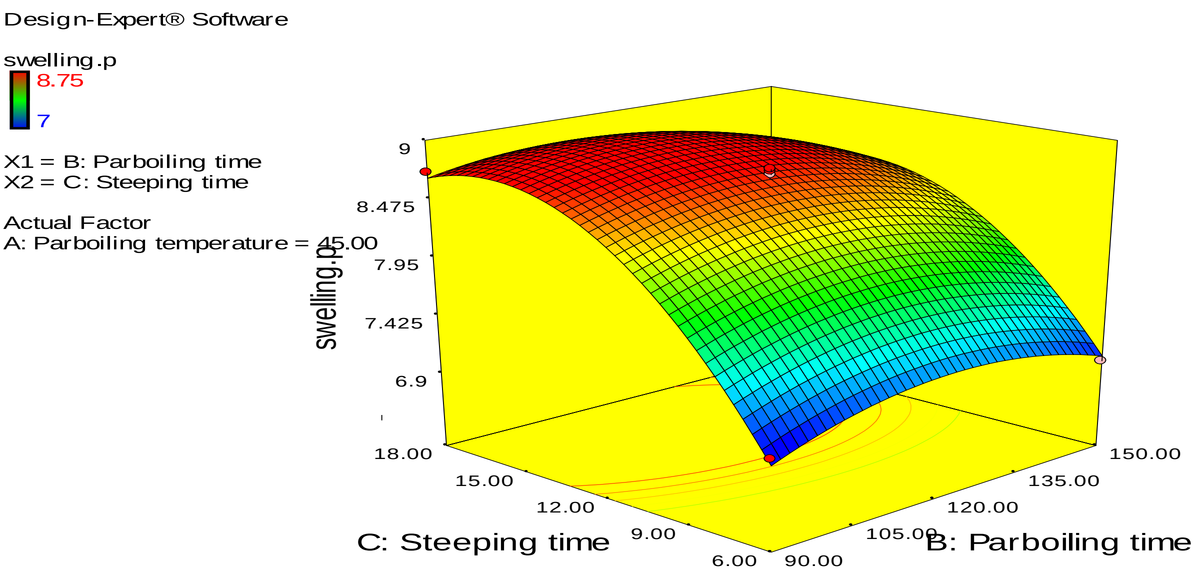

Fig. 3. Response surface plot for swelling power (%) of breadfruit elubo

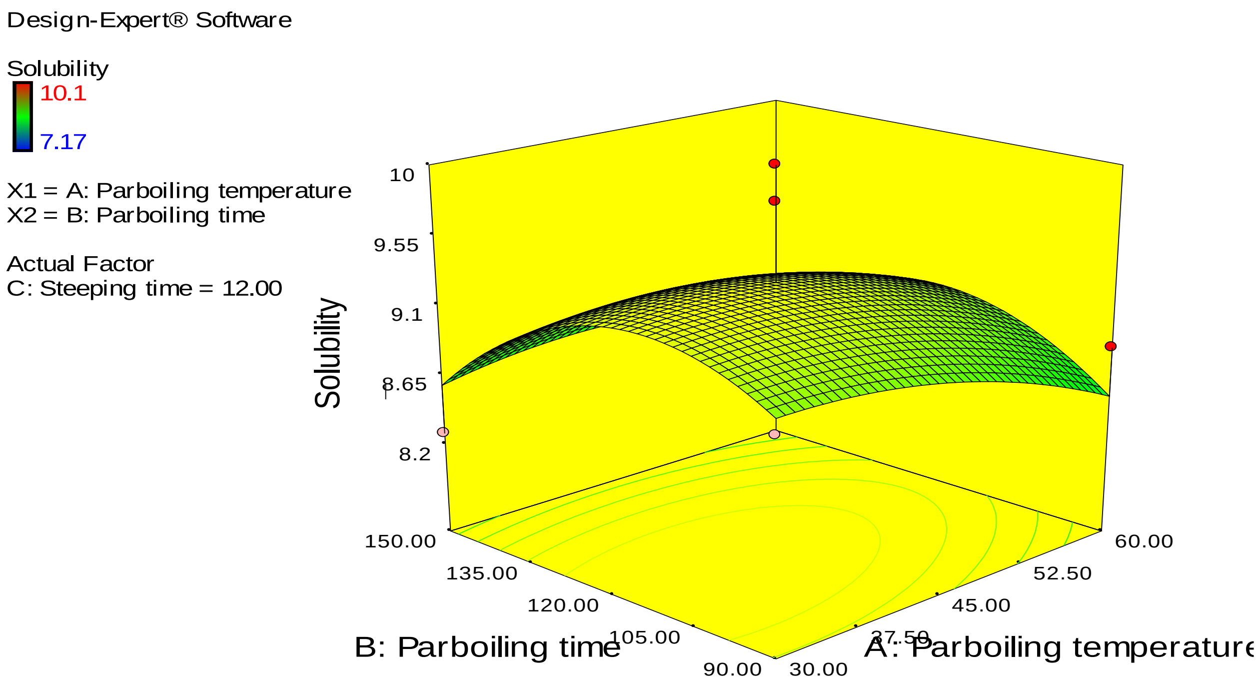

Fig. 4. Response surface plot for solubility (%) of breadfruit *elubo*

The effect of processing parameters on the solubility of breadfruit elubo

The steeping time significantly affects the solubility of the breadfruit flour. From Fig. 4, it was observed that the increases in parboiling time, parboiling temperature, and steeping time lead to an increase in the solubility of the flour. The regression model for solubility (R^2 = 0.84) shows significant negative linear effects on steeping time. The solubility was significantly ($p<0.05$) affected by X_3 (steeping time). Solubility is indicative of the penetration ability of water into starch granules of flours.

The effect of processing parameters on the dispersibility of breadfruit elubo

At a constant parboiling temperature, the increase in steeping time and parboiling time decreases the dispersibility of the breadfruit flour. The regression model for dispersibility (R^2 = 0.99) shows significant positive quadratic terms (parboiling temperature, time and steeping time) and negative linear terms (parboiling temperature and steeping time). The dispersibility was significantly ($p<0.05$) affected by X_1, X_3, X_{12}, X_{22}, and X_{23} (parboiling temperature, steeping time, quadratic effect on parboiling temperature, time, and steeping time). The dispersibility of a mixture in water indicates its ability to reconstitute, the higher the dispersibility of a mixture, the better its reconstitution property, the result from this study shows that the increase in steeping time, parboiling time, and parboiling temperature results in a decrease in dispersibility.

The effect of processing parameters on peak viscosity

From Fig. 6, it can be observed that increasing the parboiling temperature and parboiling time when steeping time is constant decreases peak viscosity. In Table 3, the regression model for peak viscosity of breadfruit elubo (R^2=0.98) shows significant positive quadratic terms (parboiling temperature, time, and steeping time), a negative linear term (parboiling temperature). Parboiling temperature significantly affects the peak viscosity of breadfruit elubo. Peak viscosity is the maximum viscosity developed during, or soon after the heating portion of the test. It is the maximum viscosity of starch suspension heated in excess water, after granule swelling has ceased and the increase in viscosity is due mainly to exudates released from the granules (Miller et al., 1973; Bakare et al., 2012). It can be concluded from this result that breadfruit will form a thick paste; this might be attributed to the high swelling power recorded for the breadfruit elubo.

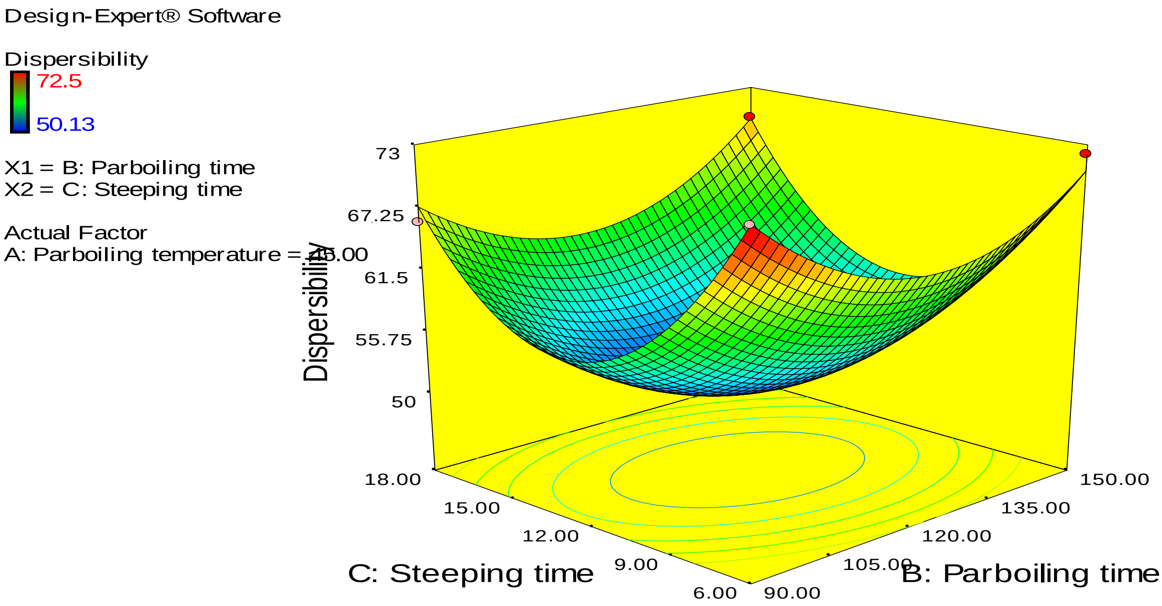

Fig. 5. Response surface plot for the dispersibility (%) parameter of breadfruit flour at various experimental conditions

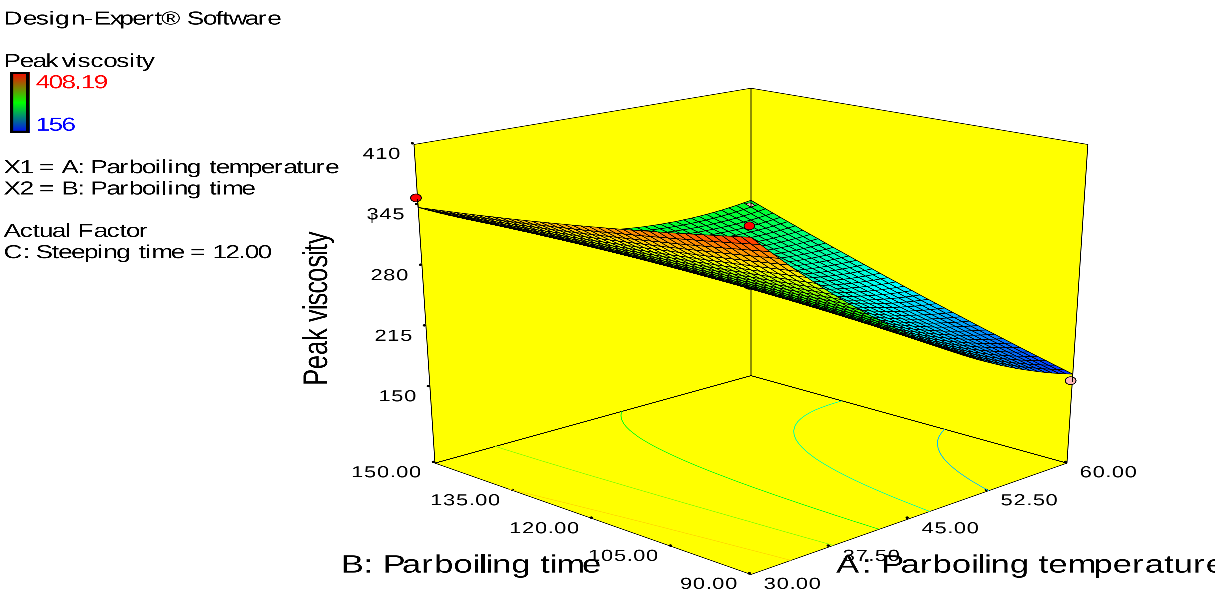

Fig. 6. Response surface plot for the peak viscosity (RVU) parameter of Breadfruit flour at various experimental conditions

The effect of processing parameters on final viscosity

From Fig. 7, increasing parboiling temperature and parboiling time when steeping time is constant decreases final viscosity. As shown in Table 3, the regression model for final viscosity of breadfruit elubo (R^2=0.99) shows significant positive quadratic terms (parboiling temperature, time, and steeping time), and a negative linear term (parboiling temperature). Final viscosity is the change in viscosity after holding cooked starch at 50 °C. It gives an idea about the ability of a material to form gel after cooking. Final viscosity is used to define the particular quality of starch and indicate the stability of the cooked paste in actual use. It also indicates the ability to form paste or gel after cooling (Ikegwu and Ekumankana, 2010). The increase in final viscosity on cooling is indicative of starch forming firm gel after cooking and cooling.

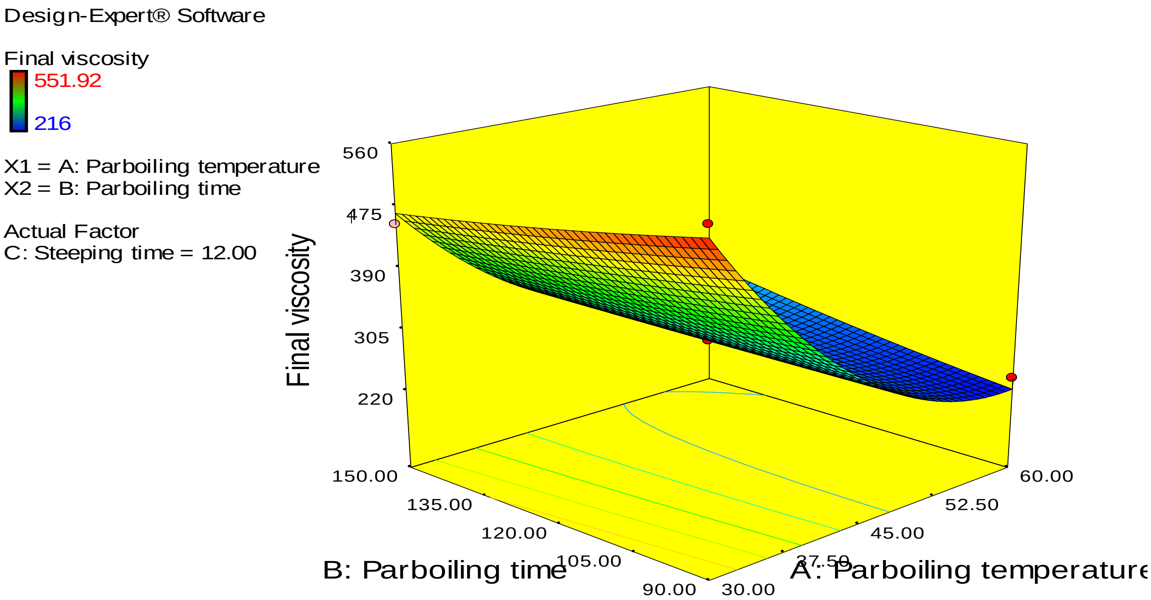

Fig. 7. Response surface plot for final viscosity (RVU) parameter of breadfruit flour at various experimental conditions

Table 3. Response surface analysis results for the pasting analysis

Parameters	Peak viscosity (RVU)	Through viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Pasting time (min)	Pasting temperature (^{0}C)
B_o	261.26	213.41	48.03	290.68	77.20	5.93	94.41
X_1	-73.17*	-73.82*	0.53	-122.73*	-48.91*	-0.021	-2.22
X_2	16.97	-3.71	19.62*	0.10	2.77	-0.34	2.61
X_3	4.47	6.41	-2.89	11.07	3.72	0.16	-0.45
X_1^2	30.25*	12.13	18.81	83.96*	72.85*	-0.50	-11.58*
X_2^2	3.80	-4.70	7.60	4.42	8.23	-0.07	-2.32
$X^2{}_3$	4.56	-1.12	4.91	6.21	-5.73	-0.35	0.19
X_1x_2	40.46*	25.99*	14.61	36.64*	8.75	-0.54	3.36
X_1x_3	43.16*	17.83	25.32*	21.79*	3.78	-0.29	1.19
X_2x_3	12.16	-4.53	15.03	-0.39	2.55	-0.50	-2.37
R^2	0.98	0.96	0.69	0.99	0.99	0.68	0.86
f. value	17.77	17.77	1.71	61.21	56.93	1.65	4.84
PRESS	21284	34164	68838	32162	9326	40.63	1983

*values are significant at 5% level. *X_1, X_2 and X_3 are parboiling temperature, parboiling time, and steeping time.

Conclusions

The functional and pasting properties of breadfruit elubo were dependent on the process parameters. All the functional properties were significantly affected by the processing parameters. Pasting properties were also affected significantly, except for pasting temperature and time. The optimum obtained processing conditions for the production of breadfruit elubo were, 60 °C, 133 min, and 10 hrs for parboiling temperature, parboiling time, and steeping time respectively. The desirability value was 0.80.

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