Effect of banana flour, screw speed and temperature on extrusion behaviour of corn extrudates

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Abstract Effect of extrusion parameters (banana flour, screw speed, extrusion temperature) on extrusion behaviour of corn grit extrudates were studied. Second order quadratic equations for extrusion properties as function of banana flour (BF), screwspeed (SS) and extrusion temperature (ET) were computed. BF had predominant effect on the Hunter color (L^* , a^* , b^*) parameters of the extrudates. Addition of BF resulted in corn extrudates with higher L^* and lower a^* and b^* values. Higher ET resulted in dark colored extrudates with lower L^* and a^* value. Higher SS enhanced the lightness of the extrudates. Expansion of the extrudates increased with increase in the level of BF and ET. WAI of the extrudates decreased with BF whereas increased with SS. However, reversed effect of BF and SS on WSI was observed. Flextural strength of the extrudates increased with increase in SS followed by BF and ET. The addition of BF and higher ET resulted in extrudates with higher oil uptake.

Keywords Extrusion · Banana flour · Corn grits · Screw speed

Introduction

Extrusion cooking is a versatile and efficient processing technique in which material is subjected to shearing and moistening that convert the raw material into viscous, plastic like dough before being subjected to pass through a die (Lazou and Krokida 2010; Rocha-Guzman et al. 2006). It is a well-

established industrial technology, employing high-temperature short-time and is often characterized by continuous cooking, mixing and forming processing and produces direct expanded materials of high quality (Ding et al. 2006). Extrusion also provides flexibility for the production of a wide variety of products such as weaning/baby foods, breakfast cereals, snack foods, bakery products, pastas, etc. (Rodriguez-Miranda et al. 2011). Starch based materials are preferred raw material for production of expanded extruded products. Corn is the third cereal in importance after wheat and rice as a staple food which is rich in starch. Corn extrudates has been obtained with good physical, functional, nutritional and sensory characteristics varying some process conditions such as extrusion temperature (ET), screw speed (SS), residence time, etc. (Zazueta-Morales et al. 2002). Corn grit is the main ingredient for production of commercial extruded products, which is obtained by dry milling of corn (Singh et al. 2014). Process variables (e.g. ET, SS and feed rate), corn type and feed characteristics (e.g. particle size and composition) are amongst the major factors that affect extrusion behaviour of corn grit (Singh et al. 1998a, b, 2000; Gujral et al. 2001; Thymi et al. 2005; Shevkani et al. 2014a).

Green banana are an excellent source of carbohydrates as well as nutritionally important bioactive compounds (Ovando-Martinez et al. 2009). Banana flour (BF) is rich in carbohydrates i.e. 75 % of which 47 % is resistant starch (Faisant et al. 1995). Resistant starch (RS) when digested produces high level of butyrate which is beneficial for colon health. BF contains up to 61.3 to 76.5 g/100 g starch on dry basis, a percentage comparable to that in the endosperm of corn grain and the pulp of white potato (Wang et al. 2012). Apart from starch, BF is high in total dietary fiber (6.28 to 15.54 g/100 g dry basis), which participates in the hypocholesterolaemic effect (Horigome et al. 1992; da Mota et al. 2000; Zhang et al. 2005). Bananas also contain high amounts of essential minerals, such as potassium, and various

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vitamins, e.g., A, B₁, B₂ and C (Chong and Noor Aziah 2010). Moreover, unripe banana is a source of antioxidant, polyphenols which show strong protective effects against certain diseases, such as cancer, rheumatoid arthritis and cardiovascular disease.

India is the largest producer of banana in the world. India produced around 24.8 million tones of banana in the year of 2012 (FAOSTAT 2014). Being a climacteric fruit and due to the habit of consuming ripened fruit, a large quantity of the fruit is lost during the commercialization and post-harvest handling operations. A better sustainable approach is to process green bananas into dried flour, and incorporate the flour into various innovative products so as to encourage consumption of banana and thus contribute to health benefits for humans (Ovando-Martinez et al. 2009). However, little or no research has been reported on inclusion of BF as an ingredient in the commercial food products. The purpose of this work was to study the effects of incorporation of BF and selected extrusion parameters (ET and SS) on the extrusion behavior and product characteristics of corn grit.

Material and methods

Materials

Green banana (*Musa Cavendish* var. *shreemanti*) was procured from local market. They were harvested at a commercial stage and were not exposed to any maturation treatment. The corn grit was kindly provided by Kulwant Nutrition, Batala (India).

Preparation of flours

Green bananas were carefully peeled and immediately rinsed in citric acid solution (2 % w/v), cut into slices (5 mm) and again rinsed with citric acid solution. The slices were dried overnight in a cabinet dryer at 55 °C. The dehydrated slices were ground to pass through 250 µm sieve. Banana flour (BF) was then stored in sealable pouches till further use.

Composition and colour properties

Ash, protein and fat contents of corn grit and BF were estimated using standard methods (AOAC 1990). Colour of the corn grit and BF was measured using Ultra Scan VIS Hunter Lab (Hunter Associates Laboratory Inc., U.S.A.) as described earlier (Shevkani et al. 2014b). A glass cell containing flour was placed in front the light source, and L^* , a^* and b^* values were recorded. The L^* value indicates the lightness, 0–100 representing dark to light. The a^* value gives the degree of the red-green colour, with a higher positive a^* value indicating

more red. The b^* value indicates the degree of the yellow-blue colour, with a higher positive b^* value indicating more yellow.

Preparation of corn grit and banana flour blends

BF was blended with corn grit at 0, 10, 20 and 30 % level and mixed properly to get homogenous corn grit-BF blends. The moisture content of the blends was determined and adjusted to 18 %.

Extrusion cooking

The extrusion was performed on a co-rotating twin screw extruder (Clextal, BC 21, Firminy, France). The screw diameter, length/diameter (L/D) ratio and die diameter of the extruder was 25, 16 and 6 mm, respectively. The terminal section of the extruder was heated by an induction heating belt and the feeding section of barrel was cooled with running water. The material was fed through a rotating screw hopper at a constant speed and the extrusion was carried out at three different temperatures of 130, 150 and 180 °C at two screw speeds of 300 and 500 rpm. When stable extrusion conditions were reached, the extrudates formed were carefully collected, air cooled and tightly sealed in PET jars. A part of the extrudates was fried in refined groundnut oil at 160 °C for 5 min. The experimental design followed in the present study is given in Table 1.

Extrudate characteristics

Mean diameter of ten extrudates was measured and the expansion ratio was calculated by dividing the average diameter with the diameter of the die orifice. Specific mechanical energy (SME) during extrusion was estimated using the equation of Bhattacharya and Choudhury (1994). Water solubility index (WSI) and water absorption index (WAI) of the extrudates were determined following the method given by Anderson et al. (1969). Flexural strength of the fried extrudates was determined using texture analyzer (TA/XT2 plus, Stable Microsystems, UK). The extrudates were subjected to 75 % compression with a probe (P/75) at a pretest and post speed of 1 mm/s. Flexural strength was determined on six extrudates and mean value was reported.

Statistical analysis

To compute a second order polynomials a factorial design with three banana flour levels, two screwspeeds, three extrusion temperatures was used (Table 1). BF, ET and SS were used as independent variables. The effects of BF, ET and SS are shown using response surface plots plotted keeping the extra factor at middle setting using Minitab Statistical Software (Minitab Inc., State College, PA, USA).

Table 1 Experimental design

Experiment	Banana flour (%)	Screw speed (rpm)	Extrusion temperature (°C)
1	0	300	130
2	10	300	130
3	20	300	130
4	30	300	130
5	0	300	150
6	10	300	150
7	20	300	150
8	30	300	150
9	0	300	170
10	10	300	170
11	20	300	170
12	30	300	170
13	0	500	130
14	10	500	130
15	20	500	130
16	30	500	130
17	0	500	150
18	10	500	150
19	20	500	150
20	30	500	150
21	0	500	170
22	10	500	170
23	20	500	170
24	30	500	170

Results and discussion

Ash, protein and fat content

Ash, protein and fat content for the corn grit were 1.5 %, 8.6 %, 1.0 % respectively, against for BF

2.7 %, 4.8 %, 0.8 % respectively. Ash, fat and protein content between 2.6–3.5, 0.33–0.82 and 2.5–3.3 %, respectively for BF from seven varieties (da Mota et al. (2000) and 0.19–1.66, 1.56–2.42 and 5.18–7.82 %, respectively for nine corn varieties (Sandhu et al. 2007) had been reported earlier.

Table 2 Coefficient of regression for Dependent Variables of Corn and Green BF extrusion

Terms	Raw extrudates			Fried extrudates		
	L*	a*	b*	L*	a*	b*
Constant	56.7117	5.08615	23.2831	54.4719	6.34031	21.8705
BF	2.0645**	−0.60475**	−3.7365**	−3.763**	−0.49725**	−5.4038**
SS	0.7308**	0.06042	−0.2267	0.7242**	−0.13875*	0.4462
Ext. temp.	−0.6950**	−0.38688**	0.5288	−0.4531	−0.52938**	−0.2375
BF × BF	0.0375	−0.14156	−0.8156	0.2869	−0.26156*	0.0553
Ext. temp. × Ext. temp.	0.7750**	−0.14063	−1.1938*	−0.8419	0.51938**	−0.1425
BF × SS	0.0305	−0.21275*	−0.271	0.5125	−0.02825	0.1273
BF × Ext. temp.	−0.2257	0.05138	−0.6315	−0.6131	−0.15787*	−0.816
SS × Ext. temp	0.3100*	−0.13313	−0.2188	−0.3294	0.15813*	−0.2388
R ² (%)	95.8	88.3	87.2	93.4	94.0	93.2

* $p \leq 0.05$; ** $p \leq 0.005$

Table 3 Actual and predicted values of hunter color of fried and raw extrudates

Banana flour(%)	Screw speed (rpm)	Extrusion temperature (°C)	L*		a*		b*	
			Actual	Predicted	Actual	Predicted	Actual	Predicted
a								
0	300	130	55.14	55.17	5.13	5,85	21.87	25.30
10	300	130	57.11	56.55	5.50	5.45	23.48	22.821
20	300	130	58.56	57.93	4.78	5.05	20.35	20.32
30	300	130	59.61	59.31	4.84	4.64	19.04	17.83
0	300	150	54.22	54.47	5.48	5.47	27.66	25.83
10	300	150	55.9	55.85	5.40	5.06	24.42	23.34
20	300	150	56.56	57.23	4.74	4.66	22.00	20.85
30	300	150	58.76	58.61	4.15	4.26	17.59	18.36
0	500	170	54.19	53.78	4.70	5.08	26.14	26.36
10	500	130	57.81	58.01	6.17	5.57	23.50	22.26
20	500	130	59.87	59.39	4.87	5.17	19.46	19.77
30	500	130	61.23	60.77	4.58	4.38	19.78	17.81
0	500	150	55.34	55.94	5.89	5.59	27.92	25.28
10	500	150	56.66	57.32	5.29	5.18	23.30	22.79
20	500	150	57.41	58.70	4.53	4.78	19.97	20.30
30	500	150	59.01	60.08	4.58	4.38	19.78	17.81
0	500	170	55.76	55.24	5.04	5.20	24.35	25.80
10	500	170	57.77	56.62	4.76	4.80	24.11	23.31
20	500	170	58.73	58.00	4.36	4.40	22.58	20.82
30	500	170	59.88	59.38	3.46	3.99	15.56	18.33
b								
0	300	130	54.23	57.52	6.37	7.74	22.63	26.99
10	300	130	52.69	55.01	6.06	7.41	20.32	23.39
20	300	130	51.00	52.50	6.00	7.07	16.00	19.79
30	300	130	58.05	49.99	6.68	6.74	27.21	16.19
0	300	150	55.60	57.07	6.77	7.21	24.62	26.75
10	300	150	49.80	54.56	6.00	6.88	17.73	23.15
20	300	150	47.73	52.05	5.36	6.54	14.91	19.55
30	300	150	58.84	49.54	7.05	6.21	28.09	15.95
0	300	170	55.63	56.61	7.04	6.68	23.00	26.52
10	300	170	53.98	54.10	7.03	6.35	21.30	22.92
20	300	170	53.32	51.59	6.52	6.01	19.12	19.32
30	300	170	59.36	49.08	6.70	5.68	28.88	15.72
0	500	130	55.12	58.97	6.62	7.46	22.64	27.88
10	500	130	54.77	56.46	6.10	7.13	21.38	24.28
20	500	130	51.00	53.95	5.10	6.80	14.92	20.68
30	500	130	56.50	51.44	6.57	6.46	26.00	17.08
0	500	150	55.70	58.52	6.42	6.93	24.97	27.65
10	500	150	53.05	56.01	6.25	6.60	20.50	24.05
20	500	150	50.26	53.50	5.43	6.27	16.23	20.45
30	500	150	54.23	50.99	6.37	5.93	22.63	16.85
0	500	170	52.69	58.06	6.06	6.40	20.32	27.41
10	500	170	51.00	55.55	6.00	6.07	16.00	23.81
20	500	170	58.05	53.04	6.68	5.74	27.21	20.21
30	500	170	55.60	50.53	6.77	5.40	24.62	16.61

Fig. 1 Effect of banana flour and screw speed on L^* value of raw extrudates

Extrudates characteristics

Color properties

The regression equation for L^* , a^* and b^* value as function of BF, SS and ET was significant as revealed by R^2 and p-value (Table 2). BF had a highly significant effect on L^* value of the extrudates followed by SS and ET. The actual and predicted values of unfried extrudates is given in Table 3. Coefficient of determination of predicted model for L^* , a^* and b^* were 0.90, 0.78 and 0.80, respectively. L^* value increased progressively with increase in BF and SS. ET showed significant negative effect on L^* value of the extrudates. The increase in L^* with increase in SS may be due to lesser residence/extrusion time at higher SS that resulted in lower degradation of the pigments (Yu et al. 2012). The higher L^* value indicated greater lightness of extrudates. As more expanded extrudates had higher surface area that caused light to disperse, giving a lighter appearance to the puffed products (Paes and Maga 2004). The interaction effect of SS and ET on L^* value was significant. Figs. 1 and 2 shows the changes in L^* value with variations in BF, SS and ET. Both BF and ET showed significant effect on a^* value. The a^* value decreased progressively with increasing BF and ET (Fig. 3). This decline in a^* value was more pronounced at higher ET. Extrudates with higher b^* values had higher yellowness. The addition of BF and increase in SS reduced the yellowness of the extrudates as evident by highly significant negative effect of both in linear terms on b^* value of extrudates (Table 2). The reduction in the yellowness

Fig. 2 Effect of banana flour and extrusion temperature (ET) on L^* value of raw extrudates

Fig. 3 Effect of banana flour and extrusion temperature (ET) on a^* value of raw extrudates

of extrudates with addition of BF might be attributed to the dilution of the carotenoid pigment of the corn grit, which is responsible for yellow color of corn grit. L^* , a^* and b^* values of 76.2, 12.5 and 38.4, respectively for corn grit against 86.2, 0.4 and 11.4, respectively for BF was observed. However, the effect of BF as compared to SS on b^* was more pronounced (Fig. 4). L^* , a^* and b^* values of fried extrudates were also determined to see the effect of frying on the colour parameters. Fried extrudates showed lower L^* , a^* and b^* value than their unfried counterpart extrudates. The actual and predicted values of L^* , a^* and b^* of fried extrudates is given in Table 3 and coefficient of determination of predicted model for was 0.88, 0.73 and 0.92, respectively. The reduction in L^* and increase in a^* and b^* values of the extrudates on frying may be attributed to the occurrence of Maillard reaction at high temperatures (Sacchetti et al. 2004).

Expansion ratio

The regression model of expansion ratio of the extrudates was significant and had sufficiently high R^2 values (Table 4). The actual and predicted values of expansion ratio of extrudates is given in Table 5 and coefficient of determination of predicted model for was 0.77. BF and ET had significant effect, in linear terms, on expansion ratio of the extrudates. The expansion ratio increased progressively with an increase in BF and ET (Fig. 5). During extrusion, high temperature and pressure conditions inside the barrel caused the moisture in the sample to superheat. Sudden pressure drop at the exit of the die caused

Fig. 4 Effect of Banana flour and Screw speed on L^* value of fried extrudates

Table 4 Coefficient of regression for dependent variables of corn and green BF extrudates

Terms	Expansion ratio	WAI	WSI
Constant	2.36042	3.52458	35.2508
BF	0.0805**	−0.35**	9.6805**
SS	−0.01	0.14833**	−1.9108*
Ext. temp.	0.07625**	0.05125	1.7856*
BF × BF	0.02625	−0.16125*	3.8888*
Ext. temp. × Ext. temp.	−0.0525**	−0.06	−2.5169
BF × SS	0.0095	0.147*	0.067
BF × Ext. temp.	0.4875**	−0.021	0.0986
SS × Ext. temp.	0.0075	0.04625	−2.0831*
R ² (%)	94.2	86.3	91.0

* $p \leq 0.05$; ** $p \leq 0.005$

the moisture to evaporate which resulted in expansion of the product (Heldman and Hartel 1997). BF alone and in interaction with ET had a significant effect on the expansion ratio. Several researchers have demonstrated that the expansion

Fig. 5 Effect of banana flour and extrusion temperature (ET) on expansion ratio of extrudates

ratio of extruded cereals depends on the degree of starch gelatinization (Case et al. 1992; Chinnaswamy and Hanna 1988). The increase in expansion ratio with addition of BF might be attributed to the lower gelatinization temperature of the BF starch as compared to corn starch (Zhang et al. 2005). The gelatinization temperature of banana starch was reported around 70 °C (Guerra-DellaValle et al. 2009) against 71–74 °C for corn starch (Sandhu and Singh 2007). Onwulata et al. (2001) reported that expansion ratio reduced with an increase in the protein content due to the decrease in the elasticity. Therefore, the reduction in protein content with

Table 5 Actual and predicted values of protein content and physical parameters of extrudates

Banana flour (%)	Screw speed (rpm)	Extrusion temperature (°C)	Expansion ratio		WAI		WSI	
			Actual	Predicted	Actual	Predicted	Actual	Predicted
0	300	130	2.24	1.64	3.40	3.55	28.36	26.18
10	300	130	2.26	1.69	3.59	3.31	25.00	32.63
20	300	130	2.26	1.75	3.16	3.08	35.34	39.08
30	300	130	2.27	1.80	2.64	2.85	42.22	45.53
0	300	150	2.31	1.71	3.73	3.60	32.88	27.97
10	300	150	2.36	1.77	3.76	3.37	30.04	34.42
20	300	150	2.41	1.82	2.99	3.13	44.00	40.87
30	300	150	2.51	1.88	2.86	2.90	52.02	47.32
0	300	170	2.31	1.79	3.64	3.65	33.00	29.75
10	300	170	2.35	1.84	3.65	3.42	32.00	36.20
20	300	170	2.40	1.90	2.95	3.18	45.32	42.65
30	300	170	2.52	1.95	2.59	2.95	51.55	49.10
0	500	130	2.19	1.62	3.66	3.84	25.32	22.36
10	500	130	2.25	1.67	3.67	3.61	27.21	28.81
20	500	130	2.25	1.73	3.25	3.38	32.52	35.26
30	500	130	2.25	1.78	3.22	3.14	48.90	41.71
0	500	150	2.26	1.69	3.59	3.89	27.36	24.15
10	500	150	2.30	1.75	3.81	3.66	29.84	30.60
20	500	150	2.37	1.80	3.40	3.43	40.13	37.05
30	500	150	2.48	1.86	3.34	3.20	43.02	43.50
0	500	170	2.30	1.77	3.74	3.95	22.84	25.93
10	500	170	2.34	1.82	3.86	3.71	31.36	32.38
20	500	170	2.39	1.88	3.51	3.48	35.30	38.83
30	500	170	2.58	1.93	3.47	3.25	42.07	45.28

Fig. 6 Effect of banana flour and extrusion temperature (ET) on WAI of extrudates

addition of BF may have also contributed to increase in expansion ratio of extrudates. ET had significant affect in quadratic terms on expansion ratio. A similar quadratic effect of ET on expansion ratio of extrudates was reported earlier by Park et al. (1993). The a^* and b^* value of the unfried extrudates showed significant negative correlation with expansion ratio ($r=-0.762$ and -0.481 , respectively, $p\leq 0.005$).

Water absorption and water solubility index

The regression model of WAI of the extrudates was significant and had sufficiently high R^2 values (Table 4). SS and BF level showed highly significant effect on WAI. WAI increased progressively with increase in SS. The actual and predicted values for WAI and WSI was calculated and given in Table 5. Coefficient of determination of predicted model for WAI and WSI were 0.71 and 0.81, respectively. Higher SS caused shearing inside the extruder resulted in formation of higher damaged starch due to higher water retention capacity (Sarawong et al. 2014). However, with increase in BF opposite effect on WAI was observed (Fig. 6). Reduction in WAI on addition of BF might be due to its higher sugar content, which limited the gelatinization as competition between starch and sucrose for available water as well as sucrose-starch interaction have been reported (Lund 1984). During extrusion the accessibility of water into the extrudate matrix restricts due to formation of compact starch structures that resulted in lower WAI (Osman et al. 2000). BF had a significant effect in quadratic terms on WAI. The interaction effects of BF and SS on WAI was also significant (Table 4). WAI depends on the availability of hydrophilic groups and on the gel formation capacity of the

Fig. 7 Effect of banana flour and extrusion temperature on WSI of extrudates

Table 6 Coefficient of regression for dependent variables of corn and green BF extrusion

Terms	Oil uptake	Flextural strength	SME
Constant	32.015	91.51	69.6601
BF	9.491**	4.814*	-0.1493
SS	2.8192**	28.359**	21.2287**
Ext. temp.	1.5925**	4.591*	-3.1*
BF × BF	-6.2906**	2.856	4.2591*
Ext. temp. × Ext. temp.	0.1763	4.685	2.9592
BF × SS	1.0570*	-2.836	1.4303
BF × Ext. temp.	0.13787	4.229	-0.27
SS × Ext. temp.	-0.0462	-2.879	1.5
R^2 (%)	98	95.3	97.7

* $p\leq 0.05$; ** $p\leq 0.0005$

macromolecules (Gomez and Aguilera 1983). The formation of inter- and intra-molecular protein bonds with amylose and amylopectin may have led to a low WAI value (Fernandez-Gutierrez et al. 2004). BF had the most pronounced effect on the WSI for extrudates. WSI increased progressively with increase in the BF (Fig. 7). WSI had been related to the amount of soluble molecules, which is related to dextrinization. WSI can be used as an indicator for the degradation of molecular compounds and measure the degree of starch conversion during extrusion. Higher ET increased the severity of thermal treatment in the extruder, which resulted into more dextrinization which consequently increased WSI. Similar increase in WSI at higher temperatures were also shown earlier for corn and corn-lentil extrudates (Lazou and Krokida 2010). BF also had a significant effect in both linear and quadratic terms on WSI. SS and EI had significant effect in only quadratic terms on the WSI. WSI increased with ET and similar effect of EI on WSI was reported earlier for corn extrudates by Gujral et al. (2001). Higher temperature caused starch degradation resulting into more water soluble carbohydrates that causes increased WSI (Sacchetti et al. 2004). The interaction effect of SS and ET also had a negatively significant effect on the WSI. Extrudates with higher a^* and b^* values had higher WAI ($r=0.476$ and 0.660 , respectively, $p\leq 0.005$) and lower WSI before frying ($r=-0.730$ and -0.727 , respectively, $p\leq 0.005$). The results indicated that degradation of starch during extrusion cooking increases the WSI which increased the expansion and a^* and b^* value.

Oil uptake

The regression equation of oil uptake as function of BF, SS and ET was significant as revealed by R^2 (Table 6). BF, SS and ET showed significant effect in linear terms on oil uptake. The actual

Table 7 Actual and predicted values of Hunter color, oil uptake and crispiness of fried extrudates

Banana flour (%)	Screw speed (rpm)	Extrusion temperature (°C)	SME		Oil uptake		Flextural strength	
			Actual	Predicted	Actual	Predicted	Actual	Predicted
0	300	130	63.43	55.95	14.91	14.74	51.96	58.7
10	300	130	58.76	55.85	23.60	21.07	65.47	61.91
20	300	130	58.31	55.75	28.35	27.40	51.35	65.12
30	300	130	59.65	55.65	29.89	33.73	72.71	68.33
0	300	150	48.00	52.85	15.10	16.33	63.53	63.3
10	300	150	45.04	52.75	26.07	22.66	60.37	66.51
20	300	150	44.57	52.65	30.13	28.99	81.40	69.72
30	300	150	52.08	52.55	31.91	35.32	66.66	72.93
0	300	170	55.92	49.75	15.36	17.92	64.14	67.9
10	300	170	54.30	49.65	26.96	24.25	74.56	71.11
20	300	170	44.45	49.55	32.54	30.58	73.12	74.32
30	300	170	48.68	49.45	35.00	36.91	89.43	77.53
0	500	130	98.13	98.35	15.87	20.38	138.39	115.5
10	500	130	97.18	98.25	28.93	26.71	124.23	118.71
20	500	130	90.93	98.15	36.89	33.04	113.99	121.92
30	500	130	98.24	98.05	38.39	39.37	127.67	125.13
0	500	150	93.48	95.25	17.15	21.97	109.06	120.1
10	500	150	95.50	95.15	31.26	28.30	124.06	123.31
20	500	150	95.90	95.05	37.94	34.63	115.34	126.52
30	500	150	101.64	94.95	38.60	40.96	124.60	129.73
0	500	170	94.59	92.15	18.69	23.56	124.80	124.7
10	500	170	90.14	92.05	35.87	29.89	124.65	127.91
20	500	170	90.14	91.95	38.66	36.22	131.24	131.12
30	500	170	96.81	91.85	39.23	42.55	137.29	134.33

and predicted values for oil uptake was calculated and given in Table 7. Coefficient of determination of predicted model for oil uptake was 0.86. However, BF showed the most pronounced affect followed by SS and ET. Oil absorption of extrudates relates to the presence of hydrophilic groups of starches present in flour (Rodríguez-Ambríz et al. 2008). An increase in oil uptake with BF might be attributed to the increase in the porosity (air cells) of the extrudates. During frying, the air inside these air cells was replaced by oil. BF in squared terms and in interaction with SS had a significant effect on the oil uptake. This might also be attributed to an increase in the pressure inside the barrel with

increase in SS. When the material was extruded from the die, the sudden pressure drop led to more porosity. High ET during extrusion also increased the porosity of the extrudates (Steel et al. 2012). Increase in oil uptake with increase in ET might be attributed to the formation of smaller molecules due to starch dextrinization during extrusion (Kadan et al. 2003). The interaction effect of BF and SS on oil uptake of the extrudates was significant (Fig. 8). Oil uptake also increased with increase in BF ($r=0.849$, $p\leq 0.005$). Extrudates with higher WAI and lower WSI showed lower oil uptake ($r=-0.366$ and 0.620 , respectively,

Fig. 8 Effect of banana flour and Screw speed on oil uptake of fried extrudates **Fig. 9** Effect of banana flour and screw speed on flextural strength of fried extrudates

$p \leq 0.005$). Similar correlation between WAI and oil uptake was reported earlier by Osman et al. (2000). Oil absorption was considered to be a water replacement process quantitatively where higher moisture content resulted in higher oil absorption of extrudates (Nair et al. 1996).

Flextural strength

Significant R^2 was obtained on driving regression equation as a function of BF, SS and ET on flextural strength of extrudates (Table 6). The actual and predicted values for flextural strength was calculated and given in Table 7. Coefficient of determination of predicted model for flextural strength was 0.93. The textural property of extrudate was determined by measuring the force required to break the extrudate (Singh et al. 1994). SS had the most prominent positive effect on the flextural strength of extrudates followed by ET and BF (Fig. 9). Flextural strength of extrudates showed positive significant correlation with oil uptake ($r = 0.419$, $p \leq 0.05$) while negative with expansion ratio ($r = -0.539$, $p \leq 0.005$). Ding et al. (2005) also correlated expansion and cell structure of the product with the hardness of extrudates.

Specific mechanical energy

The regression model of SME of the extrudates was significant and had sufficiently high R^2 values. SS and ET had the significant effect in linear terms on SME. SS had greater effect on SME as compared to ET. The actual and predicted values for SME was calculated and given in Table 7. Coefficient of determination of predicted model for flextural strength was 0.96. SME increased progressively with increase in the SS. The increase in SS decreased the residence time and increased the shear rate inducing gelatinization of starch that resulted into increase in viscosity and SME (Ilo and Berghofer 1999). ET also had a significant negative effect in linear term on SME. Higher temperature facilitated the transformation from solid flow to viscoelastic flow, resulted in less energy use (Ruiz-Ruiz et al. 2008). A sharp decline in the SME was observed on addition of 10 % BF. BF had a significant quadratic effect on SME (Table 6). Higher SME resulted in extrudates with greater WAI of the extrudates ($r = 0.401$, $p \leq 0.05$). Higher shear rate caused by higher SME might cause porous structure of the extrudates which resulted in higher WAI.

Conclusion

It was concluded that the incorporation of BF into corn grit could result into lighter extrudates having improved expansion and WSI. The results of the study also indicated that 20 %

BF addition, 150 °C and 500 rpm screw speed would result in extrudates with most desirable properties.

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