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The Effect of Corn Flour Addition on the Physico-chemical Properties of Extruded Cassava Starch

Laureat Taffoti Tatsabong and Gi-Hyung Ryu*

Department of Food Science and Technology, Kongju National University

Abstract

This study focuses on evaluating the physico-chemical properties of extruded cassava starch added with corn flour. The raw materials were mixed at different ratios (corn flour/cassava starch 0:100, 25:75, 50:50, 75:25, 100:0 [w/w]), then extruded at different barrel temperatures (120 and 140°C) and moisture contents (20 and 25%), with the physicochemical and pasting properties of extrudates finally analyzed. The obtained results showed that the addition of corn flour to the mix resulted in an increase in specific length, lightness, yellowness, water absorption index, water solubility index, final viscosity, and setback viscosity of extrudates, while there was a decrease in redness and piece density. Other properties including the expansion ratio, reducing sugars, cold viscosity, peak viscosity, hold viscosity, and breakdown viscosity were more likely to be subjected to barrel temperature and moisture content. Mixing corn flour with cassava starch ameliorated the expansion properties, color, and some pasting properties of mixed extrudates. This study demonstrated that the use of corn flour and extrusion process with different barrel temperatures and moisture contents provided valuable data for the further development of extruded cassava starch.

Key words: cassava starch, corn flour, mixture, extrusion cooking

Introduction

The increasing popularity of snacks has made the snack industry to be one of the fastest growing food sectors. Different processes are being used to produce snacks, but extrusion cooking seems to be the major process of interest (Brennan et al., 2013).

Extrusion cooking is a high temperature short time process. An extruder machine acts as a bioreactor that combines different unit operations including mixing, shearing and heating, transforming several raw materials into finish products (Tiwari & Jha, 2017). Feed materials commonly used for extrusion process are protein and starch-based materials. When extruded, starchy foods undergo multitude of modifications including the degradation of starch and proteins, and formation of complexes between starch and lipids (Mercier & Feillet, 1975). The benefits of extrusion include the destruction of anti-nutritional factors, microorganism and contaminants. In addition, dietary fibers become more soluble, oxidation of lipid occurs less and the natural color and flavor of the food is maintained (Nikmaram et al., 2015). Until now, the source of starch for extrusion has been majorly from cereals such as wheat and corn. However, due to the increase in demand and research in finding alternative source of starch, starchy roots and tubers are gaining attention.

Cassava (*Manihot esculenta*) is a root largely grown in sub-tropical parts of Asia, Africa and South America. It is considered to be the third largest supply of calories in the tropics, and its ability to grow well under harsh climate conditions and marginal lands makes it a sustainable and a cheap product (Food and Agriculture Organization, 2014; Zhu, 2015).

The application of native starch is limited in the food industry because of its undesirable characteristics such as low resistance to shear, susceptibility to high temperature, and their tendency to retrograde (Karam et al., 2005; Singh et al., 2007). Chemical cross-linking is used to improve the functional properties of starch. However due to the consumers demand for natural and healthy products, alternative ways to improve properties of native starch are being developed. Blending different starches is a simple and natural way to improve properties of starch, such as pasting, gelatinization and retrogradation (Waterschoot et al., 2015). A growing interest for cassava starch led to various blends studies such as rice-cassava blend (Yao et al., 2003), wheat-cassava (Obanni & BeMiller, 1997), corn cassava and yam starch (Karam et al., 2005). Previous studies of extrudates incorporating cassava starch stated that they had higher paste clarity, blander taste and lower tendency to retrograde compared to the conventional extrudates, but they present limitations such as exhibiting high cohesiveness (Badrie & Mellowes, 1992; Serge et al., 2011). Extruded corn flour and starch have been largely studied, being appreciated for their good aptitude to expand. But they also present some undesirable characteristics as they have more tendencies to retrograde (Gomez & Aguilera, 1984; Tiwari & Jha, 2017). The objective of this study is to evaluate the changes in physical and chemical characteristics of cassava starch extrudate with addition of corn flour.

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*Corresponding author: Gi-Hyung Ryu, Department of Food Science and Technology, Kongju National University, Chungnam, 324-39, South Korea
Tel.: +82-41-330-1484; Fax: +82-41-335-5944
E-mail: ghryu@kongju.ac.kr

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Materials and Methods

Materials

Cassava starch (Samyang Co., Seoul, Korea) and corn flour (HCP Co., Seoul, Korea) were purchased and their chemical composition was measured using AOAC (2005) methods indicated that they had 13.18 and 12.35% moisture content; 0.53 and 2.13% crude ash; 0.12 and 2.30% crude fats; 0.02% and 5.06% crude protein respectively.

Extrusion process

Corn flour and cassava starch were mixed at the ratios of 0:100; 25:75; 50:50; 75:25 and 100:0 (w/w). The extrudate was made with a co-rotating twin-extruder (THK 31T, Incheon Machinery, Incheon, Korea) with a screw configuration shown in Fig. 1. The screw diameter was 30.0 mm, the ratio of diameter to length (L/D ratio) was 23:1, and the die of the extruder had a circular shape with a diameter of 3.0 mm. The barrel temperature was adjusted to 120 and 140°C and the moisture content to 20 and 25%. The feed rate and screw speed were fixed at 100 g/min and 200 rpm respectively. Extrudates were dried in the oven overnight and stored in plastic bags until analysis.

Expansion ratio and specific length

The expansion ratio was calculated as the diameter of extrudates divided by the diameter of the die exit (3 mm). Specific length (SL) was assessed as the length of extrudates divided by their equivalent weight of each measurement having ten replications.

Piece density

Piece density was measured according to the modified miller seed displacement method. Extrudates were cut into pieces of approximately 2 cm and were weighed (around 2 g) to be put in a 125 mL cup previously filled with one quarter of millet seeds. Millet seeds were added until the cup was full and the excess was scraped out. The cup containing extrudates and millet seeds was weighed. Measurements were done in triplicate for each sample and the piece density was calculated as follow:

$$P_d = \frac{M}{M + M_0 - M_1} \times P_m \tag{1}$$

Where P_d: piece density of extrudates (g/cm^3); P_m: density of millet (g/cm^3); M: Mass of extrudates (g); M_0: Mass of millet in the cup (g); M_1: Mass of extrudate and millet in the cup (g).

Color

A colorimeter (Chroma Meter CR-300, Minolta Co. Ltd., Osaka, Japan) was used to evaluate the lightness (L), the redness (a) and the yellowness (b) of grounded samples after being calibrated against a standard white tile (L_0= 97.22, a_0= -0.02, b_0= +1.77). Measurements were done in triplicate for each sample. The total color change ΔE was calculated as follows:

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \tag{2}$$

The subscript “0” indicates initial color values of raw samples.

Water absorption and solubility index

The water absorption index (WAI) and water solubility index (WSI) were assessed as described by Anderson et al. (1969). Dried extrudates were ground and 1 g of each sample was mixed with distilled water (25 mL) and shaken in a water bath (BF45SB, Biofree Co., Seoul, Korea) at 30°C, 150 rpm for 30 min, then the centrifuge (H-1000-3, Hanil Science Industrial Co., Gangneung, Korea) was used at 3000 rpm for 15 min. The supernatant was decanted and dried in aluminum dishes at 105°C until constant weight was achieved. The gel remaining in the centrifuge tube was weighed. Each measurement was done in triplicate and the WAI and WSI were calculated as follow:

$$\text{WAI (g/g)} = \frac{\text{weight of remaining gel}}{\text{dry weight sample}} \tag{3}$$

$$\text{WSI (\%)} = \frac{\text{weight of dry dolid in the supernatant}}{\text{dry weight of sample}} \times 100 \tag{4}$$

Reducing sugar

The dinitrosalicylic acid (DNS) method (Miller, 1959) with D-glucose as standard was used to assess the reducing sugar. Measurements were done in triplicate for each sample.

Pasting properties

A rapid visco-analyzer (RVA, model-3D, Newport Scientific, Sidney, Australia) was used to measure the paste viscosity parameters of samples as a function of temperature. The sample (3.0 g, 14% moisture) in the canister containing 25 g of distilled water was mixed and kept at 25ºC for 4 min, then the temperature was raised to 95ºC at a constant rate of 14ºC/min, maintained for 3 min, then was cooled down to 50ºC for 5 min at the same rate, and finally was held at 25ºC for other 4 min. The suspension was stirred at 960 rpm for 1 min and was stirred the throughout the test at 160 rpm. All

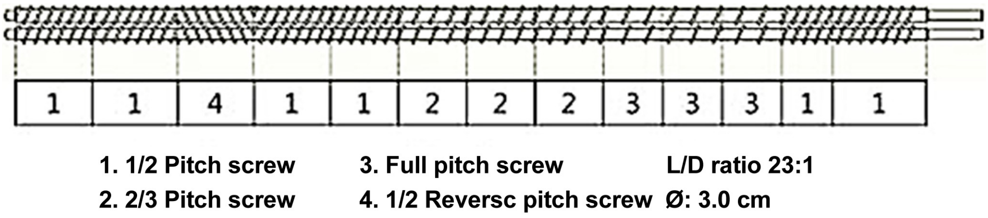

Fig. 1. Screw configuration of twin-screw extruder.

measurements were performed in triplicate for each sample.

Statistical analysis

All statistical analysis was carried out using the software program Design-Expert® version 8.06 (Stat-Ease, Inc., Minneapolis, MN, USA).The analysis of variance (ANOVA) was performed using a Duncan's multiple ranged test with 95% ($p<0.05$) confidence to compared the difference among samples means.

Results and Discussion

Expansion ratio and specific length

The expansion occurs after a succession of many brief physical changes including the nucleation and growth of bubble, followed by its coalescence and shrinkage (Kristiawan et al., 2016). The expansion ratio of extrudates was mainly affected by the moisture content ($p<0.01$) (Table 1). The expansion ratio decreased from 3.41 to 1.68 (Fig. 2A), when the moisture content increased from 20 to 25%. The greatest decrease in expansion ratio occurred when corn flour addition (CFA) was between 50 and 100%, barrel temperature of 140°C and at 20% moisture content. The increase in moisture content reduced the barrel temperature, consequently leading to the condensation of steam and shrinkage of bubble (Kristiawan et al., 2016). Expansion is negatively correlated with lipids and proteins content but it is positively correlated with starch content (Faubion & Hoseney, 1982; Badrie & Mellowes, 1992). Despite of its low content of lipids and protein, cassava starch expanded less than corn flour. The three highest expansion ratio were found when more than 50% CFA was incorporated suggesting that the addition of corn flour could improve the expansion properties of less expandable starches like cassava starch.

The specific length (SL) describes the expansion in the die flow direction (Kristiawan et al., 2016). The statistical analysis (Table 1) indicates that the SL was significantly influenced by the CFA, the barrel temperature and the moisture content ($p<0.05$). The range of increase of SL was from 22.47 to 68.88 m/kg and there was an increase as more CFA got incorporated, barrel temperature rose and moisture content was increased (Fig. 2B). Launay & Lush (1983) explained that SL of extrudates was function of the melt viscosity and elasticity. Fine particles of cassava starch heat faster than larger particle of corn flour resulting in lower viscosity. They also noted that the increase in moisture content and barrel temperature would result in a lower melt viscosity that increased the SL.

Piece density

Table 1 shows that piece density of extrudates was greatly influenced by the CFA ($p<0.001$) and the barrel temperature ($p<0.05$). Piece density decreased from 0.67 to 0.29 g/cm^3 (Fig. 2C). The piece density decreased as more corn flour was incorporated and with the increase in temperature. Temperature elevation is responsible for water vaporization inside the extruder, which encourage bubble formation and result in a decrease of piece density (Fletcher et al., 1985; Huth et al., 2000; Singkhomart et al., 2013). The decrease in piece density with increase in CFA can be related with the research of Yadav et al. (2015) who studied the effect of incorporation of cassava flour on extrudates when blended with corn grit-rice grit-chickpea flour. The study states that at low cassava level there was a decrease in piece density. Likewise, extrudate containing less cassava starch and more corn flour had a lower piece density.

Color

Color variation of extrudates indicates the degree of browning reactions, including caramelization, Maillard reaction, degree of cooking and pigments degradation happening during extrusion. Extruded samples had a lower value in lightness than non-extruded sample, showing a decrease in luminosity. Table 1 shows that the lightness of extrudates was considerably affected by the CFA ($p<0.001$), moisture content ($p<0.05$) and the interaction between CFA and barrel temperature ($p<0.01$). The value of lightness of extrudates was in the range of 76.06 to 81.39 with the CFA (Table 2). The increasing moisture content decreased the lightness of

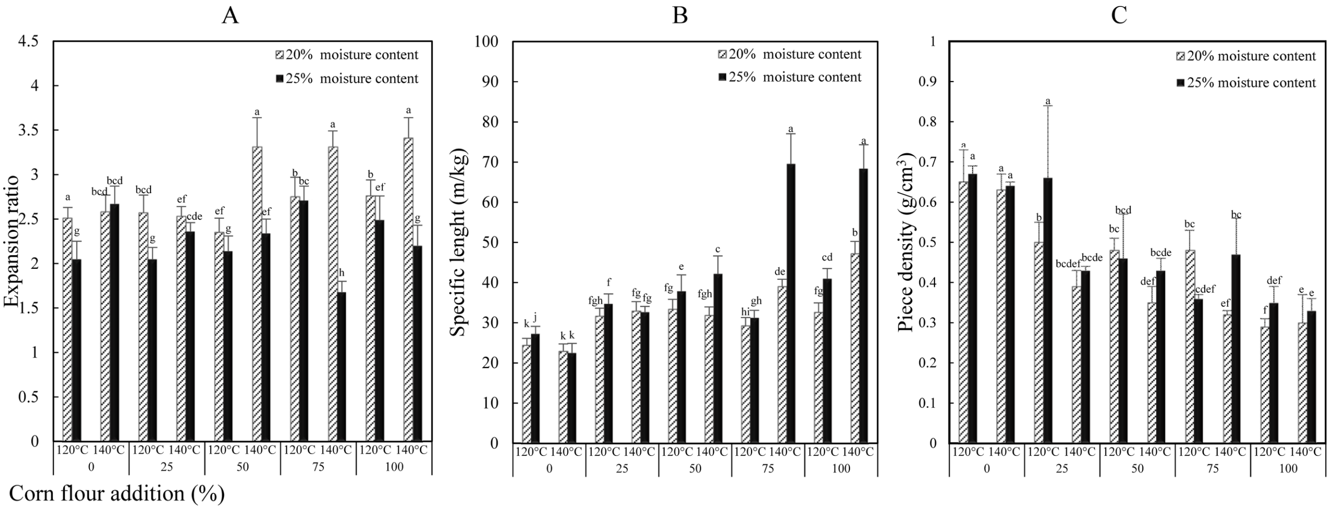

Fig. 2. Effect of corn flour addition on expansion ratio (A), specific length (B) and piece density (C) of extruded cassava starch.

Table 1. Statistical analysis of variance (ANOVA) of physical, chemical and pasting properties of extrudates

	Mean square					
	CFA1)	BT2)	MC3)	CFA x BT	CFA x MC	BT x MC
Physical properties						
Expansion ratio	0.08	0.18	1.51**	0.089	0.07	0.3
Specific length (m/kg)	30.6*	363.46*	321.6*	160.87	50.13	80.56
Piece density (g/cm^3)	0.060***	0.019*	8.40E-03	4.49E-03	1.24E-03	2.21E-03
Lightness	10.03***	0.019	0.78*	0.82**	0.09	4.05E-04
Redness	27.54***	0.073	0.084	0.04	0.03	0.02
Yellowness	1301.53***	1.89*	0.52	1.10*	0.20	0.49
Total color change	15.06***	1.56**	3.92E-03	1.63***	0.14	0.44
Water absorption index (g/g)	2.95***	3.93**	9.35***	0.65	0.30	0.01
Water solubility index (%)	10.56*	5.15	11.54	1.99	2.35	0.97
Chemical properties						
Reducing sugars (mg/g)	0.10	0.01	0.43	0.05	0.20	0.45
Pasting properties (cP)						
Cold viscosity	2.28E+05	4.533E+005*	5.501E+005*	42468.00	93039	46948
Peak viscosity	2.86E+05	7.212E+005*	1.047E+006**	52491.20	66701	1.61E+05
Hold viscosity	811.08	3.20	13312.80***	308.82	753.17	259.2
Breakdown viscosity	2.59E+05	7.186E+005*	8.238E+005*	55025.30	75779.3	1.74E+05
Final viscosity	39474.33*	2645	1.581E+005**	5080.38	11295.83	2289.8
Setback viscosity	37863**	2784.8	79632.20**	2891.68	6298.32	1036.8

* Significant at $p < 0.05$
** Significant at $p < 0.01$
*** Significant at $p < 0.001$
1) Corn flour addition
2) Barrel temperature
3) Moisture content.

extrudates. Tiwari & Jha (2017) reported that during extrusion, Maillard reaction happens specifically at higher temperature and lesser moisture content

All extrudates showed a decrease in redness value after extrusion, exception for ones with 0% CFA which the redness value increased after extrusion. Serge et al. (2011) also observed an elevation in redness value of cassava starch after extrusion. The redness of extrudates were significantly affected (Table 1) only by the CFA (p<0.001). Addition of corn flour led to a decrease in redness from 0.83 to -5.89 (Table 2). The decrease in redness with CFA can be attributed to the non-enzymatic browning reactions happening during extrusion (Chen et al., 1991) and the degeneration of heat sensitive pigment present in corn flour.

The yellowness of all sample increased after extrusion and was being influenced as shown in Table 1 by the CFA content (p<0.001), barrel temperature (p<0.05) and by the interaction between the CFA and barrel temperature (p<0.05). The increase of CFA content resulted in increasing the yellowness from 8.48 to 56.52 (Table 2). The yellowness of extrudates at 0 and 25% CFA content decreased with increasing barrel temperature, whereas the yellowness of extrudates at 50, 75, and 100% CFA content increased. All extrudates containing corn flour showed a yellow color. The total color change was affected (p<0.001) by CFA (Table 1) ranging between 17.56 and 23.14 (Table 2), thus increasing with CFA.

Water absorption and solubility index

The WAI quantifies the level of water absorbed by starch and can therefore be used as an index for gelatinized starch (Anderson et al., 1969; Ding et al., 2005). Table 1 shows that the WAI value of extrudates were significantly affected by CFA (p<0.001), barrel temperature (p<0.01) and moisture content (p<0.001). The range of WAI values was from 2.25 to 10.77 g/g (Table 2). The increase of barrel temperature and moisture content tended to increase in WAI of extrudates. Previous studies, relating to temperature and moisture content reported the same trends, showing that raising the barrel temperature to a certain level causes starch to become totally gruel, therefore leading to an increase in WAI. However, increasing the moisture content lead to less gelatinization of starch and thus also resulting in higher WAI (Gujska et al., 1990; Kothakota et al., 2013). The increase of WAI with CFA can be due to the fact that corn flour contains higher level of lipids and proteins than cassava starch, such can act as plasticizer during extrusion thus reducing the degradation of starch molecules.

The WSI is usually used to assess the level of degeneration of molecular components of starch and can also help to measure the level of soluble elements such as gelatinized starch, inorganic ions and small sugars, yielded from the feed material during the extrusion process (Anderson et al., 1960; Kirby et al., 1988; Tiwari & Jha, 2017). The WSI of extruded was affected (p<0.05) only by the CFA (Table 1) thus increasing from 3.46 to 12.06% (Table 2)

Table 2. The effect of corn flour addition (CFA) on color, water absorption index (WAI), water solubility index (WSI), and reducing sugar (RS) of cassava starch extrudates

CFA (%)	Extrusion conditions		Color				WAI (g/g)	WSI (%)	RS (%)
	BT[1] (°C)	MC[2] (%)	L[3]	a[4]	b[5]	ΔE[6]			
0	Non-extruded		93.33^{a}	-0.72^{d}	2.45^{p}	-	2.27^{i}	0.02^{n}	1.63^{ijk}
	120	20	76.47^{o}	0.79^{b}	8.79^{o}	18.07^{kl}	6.15^{i}	6.27^{def}	2.02^{c}
		25	76.95^{n}	0.83^{a}	8.91^{o}	17.68^{lm}	7.74^{defgh}	3.46^{ijk}	$1.74^{defghij}$
	140	20	76.06^{p}	0.68^{c}	8.48^{o}	18.34^{jk}	8.07^{efgh}	4.89^{gh}	1.65^{ijk}
		25	76.5^{o}	0.77^{b}	8.49^{o}	17.94^{klm}	9.64^{b}	6.68^{de}	1.89^{cdef}
25	Non-extruded		91.89^{b}	-2.55^{e}	12.71^{n}	-	2.25^{j}	0.96^{mn}	1.56^{j}
	120	20	78.55^{m}	-4.24^{h}	28.81^{j}	20.98^{e}	6.80^{hi}	7.67^{b}	$1.76^{defghij}$
		25	78.78^{l}	-4.21^{h}	28.73^{j}	20.76^{f}	7.91^{defgh}	7.91^{bcd}	$1.72^{efghijk}$
	140	20	80.12^{h}	-4.16^{h}	28.1^{kl}	19.44^{i}	7.14^{ghi}	7.73^{cd}	2.44^{ab}
		25	80.22^{h}	-4.19^{h}	28.48^{jk}	19.68^{i}	7.32^{cdefg}	5.38^{efg}	1.67^{hijk}
50	Non-extruded		91.07^{c}	-3.38^{f}	20.54^{m}	-	2.40^{j}	1.58^{lm}	1.65^{hijk}
	120	20	78.88^{l}	-5.3^{mn}	38.51^{h}	21.80^{d}	7.17^{ghi}	8.41^{b}	1.68^{ghijk}
		25	79.43^{j}	-5.22^{lm}	38.86^{h}	21.78^{d}	8.35^{cdef}	10.85^{a}	1.92^{ghijk}
	140	20	79.13^{k}	-5.19^{l}	39.5^{g}	22.48^{b}	7.63^{defgh}	12.06^{a}	2.28^{b}
		25	78.74^{m}	-5.39^{no}	40.02^{g}	23.14^{a}	8.63^{bcde}	6.65^{de}	1.86^{defg}
75	Non-extruded		90.05^{d}	-3.61^{g}	27.77^{l}	-	2.42^{j}	2.18^{klm}	1.70^{fghijk}
	120	20	78.71^{m}	-5.61^{p}	46.52^{f}	22.01^{cd}	7.26^{fgh}	7.64^{bcd}	1.76^{fghij}
		25	79.21^{k}	-5.42^{o}	47.08^{f}	22.22^{bcd}	8.76^{bcd}	6.84^{de}	1.91^{cde}
	140	20	78.68^{lm}	-5.89^{q}	46.85^{f}	22.34^{bc}	8.07^{cdefg}	4.44^{ghi}	1.78^{defghi}
		25	79.81^{i}	-5.32^{n}	48.4^{e}	23.10^{a}	10.77^{a}	4.44^{efg}	1.68^{ghijk}
100	Non-extruded		88.77^{e}	-3.59^{g}	37.68^{i}	-	2.86^{j}	2.80^{jkl}	1.82^{de}
	120	20	81.23^{f}	-4.98^{j}	54.49^{c}	18.48^{g}	8.48^{cde}	9.57^{bc}	1.60^{ijk}
		25	81.39^{f}	-4.38^{i}	53.59^{d}	17.56^{m}	9.68^{b}	5.11^{fg}	1.57^{jk}
	140	20	80.10^{h}	-5.09^{j}	55.7^{b}	20.05^{fg}	9.13^{bc}	7.57^{bcd}	2.50^{a}
		25	80.84^{g}	-5.17^{kl}	56.42^{a}	20.41^{cd}	10.77^{a}	3.74^{hij}	0.48^{l}

Means with the same letter in the same column are not significantly different ($p < 0.05$).

[1] Barrel temperature

[2] Moisture content

[3] Lightness

[4] Redness

[5] Yellowness

[6] Total color change.

with CFA and reached its maximum at value at 50% CFA but decreased with more CFA. Small granule particles like cassava starch granules are more sensitive to heat degradation therefore more likely to increase the WSI. However, contrary results were observed showing and increase in WSI with less cassava starch concentration. Previous studies also revealed that cassava starch displays a low WSI after extrusion (Serge et al., 2011). Karam et al. (2005) studied the gel textural characteristics of corn, cassava and yam starch blends, and found that cassava starch had a high cohesiveness enhanced by its high level of amylopectin. They also found that cassava starch cohesiveness decreased when blended in adequate proportion with yam and/or corn starch. The increase of WSI of cassava starch mixed with corn flour sample can be explained as the reduction of cassava cohesiveness thus favoring its denaturation during extrusion.

Reducing sugar

There was no significant effect of the CFA, barrel temperature and moisture on the RS of extrudates (Table 1). RS of extrudates were ranged between 0.48 and 2.50 % (Table 2). The combinations of CFA at 25, 50, and 75% with cassava starch resulted in decreasing RS content at 140°C; however, it increased as the temperature increased to 20% moisture content. Singkornart et al. (2013) reported that the RS content generally decreases during extrusion cooking due to the Maillard reaction and the formation of bonds between reducing sugar and amino acids.

Table 3. The effect of corn flour addition (CFA) on pasting properties of extruded cassava starch Unit: cP

CFA (%)	Extrusion conditions		Cold viscosity	Peak viscosity	Though viscosity	Breakdown viscosity	Final viscosity	Set back viscosity
	BT[1] (°C)	MC[2] (%)						
0	Non-extruded		0^{o}	4218^{a}	1489^{a}	2730^{a}	4124^{b}	2635^{b}
	120	20	587^{m}	588^{o}	67^{mno}	522^{l}	332^{r}	266^{o}
		25	1544^{b}	1549^{f}	102^{ijk}	1447^{d}	443^{mno}	341^{mn}
	140	20	1090^{f}	1094^{jk}	87^{jklm}	1007^{gh}	396^{pq}	309^{n}
		25	1430^{c}	1431^{g}	97^{jklm}	1333^{e}	415^{pq}	318^{n}
25	Non-extruded		0^{o}	2835^{b}	1111^{c}	1724^{c}	3317^{d}	2206^{d}
	120	20	815^{j}	815^{n}	88^{jklm}	727^{j}	431^{opq}	343^{mn}
		25	1281^{d}	1137^{ij}	102^{ijkl}	1035^{gh}	493^{lmn}	391^{l}
	140	20	855^{i}	845^{mn}	85^{jklm}	760^{j}	423^{opq}	338^{mn}
		25	1541^{b}	1535^{f}	115^{i}	1421^{d}	512^{klm}	398^{l}
50	Non-extruded		0^{o}	1882^{e}	918^{e}	964^{hi}	3044^{c}	2126^{e}
	120	20	1051^{g}	1210^{ih}	80^{jklmn}	1130^{f}	521^{kl}	441^{k}
		25	774^{k}	1243^{h}	159^{fg}	1084^{fg}	766^{h}	608^{h}
	140	20	1102^{f}	1222^{hi}	78^{jklmno}	1144^{f}	468^{mno}	391^{l}
		25	1977^{a}	2683^{c}	123^{hi}	2561^{b}	601^{j}	479^{j}
75	Non-extruded		0^{o}	1628^{f}	999^{d}	629^{k}	3557^{c}	2558^{c}
	120	20	905^{h}	1159^{hij}	67^{mno}	1092^{fg}	547^{k}	480^{j}
		25	620^{m}	919^{lm}	107^{ij}	812^{j}	680^{i}	574^{i}
	140	20	1125^{f}	1182^{hij}	53^{o}	1129^{f}	434^{opq}	382^{l}
		25	1167^{e}	1898^{e}	170^{f}	1728^{c}	907^{f}	737^{f}
100	Non-extruded		0^{o}	2136^{d}	1318^{b}	818^{j}	4916^{a}	3598^{a}
	120	20	401^{n}	576^{o}	16^{p}	560^{ef}	388^{q}	372^{lm}
		25	714^{l}	892^{mn}	142^{h}	750^{j}	833^{g}	691^{g}
	140	20	608^{m}	1008^{kl}	55^{no}	954^{hi}	490^{lmn}	436^{k}
		25	808^{kj}	988^{l}	75^{lmno}	913^{i}	558^{jk}	483^{j}

Means with the same letter in the same column are not significantly different ($p<0.05$).

[1] Barrel temperature

[2] Moisture content

Pasting properties

Several factors such as the granule size, amylose/amylopectin ratio and the molecular characteristic of starch can influence the pasting properties (Zhou et al., 1998). The cold viscosity (CV) is related to the water absorption ability of starch at room temperature forming a gel, paste or viscous liquid. The CV of extruded sample was significantly affected ($p<0.05$) by the barrel temperature and the moisture content (Table 1). CV increased from 401 to 1977 cP (Table 3) with the increase of both the barrel temperature and moisture content. This finding was in accordance with previous reports (Leonel et al., 2009; Serge et al., 2011).

The peak viscosity (PV) informs about the degree of starch swelling during heating. It can also reflect on the amount of starch degraded by extrusion (Ragaee & Abdel-Aal, 2006).The PV of extrudates was mostly affected by the barrel temperature ($p<0.05$) and the moisture content ($p<0.01$) as shown in Table 1. Increasing both the temperature and the moisture content resulted in an increase in PV value of extrudates from 576 to 2686 cP (Table 3). The hold viscosity (HV) was significantly affected ($p<0.001$) by the moisture content (Table 1). It increased with the increase of moisture content and ranged between 16 to 170 cP (Table 3). The breakdown viscosity (BDV) represents the fall in viscosity and is linked to the breaking of starch granule on continuous heating and shearing (Hedayati & Niakousari, 2018). The significant effect on BDV were those of the barrel temperature and moisture content ($p<0.05$) as shown in Table 1. BDV increased from 522 to 2561 cP along with the increase of both barrel temperature and moisture content (Table 3). Leonel et al. (2009) reported that high moisture content acts as a lubricant and therefore decrease the viscosity of the melt leading to high starch breakdown. However the results from this experiment showed a high breakdown at low temperature. Previous studies observed than blending starches had not specific effect on Hold and breakdown viscosity (Waterschoot et al., 2015), thus explaining why CFA had no significant effect on both HV and BDV.

The final viscosity (FV) and setback viscosity (SBV) indicate the predisposition of starch to form gel and retrograde. As shown in Table 1, the FV of extruded sample was significantly affected by the CFA ($p<0.05$) and the moisture content ($p<0.01$). It increased from 332 to 907 cP (Table 3) with CFA and moisture content raise. According to Table 1, the SBV of extrudates were significantly affected by the CFA ($p<0.01$) and moisture content ($p<0.01$). Table 3 shows that SBV of extrudates varied between 266 and 737 cP thus increasing with CFA and moisture content augmentation. When the process of swelling and gelatinization occurs, amylose chains are yielded from starch in the aqueous phase. All the while cooling yielded molecules form interactions, mainly hydrogen bonding associations between starch molecules resulting in retrogradation (Hedayati & Niakousari, 2018). The presence of water in the melt favors the hydrogen bong forming, therefore the SBV increased with the moisture content. The increase in SBV and FV value of extrudates can be due to the considerable amount of amylose content corn flour, thus predisposing sample with high CFA to retrogradation. In regard with retrogradation properties there was thus a non-additive effect between corn flour and cassava starch. Same results were recorded for blends of potato and maize starches (Obanni & BeMiller, 1997).

Conclusion

Substitution of cassava with corn flour gives interesting physical extruded products properties. Corn flour tends to ameliorate the expansion properties of cassava starch. Beside the formulation, temperature at 140°C and moisture content at 20% were also favorable for the production of expanded products. CFA is suggested to give a favorable color rather than the dark brown color observe in cassava starch unmixed extrudates. Mixing corn flour and cassava starch can be used to obtain special desirable physical, nutritional properties, avoiding the use of chemical modifications. The mechanisms responsible for the behaviors of blended extruded starches are still unclear. There is therefore a need for further investigation of mixed extruded starches.

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