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Effects of Feed Moisture and Barrel Temperature on Physical and Pasting Properties of Cassava Starch Extrudate

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수분주입량과 배럴온도에 따른 카사바 전분 압출성형물의 물리적 특성

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Abstract

Considering the importance of cassava as food crops in humid tropics, the effect of feed moisture (20, 25%) and barrel temperature (110, 130℃) on physical properties (piece density, expansion, mechanical properties, color, water solubility index, water absorption index) and pasting properties of extruded cassava starch was investigated. The feed moisture used during extrusion processing had a significant effect on extrudates SME input, specific length and piece density at ($p<0.05$) while effect on cross-sectional expansion index, apparent elastic modulus and breaking strength in bending shown significantly at $p<0.1$. Furthermore, the interaction effect of feed moisture and barrel temperature gave a significantly affected the SME input and piece density ($p<0.1$), specific length ($p<0.05$) and on redness ($p<0.01$). The increase in water injection rate led to increase in piece density, apparent elastic modulus, breaking strength in bending, cold peak viscosity, breakdown and final viscosity and decrease in cross-sectional expansion index and specific length. It was found that the extrusion cooking process did not affect the value of color L, color b, water solubility index and water absorption index. Thus, the results of this study can be useful to some extent in developing extruded cassava starch as human and animal feeds.

Key words : cassava starch, extrusion cooking, physical properties, pasting properties.

Introduction

Cassava (*Manihot esculenta*) is a root found mostly in tropical regions in the world. The starch from this root possesses interesting properties such as low gelatinization temperature, clarity and taste bland for food and industrial applications.However, it has also some properties unfit for human food and animal like the long texture (high cohesion), sensitivity to shear at high temperature and low pH (1,2).

Extrusion cooking is a powerful processing operation which uses a high temperature, high pressure and high shear force to produce the extrudates with low density, high expansion and having a unique texture (crispy, crunchy). The process variables such as water injection rate, screw configuration, screw speed, feed rate, barrel temperature and raw materials used in general have a great influence on physical and chemical properties of the product obtained at the end of extrusion cooking. Thus,extrusion of starchy food results in gelatinization, partial or complete destruction of the crystalline structure and molecular fragmentation of starch polymers. The high shear, temperature and pressure applied caused breaking of starch granular structure and change in special arrangement of carbohydrate chains. Physical properties such as expansion, density, hardness and sensory attributesare important parameters to evaluate the consumer acceptability of the final product.

The effects of process variables on final product quality are also reflected by their influence on process responses or extruder system parameters such as motor torque, die pressure, melt temperature and specific mechanical energy

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(SME) input (3). The SME input is correlated with some physical properties of extrudates such as expansion, density and texture characteristics (4). Likewise, theexpansion increased with decreasing water injection rate and/or increasing barrel temperature. The apparent elastic modulus and breaking strength in bendingdecreased with decrease in water injection rate (5,6). Resistance stress of cereal extrudates is positively correlated with apparent density (7). Desirable products characterized by higher cross-sectional expansion index, low piece density and hardness at low feed moisture, high screw speed and medium to high barrel temperature (8,9). It is possible to obtain interesting physical and chemical properties by extrusion cooking of cassava starch for make some manufactured products such as breakfast cereals and snacks (10). This experiment was carried to investigate the influences of feed moisture and barrel temperature on physical and pasting properties of cassava starch extrudates.

Materials and methods

Materials

The cassava starch was purchased from local market (Yesan, Korea) and the chemical composition were 12.28% moisture content, 0.07% crude ash, 0.12% reducing sugar, 0.25% crude fats and 0.8% crude proteins.

Extrusion

A twin-screw extruder (Incheon Machinery Co, Incheon, Korea) equipped with a 32 mm diameter at 24:1 L/D (length/diameter ratio) and three heating zones was used to prepare each sample. The screw configuration of the extruder is shown in Fig. 1. The extruder was run at 200 rpm and feed rate at 100 g/min. The barrel temperature varied from 110 to 130℃ and water was pumped into the barrel to vary moisture content from 20 to 25% during process. The extrudate samples were dried in drying oven at 80℃ for 7 hr and the dried samples were stored in plastic bags at room temperature and used for analysis.

Chemical analysis

Moisture content, crude protein, crude fat and crude ash were analyzed by the standard method (11). The reducing sugar was determined with the colorimetric method using 3.5-dinitrosalicilic acid (DNS) (12). Glucose solution was used as standard. Determinations were performed in triplicate for each sample.

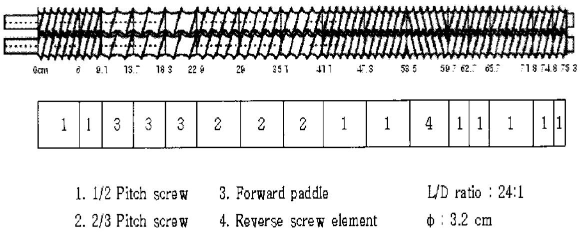

Fig 1. Screw configuration for extrusion process (Model THK 3)

Specific mechanical energy input

The specific mechanical energy (SME) input was calculated using the following equation.

$$SME = \frac{E^{V} - E^{0}}{F^{r}} \tag{1}$$

Where E = electric current after feed material (amperes); E^{0} = initial electric current (amperes); E^{V} = the voltage applied to the armature of the motor (volts) and F^{r} = the feed rate supplied to extruder (kg/s).

Expansion

The cross-sectional expansion index (SEI) was determined as the diameter of extrudates divided by the diameter of the die exit (3 mm) (7). Each value was an average of ten readings. The specific length of extrudes was evaluated as the straight length of extrudates divided by the equivalent weightof extrudates (13). The values were presented as an average of ten readings.

Piece density

The piece density (D_e) was determined as the weight of extrudates (W_e) divided by the equivalent volume of extrudates (V_e). The volume of extrudates (V_e) was determined by substituting rapeseed weight (W_r) for extrudates volume and dividing it by rapeseed density (D_r). For each sample, the piece density was calculated as following equation and presented as an average of ten readings (7).

$$D_{e} = W_{e} \times \frac{D_{r}}{W_{r}} \tag{2}$$

Mechanical properties

Mechanical properties were determined with a texture analyser (Compac-100, Sun Scientific Co, Ltd, Tokyo, Japan). The apparent elastic modulus (E_{app}) and breaking strength

(F_{bs}/S) in bending tests of extrudates were evaluated (6). The E_{app} in bending of extrudates between two supports was determined as the extrudates strand deformed in bending until fracture occurred. E_{app} was calculated as equation.

$$E_{app} = \left(\frac{dF}{dl}\right)\left(\frac{64\,d^3}{48\,\pi D^4}\right) \qquad (3)$$

Where dF/dI = the slope of the linear section of the force-distance curve; d = distance between two supports (30 mm); D = the diameter of extrudates.

Breaking strength (F_{bs}/S) in bending was calculated as maximum peak divided by the cross-section area of extrudates. Extrudate sample was cut at 42 mm length. The singleextrudate was placed on the two support bars perpendicular to the probe. Each value was presented as an average of ten readings.

Color

Extrudate color was determined by using Colorimeter (CR-300, Minolta, Japan). The results were expressed as *L*, a and b. Where *L* represents the lightness which varied from black 0 to white 100, *a* represents redness or greenness, and *b* represents blueness or yellowness. Measurements were performed in triplicate.

Water absorption index and water solubility index

The water absorption index (WAI) measuresthe volume occupied by the starch granule after swelling in excess of water. The water solubility index (WSI) determines the amount of free molecules leached out from the starch granule in addition to excess water (14). WAI and WSI were determined according following formula.

$$WSI(\%) = \frac{Dry\ Solid\ weight\ tecoveredby\ evaporation\ the^{ernatant}}{Dry\ sample\ weight} \times 100 \qquad (4)$$

$$WAI(g/g) = \frac{Hydrated\ sample\ weight - Dry\ sample}{Dry\ sample\ weight} \qquad (5)$$

Pasting properties

Pasting properties were determined with a Rapid Visco Analyser (RVA) (Model-3D, Newport Scientific, Sidney, Australia). A extrudate powder (3 g, 14 % wet basis) and water (25 mL) were equilibrated at 50℃ for 1 min, heated to 95℃ for 3.5 min, maintained for 3 min and then cooled down to 50℃ within 3.8 min, and finally held for 2 min. The suspension was stirred at 960 rpm for 1 min and then at 160 rpm thoroughly of the test. The changes in viscosity were expressed in rapid visco unit (RVU). All measurement was performed in triplicate.

Statistical analysis

All experimental results were expressed as means±S.D (Standard deviation). Analysis of variance was performed by ANOVA procedures. PASW software was used forstatistical calculations. The results with $p<0.05$ were regarded to be statistically significant.

Results and Discussion

Specific mechanical energy

Specific mechanical energy (SME) input is defined as the energy transmitted to the material being extruder by screw. It characterizes the operations of extrusion cooking and is often correlated with the conversion degree of starch used

Table 1. Analysis of variance of extrusion process variables on properties of cassava starch extrudates

Parameters	Means square		
	Moisture content (MC)	Barrel temperature (T)	MC*T
SME input[1)] (kJ/kg)	103166.22**	6485.88	542.79*
WSI[2)] (%)	32.77	0.64	25.18
WAI[3)] (g/g)	0.74	0	0.002
Physical properties			
Cross-sectional expansion index	0.19*	0.014	0.1
Specific length (m/kg)	1078.79**	6.78	542.79**
Piece density (g/cm^3)	0.05**	0	0.02*
Apparent elastic modulus (N/m^2)	0.0*	0	0
Breaking strength (N/m^2)	5.01E+10*	2.20E+09	2.62E+10
Pasting properties			
Cold peak viscosity (RVU)	49.36**	16.66	24.89
Breakdown viscosity (RVU)	51.97***	13.98	26
Final viscosity (RVU)	10.66***	1.54	5.43
Setback viscosity (RVU)	11.84*	0.821	6.36
Color			
Lightness (*L*)	3.38	0.76	2.31
Redness (*a*)	0.01	0.02	0.24***
Yellowness (*b*)	0	0.04	0.02

*Significant ($p<0.1$) **significant ($p<0.05$) ***significant ($p<0.01$).
[1)]Specific mechanical energy
[2)]Water solubility index
[3)]Water absorption index

during cooking. In fact,SME input was significantly affected by water injection rate ($p<0.05$) and by the interaction of water injection rate and barrel temperature ($p<0.1$) as shown in Table 1. The SME in this study was decreased from 827.37 to 425.62 KJ/Kg with increase in water injection ratefrom 20 to 25%, and barrel temperature from 110 to 130℃ (Table 2). LowestSME input (425.62 KJ/Kg) was obtained at 25% water injection rate because of water contributed to reduce the dough viscosity of the extrusion system and reduce SME input (14,15).

Expansion

The cross-sectional expansion index (SEI) of extrudate was significantly affected by water injection rate ($p<0.1$) (Table 1) and it decreased from 2.68 to 2.12 with increase in water injection rate from 20 to 25%. The specific length was also significantly affected by water injection rate ($p<0.05$), while the interaction effect of water injection rate and barrel temperature also affected significantly specific length ($p<0.05$). The specific length was decreased gradually from 107.41 to 68.31 m/kg with increase in water injection rate from 20 to 25% at barrel temperature of 110℃ (Table 2). The moisture content in the feed material influences the rheological properties of the melt and builds up the vapour pressure and causes extensive flash-off of internal moisture when the melt exits the die. However, the viscosity of the melt affects bubble growth as well as shrinkage of generated bubble. At high water injection rate, the viscosity of the melt is lower, thus bubble shrinkage and collapse are increased when the viscosity of the melt exit (17).

Piece density

The piece density of extrudate was significantly affected by water injection rate ($p<0.05$) and by interaction effect of barrel temperature and water injection rate ($p<0.1$) as shown in Table 1. Piece density increased from 0.17 to 0.44 g/cm^3 with increase in water injection rate from 20 to 25% at barrel temperature of 110℃. The increase of piece density could be explained by the greater expansion in both cross-sectional expansion index and specific length. The volume expansion phenomena are basically dependent on viscous and elastic properties of melted dough (19). The high dependence of piece density on water injection rate would reflect its influence on elasticity characteristics of the starch-based material.

Table 2. Effect of feed moisture and barrel temperature on physical properties of cassava starch

Parameters	Raw material	Extrusion conditions			
		20% MC		25% MC	
		110℃	130℃	110℃	130℃
SME input[2](kJ/kg)	-	827.37±8.02[1]	729.18±0.6	488.52±0.2	425.62±6.30
WSI[3](%)	0.03±0.00	19.03±0.02	19.51±2.21	17.98±1.20	9.11±1.78
WAI[4](g/g)	4.35±0.10	4.65±0.12	4.58±0.76	4.52±0.22	4.29±0.03
Physical properties					
Cross-sectional expansion index	-	2.54±0.07	2.68 ±0.07	2.12±0.12	2.13±0.07
Specific length (m/kg)	-	107.41±4.97	98.55±4.72	68.31±2.48	71.55±3.11
Piece density (g/cm^3)	-	0.17±0.01	0.19±0.01	0.44±0.04	0.39±0.03
Apparent elastic modulus (N/m^2)	-	1.80E+04	1.70E+04	4.60E+04	3.30E+04
Breaking strength (N/m^2)	-	1.67E+05	1.99E+05	4.70E+05	3.44E+05
color					
Lightness (*L*)	94.23±0.30	84.58±0.30	84.76±0.25	83.67±0.27	81.74±0.53
Redness (*a*)	-0.89±0.12	0.39±0.02	0.24±0.06	0.27±0.04	0.12±0.03
Yellowness (*b*)	3.37±0.23	8.29±0.006	7.87±0.15	8.09±0.27	8.10±0.33

[1]Values are means of triplicate determinations (n=3)±standard deviation.
[2]Specific mechanical energy
[3]Water solubility index
[4]Water absorption index

Expansionat die probably was caused by starch gelatinization (16). Gelatinized starch forms a viscoelastic matrix in the barrel and gains the ability to hold air cells in extrudate. Increased water injection rate during extrusion would reduce the melt elasticity thus decrease in expansion,but increase in piece density of extrudate (16).It was observed in this study that extrudate produced with higher water injection rate became denser than those produced with lower water injection rate. Likewise, piecedensity is directly related to the texture of final product of expanded starch and it is determined by the growth and subsequent shrinkageor collapse of water vapour bubbles in the extrudates and also by effect of die swelling due to the elastic property of the melted matrix (20).

Mechanical properties

The water injection rate affected significantly the apparent elastic modulus and breaking strength ($p<0.1$) as shown in Table 1. Thus, breaking strength in bending increased from 1.67E+05 to 4.70E+05 N/m^2 with increase in water injection. High breaking strength was obtained at 25% water injection rate (Table 2). This result indicated that extrudate became brittle when extrusion was performed at high barrel temperature. Breaking strength depends on degree of expansion and cell wall strength and it also decreased with increasing cross-sectional expansion index (i.e., a decrease in piece density) (20,21). In addition, the apparent elastic modulus in bending was also significantly affected by water injection rate (Table 1) and it increased from 1.70E+04 to 4.60E+04 N/m^2 with increase in water injection rate. Generally, the apparent elastic modulus is the stiffness degree of extrudates and it depended on the intrinsic rigidity of expanded matrix and on the longitudinal expansion (7).

Color

Color is an important characteristic of extruded. Color changes can give information about the extent of browning reactions such as caramelization, Maillard reaction, degree of cooking and pigment degradation that take place during extrusion (22). Analysis of the starch color components before and after extrusion evidenced that the value of the Lcomponent from extruded varied from 81.74 to 84.76, indicant a decrease in lightness after extrusion when compared with the value of L component from raw material about 94.23 (Table 2). As shown in Table 1, the lightness of extrudate was not significantly affected by the barrel temperature and water injection rate. After extrusion, a maximum *L* value (84.76) was obtained at 130℃ with 20% water injection rate. When the temperature increased from 110 to 130℃, *L* value decreased at 25% water injection rate.

The a values of cassava starch was -0.89. Increase in water injection rate reduced the redness of extrudate from 0.36 to 0.12 with increase in barrel temperature from 110 to 130℃ (Table 2). The high a values were obtained from low barrel temperature and low water injection rate. As shown in Table 1, the interaction effect of barrel temperature and water injection rate affected significantly the redness of extrudates ($p<0.01$). This change may be associated with the Maillard reaction or non-enzymatic browning and destruction of heat sensitive pigments (23). Similarly, the Maillard reaction or no enzymatic browning may also be due to reactions initiated between amines and carbonyl compounds (24).

The bvalues indicate the yellowness of sample. The low magnitude of b indicates that the development of the yellow coloration of cassava starch was negligible before extrusion. After extrusion, bvalues were increased from 7.87 to 8.29 at 20% water injection rate and from 8.09 to 8.10 at 25%. The high of b values was obtained from low barrel temperature and low water injection rate.

Water solubility index and water absorption index

The results shown in Table 2 revealed that water that extrudate had higher WSI than raw material. Thewater injection rate and barrel temperature were not affected significantly WSI and WAI of extrudate (Table 1). Increase in water injection rate from 20 to 25% at barrel temperature from 110 to 130℃reduced the WSI from 19.51 to 9.11% (Table 2).

The water solubility index is a parameter that indicates the total degradation by starch granules. It is the integration of the effects of gelatinization, dextrinization, and the consequent solubilization. The increase in solubility in extruded products is attributed to dispersion of amylase and amylopectin molecules following gelatinization, when processing conditions are mild, and to formation of low molecular weight compounds under drastic conditions (10). Starch gelatinization produced significantstructure modification, with destruction of polymer chains which allowed their release. As the gelatinization gets more intense, there is an increase in starch fragmentation with lowered absorption of water. In contrast, WSI depends on the amount of soluble molecules and is related to starch degradation. Therefore, WSI increases with more treatment (25). Water is absorbed and bound to the starch molecule with a resulting change in the starch granule. Barrel temperature and water injection rate are found to exert the greatest effect on gelatinization. The maximum gelatinization occurs at high water injection rate and low temperature.

As shown in Table 2, water absorption index (WAI) of extrudate varied from 4.29 to 4.58 g/g, such values were not very high than those observed for raw material (4.35

g/g). WAI was not significantly affected by water injection rate and barrel temperature (Table 1).

The WAI measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion. Barrel temperature and water injection rate are found to exert the greatest effect on gelatinization. The maximum gelatinization occurs at high water injection rate and low barrel temperature (26).

Pasting properties

The Table 3 shown that the peak viscosity (PV) of cassava starch was 286.33 RVU, breakdown viscosity (BV)was 117.39 RVU, final viscosity (FV) was 366.75 RVU and setback (SB) was 196.42 RUV. Therefore, the initial viscosity of cassava starch was too close zero due to absence of gelatinization of starch. The cold peak viscosity indicates the capacityof starch to absorb water at room temperature and to form paste, gel or viscous liquid (27). CPV of extrudate varied from 6.45 to 14.59 RVU. Considering that the PV of cassava starch before extrusion was practically zero, the extrusion cookingled to considerable increased in cold viscosity. Analysis of variance shown in Table 1 revealed that water injection rate affected significantly CPV ($p<0.05$), BV ($p<0.01$), FV ($p<0.01$) and SB ($p<0.1$) of extrudate. The increase in water injection rate led to an increase of the CPV indicating degradation of the crystalline structure.

The BV varied from 8.36 to 17.3 RVU and was regarded as the measure of degree of disintegrationgranules or paste stability. The water injection rate affected significantly the BV (Table 1) and it increased with increase in water injection rate from 20 to 25%. Highest BV was obtained at 110℃, with 20% water injection rate because the degradation of the starchy fraction did not leadto significantly PV of extrudate.

The FV of extrudate measures the retrogradation of starch which depends of the starch degradation degree (20). FV was increased from 2.5 to 6.82 RVU with increase in water injection rate (Table 3) resulting in a high degree of retrogradation of starch (23,28). The SB also increased at high water injection rate indicating the severity of the extrusion process, causing the degradation of polymers, rupture of their molecular structureand reduction of their recrystallization capacity. Thus, the highest retrogradation of extudate 9.52 wasobserved at 25% water injection rate (Table 3).

Conclusion

The water injection rateand barrel temperature induced significant changes in physical and pasting properties of extruded cassava starch, while the most extrudateproperties were less influenced by the barrel temperature. A better quality of extruded cassava with high cross-sectional expansion index (2.68), low density (0.17 g/cm^3), low apparent elastic modulus (1.7E+04 N/m^2) and breaking strength in bending (1.67E+05 N/m^2), were produced at low feed moisture. At high feed moisture, characteristics of extrudates were denser and less expanded. The extrudates have exhibited low water solubility index and high values of pasting parameters with increase inwater injection rate. Likewise, the SME input was significantly affected by water injection rate and barrel temperature. The results proved that the potential of cassava starch as raw materials could be used for make some manufactured products such as breakfast cereal and snacks.

Table 3. Effect of feed moisture and barrel temperature on pasting properties of cassava starch

Pasting properties	Raw material	Extrusion conditions			
		20% MC		25% MC	
		110℃	130℃	110	130℃
Cold peak viscosity (RVU)	-	6.45±4.44	5.52±0.43	14.59±1.00	10.88±1.00
Peak viscosity (RVU)	286.33±1.46[1)]	-	-	-	-
Trough Viscosity (RVU)	170.33±8.72	0	0	0	0
Breakdown viscosity (RVU)	117.39±7.27	8.58±3.24	8.36±0.43	17.3±7.65	13.3±1.00
Final viscosity (RVU)	366.75±18.81	2.5±0.59	3.14±0.05	6.82±0.57	5.96±0.53
Setback viscosity (RVU)	196.42±13.30	4.64±0.79	5.97±0.05	9.52±0.44	8.38±0.53

[1)]Values are means of triplicate determinations (n=3)±standard deviation.

요 약

다습한 열대지방에서 카사바는 중요한 식물자원이다. 수분함량(20, 25%)와 배럴온도(110, 130℃)에 따른 압출성형 카사바전분의 물리적 특성(밀도, 팽화율, 비기계적 에너지, 색, 수분용해지수, 수분흡착지수)와 호화특성을 조사하였다. 카사바전분 압출성형공정에서 수분 투입량은 압출성형물의 비기계적 에너지 투입량, 비길이, 밀도에 유의적으로 영향을 미쳤으며($p<0.05$) 직경팽화지수, 겉보기탄성계수와 절단강도에서 유의성을 보여주었다($p<0.1$). 또한 수분투입량과 배럴온도의 상호관계에서 비기계적 에너지 투입량과 밀도($p<0.1$), 비길이($p<0.05$), 적색도($p<0.01$)는 유의성을 나타내었다. 수분투입량이 증가함에 따라 밀도, 겉보기탄성계수, 절단강도, 저온최고점도, 구조파괴점도, 최종점도는 증가하였으며, 직경팽화지수와 비길이는 감소하였다. 카사바전분 압출성형공정에서 수분투입량과 배럴온도는 명도와 황색도, 수분용해지수, 수분흡착지수에 영향을 미치지 않았다. 이 연구의 결과는 카사바 전분을 압출성형하여 사료와 식품을 개발하는데 유용하게 이용될 수 있을 것이다.

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