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Effects of incorporation of cassava flour on characteristics of corn grit-rice grit-chickpea flour blend expanded extrudates

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A rice grit-corn grit-chickpea flour blend was used as a model feed system for extrusion. Response surface methodology was used to study the effects of level of incorporation of cassava flour in feed composition (5-25%), feed moisture (12-16%), screw speed (1000-1400 rpm) and barrel temperature (80-120°C) by using a single screw extruder. Among the independent variables, feed moisture was found to be the most influential (p<0.05) to bulk density (BD), water solubility index (WSI) and water absorption index (WAI). Cassava flour level affected lateral expansion (LE) most significantly, however, temperature affected all the dependent variables equally at p<0.05, while screw speed altered significantly BD, WSI and WAI only.

Key words: Single screw extrusion, response surface methodology, rice and corn grit, chickpea flour, cassava flour.

INTRODUCTION

Snack foods (SF) are popular worldwide as they provide taste, convenience, are manageable portions for enjoyment and fulfill short-term hunger. Among several technologies for production of SF, extrusion is highly efficient and versatile in terms of differentiation in texture and size of SF. The physical properties and sensory attributes of extruded products are generally influenced by large number of process variables, of which the amount and structure of starch and protein, and their interaction in native form and during processing are of primary importance (Liu et al., 2000). Parameters such as degree and extent of gelatinization (leading to partial or complete destruction of the crystalline structure), shear induced molecular fragmentation of starch polymers, denaturation of protein are known to affect the quality of extruded SF (Harper, 1981).

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Table 1. Proximate composition of raw materials.

Raw materials	Moisture content (%)	Crude Fat (%)	Crude Protein (%)	Crude Fiber (%)	Ash Content (%)	Starch Content (g/100g)	Bulk Density (g/100ml)	Particle size (%)		
								> 600 µm	150-600 µm	>150 µm
Rice grit	12.15±1.1	0.58±0.1	6.51±0.3	0.21±0.3	0.67±0.7	75±1.4	74.52±1	42.4	56.8	0.8
Corn grit	12±1.1	3.21±0.3	8.88±0.2	3.72±0.2	1.54±0.2	60±2	45.23±2.1	77.7	21.2	1.1
Chickpea flour	11.6±0.8	5.1±0.23	20.76±0.1	1.2±0.5	2.82±0.5	45±2	62.1±0.9	0	31	69
Cassava flour	9.2±1.2	1.09±0.2	5.5±0.6	1.59±0.4	3.23±0.4	80±1.6	62.45±3.7	0	30	70

* Values are means ± standard deviation of triplicate analyses.

Though cereals are the main raw material for extruded snack foods, the use of tubers in product formulation of extrudates is becoming popular (Chiu et al., 2013; Hashimoto and Grossmann, 2003; Jisha et al., 2010; Seth et al., 2013). Among tubers, cassava flour can be used as a good alternative due to its relatively high starch content, and low protein and lipid content compared to cereals. In addition, cassava starch is odorless and has a high paste clarity with low stickiness (Adejumo et al., 2011) making it a suitable ingredient for extrusion (Santillán-Moreno et al., 2011). Furthermore, cassava starch does not block the extrusion barrel even at low moisture conditions (Rampersad et al., 2003).

Chickpea flour has also been widely used in extrudates (Meng et al., 2010; Shirani and Ganesharanee, 2009). However, contradictory effects have been reported regarding the properties of extrudates with chickpea flour. Shirani and Ganesharanee (2009) found that the addition of chickpea flour on extrudates significantly reduced their lateral expansion of extrudate. In contrast, Meng et al. (2010) found positive correlation between the amount of chickpea flour and lateral expansion in a work related to multiple blend of chickpea flour, potato starch, protein concentrate, and other additives. The interactive effect of cassava on major commercial extrusion ingredients such as corn grits, rice grits and chickpea flour has not been fully assessed yet so this report is focused on evaluating effects of cassava levels in properties of extrudates based on rice grits, corn grits and chickpea flour.

MATERIALS AND METHODS

Raw materials

Corn grits, rice grits, and chickpea flour were supplied by a local company (CG Foods Pvt. Ltd., CUG, Nawalparasi, Nepal). The mature cassava tubers (grown locally) were harvested, trimmed using stainless steel knife, sorted and peeled manually before dipping in a 2% NaCl solution at room temperature (28°C) for 30 min. This process prevents the initial browning. The tubers were sliced to 4 mm thickness and immersed in solution containing (0.5%) potassium meta-bisulphate and (0.5%) citric acid for 30 min. Then slices were dried at 60°C to 9% moisture content (wet basis). The dried slices were milled and fractions between 600 and 150 µm sieve were stored in an air tight container until further use. The particle size distributions of each raw material are presented in Table 1.

Methods

Triplicate samples of each raw material were taken to measure moisture (AOAC 935.29), fat (AOAC 922.06), protein content (AOAC 992.23), ash content (AOAC 923.03), and crude fiber (AOAC 962.09) using standard AOAC (2005) methods. Protein content was calculated using conversion factors 5.8, 5.95, 5.3, and 6.25 for corn grits, rice grits, chickpea flour and cassava flour, respectively. Starch content was analyzed using a modified iodine binding method (Dhital et al., 2010).

Experimental design

Response surface methodology (RSM) was used for the experimental design using a five-level, four-factor Central Composite Rotatable Design (Mayers et al., 1976). RSM can be used for the modeling and analysis of the problem in which a response of interest is influenced by several variables. Design Expert software (STAT-EASE Inc., USA, version 6.0) was used to apply RSM.

Extrusion of composite feed blends

In the blend, corn flour was substituted by cassava flour at levels of 5, 10, 15, 20, and 25% by weight while keeping the proportion of rice flour (50%) and chickpea flour (8%) constant. Detailed formulations for extrusion are given in Table 2. Extrusion experiments were performed using a single-screw extruder (main motor capacity 30kw; model DLG100, Jinan Shengrun Machinery Co., Ltd). The moisture was adjusted by sprinkling calculated amount of water into dry ingredients and the composite mixture was homogenously mixed in a small scale planetary mixture (Jiangmen Cheongfai Electronic Manufactory Ltd, China, 250W) for 20 min followed by sieving through a 2 mm sieve to break up the lumps formed due to the addition of moisture. The blends were kept at 30°C for 12 h in an air tight container for moisture equilibrium.

The single screw extruder was kept running for 30 min to stabilize the set temperatures and samples were then fed into the hopper at a rate of 75 kg/h. The extrudates exiting from 3 mm diameter were dried at 60°C to 6% moisture (wet basis) and packed in an air tight container for future analysis.

Determination of properties of extrudates

Lateral expansion and bulk density: Lateral expansion (LE, %) and Bulk density (BD, g/cm^3) were calculated by equation 1 and 2 respectively (Stojceska et al., 2008).

Table 2. Experimental combinations in both Coded and Uncoded levels for cassava flour with rice grit, corn grit and chickpea flour.

Coded variables				Uncoded variables			
A	**B**	**C**	**D**	**Feed Proportion (%)**	**Feed moisture (%)**	**Temperature (^{0}C)**	**Screw speed (rpm)**
-1	-1	-1	-1	58:32:10	13	90	1100
1	-1	-1	-1	58:22:20	13	90	1100
-1	1	-1	-1	58:32:10	15	90	1100
1	1	-1	-1	58:22:20	15	90	1100
-1	-1	1	-1	58:32:10	13	110	1100
1	-1	1	-1	58:22:20	13	110	1100
-1	1	1	-1	58:32:10	15	110	1100
1	1	1	-1	58:22:20	15	110	1100
-1	-1	-1	1	58:32:10	13	90	1300
1	-1	-1	1	58:22:20	13	90	1300
-1	1	-1	1	58:32:10	15	90	1300
1	1	-1	1	58:22:20	15	90	1300
-1	-1	1	1	58:32:10	13	110	1300
1	-1	1	1	58:22:20	13	110	1300
-1	1	1	1	58:32:10	15	110	1300
1	1	1	1	58:22:20	15	110	1300
-2	0	0	0	58:37:05	14	100	1200
2	0	0	0	58:17:25	14	100	1200
0	-2	0	0	58:27:15	12	100	1200
0	2	0	0	58:27:15	16	100	1200
0	0	-2	0	58:27:15	14	80	1200
0	0	2	0	58:27:15	14	120	1200
0	0	0	-2	58:27:15	14	100	1000
0	0	0	2	58:27:15	14	100	1400
0	0	0	0	58:27:15	14	100	1200
0	0	0	0	58:27:15	14	100	1200
0	0	0	0	58:27:15	14	100	1200
0	0	0	0	58:27:15	14	100	1200
0	0	0	0	58:27:15	14	100	1200
0	0	0	0	58:27:15	14	100	1200

$$LE = \frac{(diameter\ of\ product - diameter\ of\ die\ exit)}{diameter\ of\ die\ exit}\ X\ 100 \quad (1)$$

$$BD = \frac{4\ m}{\pi\ d^2\ L}\ (\mathrm{g/cm^3}) \quad (2)$$

Where, m is weight (g), L is length (cm), and d is diameter (cm) of extrudate.

Since the extrudates were not uniform in diameter, 10 extrudates were picked randomly and the diameter was measured at various positions. The maximum value was selected from each and the diameter was expressed as mean. For bulk density, a section of extrudate having maximum diameter was selected and then corresponding length and weight was measured. Bulk density of 10 individual sections was measured and final value was expressed as mean of 10 readings.

Water absorption and solubility index: Water absorption index (WAI) and water solubility index (WSI), of the extrudates were determined using the methodology described by Anderson et al. (1969). In brief, 2.5 g (dry basis) ground extrudate (< 60 mesh) was suspended in 30 mL of water at 30°C for 30 min followed by centrifugation at 3000 g for 10 min. The supernatant was separated from the gel and dried at 105°C till constant weight. WAI and WSI were calculated using equations 3 and 4 respectively.

$$\mathrm{WAI\ (g/g)} = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}} \quad (3)$$

$$\mathrm{WSI\ (\%)} = \frac{\text{Weight of dry solid in supernatent}}{\text{Dry weight of extrudate}}\ \mathrm{X}\ 100 \quad (4)$$

Data analysis

The responses (bulk density, lateral expansion, WAI and WSI) as affected by independent variables namely cassava flour, moisture content, screw speed and barrel temperature, were modelled by

Table 3. Regression coefficients of second order polynomial and their significance for dependent variables

Factors	Lateral Expansion			Bulk density			Water absorption index			Water solubility index		
	Coefficient	*F* value	*P* value	Coefficient	*F* value	*P* value	Coefficient	*F* value	*P* value	Coefficient	*F* value	*P* value
Intercepts	127.17	9.1937	<0.0001**	0.294	9.50	< 0.0001**	5.47	15.28	< 0.0001**	8.45	15.0200	<0.0001
A	7.94	32.0125	< 0.0001**	-0.015	7.15	0.0173*	-0.09	6.34	0.0236*	-0.39	14.9665	0.0015
B	-3.78	7.249	0.0167*	0.019	11.75	0.0037*	0.12	12.60	0.0029*	-0.78	58.9524	<0.0001
C	4.11	8.5763	0.0104*	-0.016	8.09	0.0123*	-0.08	4.88	0.0432*	-0.44	19.0647	0.0006
D	0.81	0.3320	0.5730	0.014	6.03	0.0268*	-0.11	9.64	0.0072*	0.57	31.2313	< 0.0001
AB	1.80	1.0933	0.3123	0.021	9.25	0.0082*	-0.09	4.95	0.0419*	-0.23	3.3977	0.0851
AC	-2.89	2.8246	0.1135	-0.001	0.04	0.8484	-0.01	0.06	0.8137	0.31	6.2956	0.0241
AD	-5.05	8.6360	0.0102*	0.014	4.04	0.0626	0.01	0.04	0.8398	0.26	4.5286	0.0503
BC	-7.51	19.0681	0.0006*	0.003	0.14	0.7093	0.10	6.27	0.0243*	0.89	51.4957	< 0.0001
BD	2.43	2.0008	0.1776	0.016	5.46	0.0337*	0.08	3.47	0.0823	-0.04	0.0888	0.7698
CD	7.63	19.7259	0.0005*	-0.021	8.93	0.0092*	-0.17	15.86	0.0012*	0.28	5.1599	0.0383
A^2	1.79	1.8589	0.1929	-0.029	29.66	< 0.0001**	0.18	30.12	< 0.0001**	-0.29	9.5114	0.0076
B^2	-0.23	0.0309	0.8628	-0.036	46.72	< 0.0001**	0.21	43.12	< 0.0001**	-0.17	3.2057	0.0936
C^2	-6.26	22.7273	0.0002*	-0.018	12.20	0.0033*	0.19	35.90	< 0.0001**	-0.19	3.9016	0.0669
D^2	-0.05	0.0016	0.9686	-0.014	7.60	0.0147*	0.31	97.06	< 0.0001**	-0.20	4.2751	0.0564
R^2		0.89			0.89			0.93			0.93	
Adj R^2		0.79			0.80			0.87			0.87	
Adeq precision		11.87			9.70			12.43			15.13	
Lack of fit		0.28	0.9602		1.85	0.2575		2.26	0.1904		1.70	0.2898

*Significant at $P < 0.05$, **Significant at $P < 0.001$.

multiple regression analysis and the statistical significance of the terms was examined by analysis of variance (ANOVA) for each response. Second degree polynomial equation considered for modeling was as follows:

$$Y=\beta_0+\beta_1 A+\beta_2 B+\beta_3 C+\beta_4 D+\beta_{11} A^2+\beta_{22} B^2+\beta_{33} C^2+\beta_{44} D^2+\beta_{12} AB+\beta_{13} AC+\beta_{14} AD+\beta_{23} BC+\beta_{24} BD+\beta_{34} CD+\varepsilon \quad (5)$$

Where A, B, C and D are the coded values of independent variables namely feed composition (% cassava), feed moisture content (%), extrusion temperature (°C) and screw speed (rpm), respectively. The coefficients of the polynomial were represented by β_0 (intercept), β_1, β_2, β_3, β_4 (coefficient of linear effects); β_{12}, β_{13}, β_{14} β_{23}, β_{24}, β_{34} (coefficient of interaction effects); β_{11}, β_{22}, β_{33}, β_{44} (coefficient of quadratic effects); and ε (random error). Design Expert software (STAT-EASE Inc., USA, version 6.0) was used to analyze data.

RESULTS AND DISCUSSION

Effects of process variables on lateral expansion

The expansion of the extrudate varied between 95.1 and 148.7%. The expansion in lower extreme level (5%) (S No.17, Table 2), upper extreme level (25%) (S No.18, Table 2) and central level (15%) of cassava flour were found to be 118, 148.7 and 127.2% (average of six centerpoint combinations, S No. 25-30, Table 2) respectively. Table 3 shows the coefficients of the model and other statistical attributes of LE.

Among the linear terms, all independent variables except feed moisture had a positive effect on LE, indicating that extrudates are more expanded when the proportion of cassava flour in feed rate; extrusion temperature and screw speed is increased. Similarly, increases in LE could be the result of a decrease in fiber content in feed because cassava flour contains less fiber than

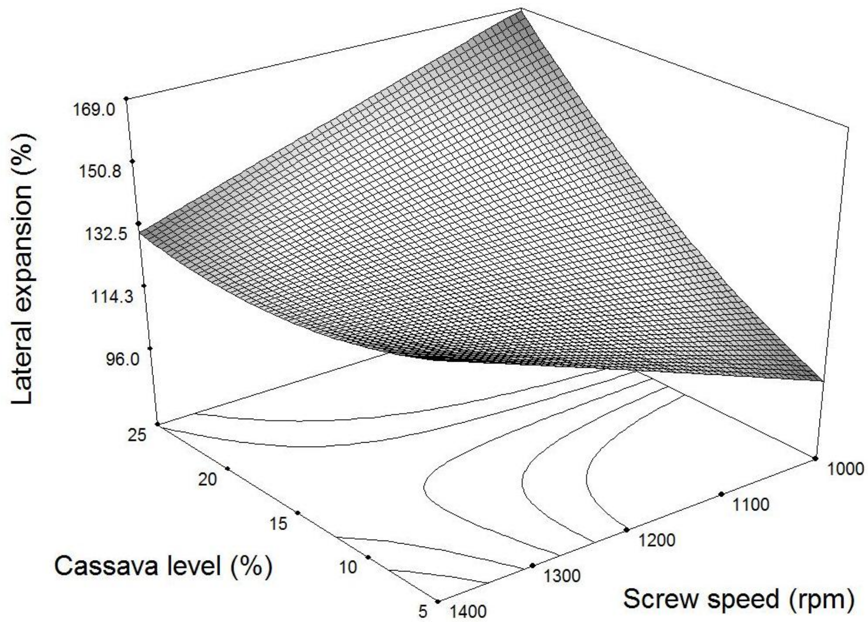

Figure 1. Response surface plot for lateral expansion ratio as a function of screw speed and feed composition at center value of feed moisture and barrel temperature.

corn grits (Table 1). Generally fiber associated with lowered LE is due to a reduction in cell size, which is caused by premature rupturing of gas cells, which reduces overall expansion and results in a less crispy product (Liu et al., 2000). However, increasing moisture significantly decreases the LE, which is consistent with previous findings (Bartholomew and Osualo, 1986; Hashimoto and Grossmann, 2003). Positive coefficient of barrel temperature (Table 3) shows that lateral expansion increases with increase in temperature which is in accordance to previous report of Ding et al. (2006). The increase in LE may be due to a higher degree of water heating in the extruder which induces the bubble formation. Although screw speed did not significantly ($p>0.05$) affect LE, a positive coefficient (Table 3) indicated that LE increased, with an increase in screw speed. This may be the result of a high degree of mechanical shear; resulting in higher rates of expansion as reported by Ding et al. (2006). However, with lower cassava content, lateral expansion was found to be decreased with increasing screw speed (Figure 1). The reason might again be effect of fiber from corn grits, since fiber breaks the bubbles in molten extrudate mass causing decrease in expansion.

Effects of process variables on product bulk density

Bulk density is a major physical property of the extrudate products. The BD, which considers expansion in all direction, ranged from 0.14 to 0.37 g/cm^3. BD in lower extreme level, upper extreme level and central level of cassava flour were found to be 0.23, 0.14 and 0.29 g/cm^3 (average of six centerpoint combinations; Table 2) respectively, with Table 3 showing the model coefficients and statistical attributes of BD.

Moisture content showed a highly significant positive effect on the BD of extrudates, which is attributed to the reduction in melt elasticity due to change in molecular structure of amylopectin at higher moisture level as described in several reports (Fletcher et al., 1985). As expected, the coefficient of feed composition was negative and also both LE and BD share negative correlation with each other (Table 3). At low cassava substation, the high fiber content from corn grits reduced the bulk density BD was found to be negatively correlated with die temperature (Table 3) which is in agreement with previous reports (Ding et al., 2006; Fletcher et al., 1985; Meng et al., 2010) With an increase in the die temperature, there was an increase in degree of superheating of water vapor in the extruder increasing expansion and decreasing BD (Fletcher et al., 1985). Positive coefficient of the screw speed shows that BD increases with increasing screw speed indicating molecular breakdown of starch in large extent at higher speed. It was observed from (Figure 2) that at a lower screw speeds, BD decreased with an increase in cassava level. However, at higher cassava level, BD increased with increase in screw speed.

Effects of process variables on product WSI

The WSI values ranged from 5.22 to 10.21%. The

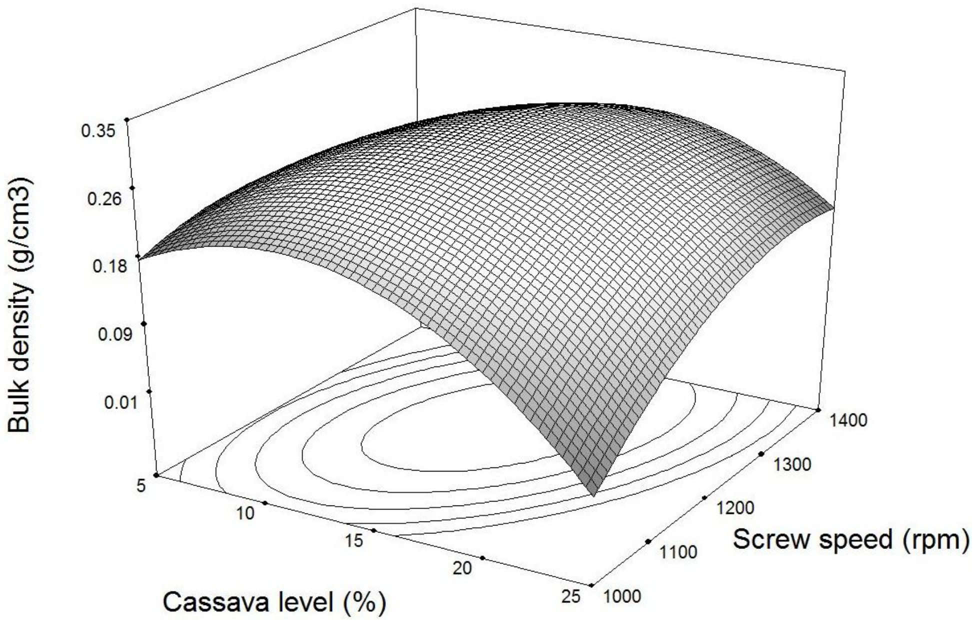

Figure 2. Response surface plots for the variation of bulk density as function of cassava level and screw speed at central level of feed moisture and barrel temperature.

coefficients of the model and other statistical attributes of WSI are shown in Table 3.

It was apparent from Table 3 that feed moisture content was the main determinant of WSI among linear terms. However, negative effect of moisture content on WSI indicated that the value will decrease significantly with increasing feed moisture content. WSI is an indicator of degree of degradation of starch and reflects the amount of free polysaccharide or polysaccharide released from the granule after addition of excess water (Sriburi and Hill, 2000). Variation in WSI as affected by feed moisture was consistent with results of study on wheat -based extruded products (Ding et al., 2005) and wheat semolina /pea hull extrusion (Sabota and Rzedzicki, 2009). It was hypothesized that feed moisture, when increased, acted as plasticizer allowing less friction between feed material and extruder wall. Figure 3 shows the interactive effect of temperature and moisture indicating a decrease in both parameters increases WSI. Although linear effect of temperature on WSI is positive, which is consistent with (Sabota and Rzedzicki, 2009); however, simultaneous increase in temperature and moisture decreased WSI which may be due to fairly higher influence of moisture on WSI than temperature. This can be apparent by comparing F- value of moisture and temperature which are 58.95 and 19.06 (Table 3) respectively.

Negative coefficient of feed composition shows that WSI increases as cassava level in feed decreases. Sabota and Rzedzicki (2009) also reported increase in WSI by extrusion in their extrusion studies of fiber enriched product. The result may be due to degradation of fiber present in corn grits. Screw speed showed significant positive effect of product WSI which is in accordance with results reported for corn meal and corn and wheat extrudates (Jin et al., 1995). The increase of screw speed induced a sharp increase in SME, which in turn degraded starches and fibers possibly through chain splitting increasing product WSI (Colonna and Mercier, 1983).

Effects of process variables on product WAI

WAI, measures of amount of water absorbed by extrudate, ranged from 5.31 to 6.91 g/g. Table 3 shows the coefficients of the model and other statistical attributes of WAI.

Negative coefficient of feed composition indicates that decrease in cassava flour proportion in feed will increase the WAI of the product. Increasing the fiber content resulted in an increase in WAI, which can be explained by fiber having a higher water absorption capacity, when starch content was reduced. Similar findings were reported by Artz et al. (1990) in extrusion of corn fiber and corn starch blend. The model coefficient suggests that increase in feed moisture caused increase in WAI. The other reason might be difference in water absorption capacity of corn and cassava starch. The negative coefficients of temperature indicate that increasing in temperature will decrease the WAI value of the product. This decrease in WAI values with an increase in temperature might be due to an increase in starch degradation (Pelembe et al., 2002). Ding et al. (2005) also stated that the WAI decreased with increasing

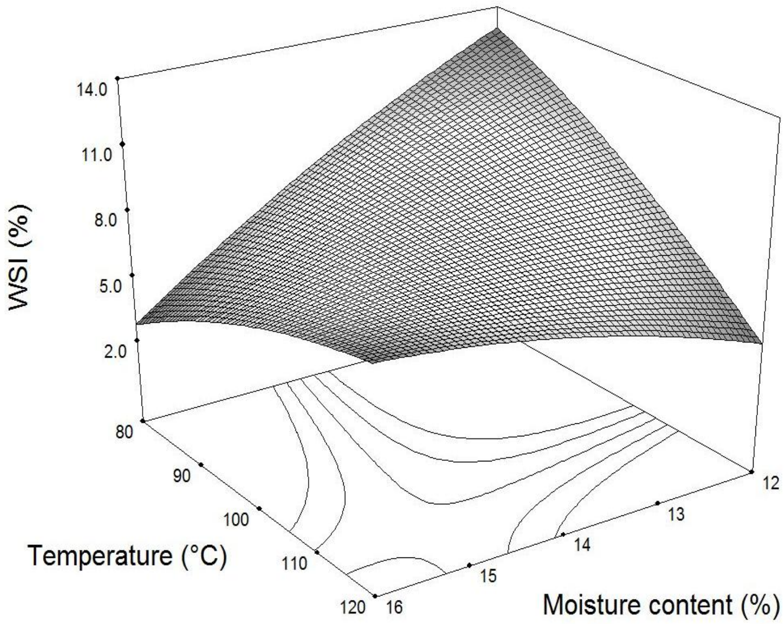

Figure 3. Response surface plot for water solubility index as a function of feed moisture and barrel temperature at center value of feed composition and screw speed.

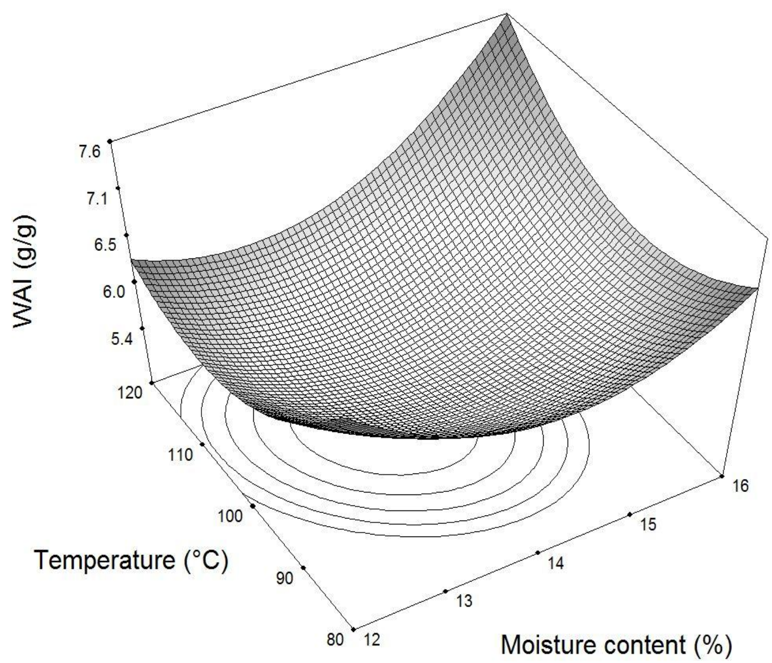

Figure 4. Response surface plot for water absorption index as a function of barrel temperature and feed moisture at center value of feed composition and screw speed.

temperature if starch dextrinization or starch melting prevails over the gelatinization phenomenon. At higher temperature, increase in feed moisture caused increase in WAI when keeping screw speed and feed composition constant at centre value respectively (Figure 4). This might be due to higher moisture content, acting as a plasticizer during extrusion which reduced the degradation of starch granules and simultaneously favors gelatinization resulting in an increased capacity for water absorption (Bartholomew and Osualo, 1986; Colonna and Mercier, 1983). Screw speed had significant negative effect on WAI which showed that increase in screw speed will decrease WAI. The reduction of WAI suggested that there might have been some starch degradation and the structural modification of fiber at higher shear conditions. At a low shear rate (low screw speed) and/or low temperature, there will be more undamaged carbohydrate polymer chains and a greater availability of hydrophilic groups which can bind more water resulting in higher values of WAI (Gomez and Aguilera, 1983).

Conclusions

The results showed that the product response variables were almost equally affected by changes in cassava flour level, feed moisture, extrusion temperature and by screw speed. Increasing barrel temperature resulted in an increase in expansion with a decrease in BD, WAI and WSI. A higher proportion of cassava flour in feed resulted in maximum expansion with a minimum BD, WAI and WSI. It was apparent that cassava starch could play a key role to enhance its functional attributes of expanded extrudate.

Conflict of interests

The authors did not declare any conflict of interest.

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