Title	キャッサバの加熱押出し加工特性とその生成物の性質に与える含水量及び温度の影響(農業工学科)
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Effects of Feed Moisture Content and Process Temperature on the Product Properties and Processing Characteristics of Cassava Extrusion

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Summary

Cassava flour was hydrated to 10, 13, 16 and 19 % (w.b.) of moisture content and extruded at 140° , 160° and 180℃ of barrel temperature on constant screw speed of 150 rpm. The effect of feed moisture content and process temperature on product properties (product appearances, moisture content, expansion ratio, bulk density, water absorpsion, shearing strength) and extrusion process characteristics (product rate, torque and pressure) were determined.

The analysis showed that the interaction of the process temperature and feed moisture content significantly correlated with all extrudate properties, but on the other hand, the individual analysis indicated that only feed moisture content correlated with product properties. The physical appearence clearly showed that the good extrudate produced at process temperature of 140°-160℃ for feed moisture content of 13-16% (w.b.). The analysis also described that there were inter correlation between product properties.

The feed moisture content was critical parameter on the operation of the extruder used in this experiment, and analysis showed that interaction with process temperature related to torque and pressure, but no relation with product rate. For all level of process temperature, the safe operation conducted for feed moisture content of 13-16% (w.b.).

Introduction

Cassava (Manihot esculenta Crantz) become an important source of calories for the people living close to subsistence levels in tropical areas. The main problems on using cassava for human food and animal feed were highly prussic acid accounted and poor quality and quantity of protein in cassava. The use of protein rich plant and animal protein supplements have been recommended to improve the protein quality and quantity of cassava [9].

Because so low in protein, cassava must be supplemented with a protein concentrate if it is to be used as animal feed. An alternative to the use of a protein concentrate would be to use cassava as the carbohydrate source in a microbial fermentation in which non protein nitrogen is converted into microbial protein. This principle was used by Reade et al[10] and Pancras et al[9].

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The processing of food by extrusion cooking to produce products suitable for human and animal foods is now well establised. The high shear, temperature and pressure applied during extrusion make it possible to thermomechanically modify starch for a variety of end used or for subsequent bioprocess application[4]. Harper[7] also described that the extrusion cooking of starchy materials to increase their susceptibility to enzymatic hydrolysis has become an important preprocessing step for fermentation process.

Several studies have been directed experimental verification of inter relationship between raw material properties, processing condition and extrudate product characteristics for starchy materials[1,2,4,5,8,11,]. However, until now the study of factor effecting on cassava extrusion was limited.

The objective of this study is to find out the effects of feed moisture content and process temperature on the product properties and extrusion characteristics of cassava extrusion.

Materials and Methods

Preparation of Raw Materials

This study used cassava which was harvested from Research Institute of Tropical Agriculture, University of The Ryukyus, Iriomote Island, Okinawa-Japan.

The cassava was preground by National Food Processor and passed through the 2 mm sieve but no through the 1 mm sieve, to make same diameter of raw materials about 1 mm.

10, 13, 16 and 19%(w.b.) of moisture content of cassava were prepared. A predetermined amount of destilled water was added by hand sprayer to the cassava which placed on bowl, and mixed by spoon for some minutes. The samples were sealed in plastic bags and stored overnight at 5 ℃ for equilibrium. Before extruded, the samples were allowed to return to room temperature.

Extrusion

The experiment was accomplished using the Rheomex Type 202, a laboratory size single screw extruder (Haake, Inc.,Saddle Brook, N.J.) with the following specifications : screw : diameter, 3／4 inch (1.9 cm) ; length-to-diameter ratio, 20 : 1 ; compression ratio,2 : 1 ; die : diameter, 2 mm ; length, 5.08 mm; shape, circular. The extruder barrel contained three sections and the temperature in each section was controlled independently. All temperatures were recorded at 1 minute intervals by TEAC Type DL-350, digital data logger equipped with Sharp CE-515P color plotter printer.

All samples extruded on normal screw speed about 150 rpm and on constant auger screw speed of feeder 55 rpm. Three levels of processing temperature (as second section and die head of barrel temperature) were 140°, 160° and 180°C, while the barrel feed (first) section kept at 125°C for all experiments[6].

Pressure was measured using a Dynisco Type Pt 462E - 10M - 61／18 pressure transducers, and data was recorded by YEW Type 3057 Portable Recorder. Torque was measured and recorded by Reocord Type M Torque Rheometer (Haake, Inc., Saddle Brook, N.J.).

After the flow reached steady, as indicated by smooth extrudate production, batches of extruded products equivalent to 40 second operation were collected for the duration of each samples to determine the product rate. The extrudate was allowed to stay in open pan for about 2 hours at room temperature to a stable moisture content and then put in the polyethylene bags before analysis of product properties.

Determination of Product Properties

Moisture of extrudates was determined in duplicate from loss of weight on drying 2–3 g samples for 24 hrs at 105℃. Bulk density of cylindrical extrudates was determined from weight and diameter. Determination was performed in triplicate. The expansion ratio was calculated as the ratio of cross-sectional areas of extrudate and the die orifice.

Water absorption was determined according to Aguelera et al[1]. The samples was soaked for 15 min. in water at 25℃. After rehydration, the excess water was removed by draining and blotting on filter paper. Values were reported as grams of water absorbed/gram dry weigth of product. Determination was arranged in duplicate.

The shearing strength of extrudate determined using the method conducted by Zulichem et al[12]. Dry strands of extrudates were placed across the width of an Allo-Kramer shear cell. The peak force required to shear the product was recorded using Tensilon Model UTM-4-100 at crosshead speed of 10 mm/min and chart speed of 50 mm/min. Shearing strength was calculated by dividing the shear force by the total cross-sectional area of the extrudates sheared. Duplicate determination were made on each samples.

Experimental Design and Data Analysis

The study was conducted according to a complete fractional experiment[3]. This design was essentially a complete block design which randomly tested four combinations of feed moisture content at three levels of process temperature, making a total 12 combinations of the two parameters. Each of combination run in three replications making a total of 36 extruders' runs necessary to complete the design.

Multiple regression analysis was done with the program Statistical Analysis System (NEC Corp./Micrososft Corp.) on a NEC PC-9801VM. All data experiments were plotted as graphics of moisture content as x-absis versus product properties and process characteristics as y-ordinate for each of process temperature using program LOTUS 123.

The first order model describing the correlation of feed moisture content and process temperature as independent variables with process characteristics and product properties as dependent variables was developed using multiple regression analysis. The model was fitted to each set of data as follows

$$Y = a_0 + a_1 X_1 + a_2 X_2$$

whre Y : product properties (moisture content, expansion ratio, bulk density, shearing strength or water absorption) or process characteristics (pressure, product rate or torque) ; a_0, a_1 and a_2 : estimated regression analysis ; X_1 : feed moisture content (%w.b.) and X_2 : process temperature(℃)

Results and Discussion

The extrusion process variables depend on size and configuration of extruder that was used, therefore, it is difficult to compare one study with another investigations. Further, Harper[7] noted that no specific functional relationships had been found between product properties and process variables. However, some studies reported that the same trend was occured, as general relationship, between extrusion parameters and extrudate properties for the same cases. The extruder used for this study is typical of small, a laboratory type featured in many other studies.

The use of different feed materials and condition further complicates comparisons among studies. The limit of study on cassava extrusion made the result of this study compared with another starchy materials reported by some investigators.

The wide variety of physical appearances of extruded product obtained under the experiment pattern are shown in Figure 1. The effects of process temperature and feed moisture content on product properties and process characteristics are expressed in Figure 2 and 3, respectivelly. Regression coefficients and result of correlation analysis between independent and dependent variables are listed in Table 1 and 2, respectivally. Table 3 illustrated the correlation analysis between extrudate properties.

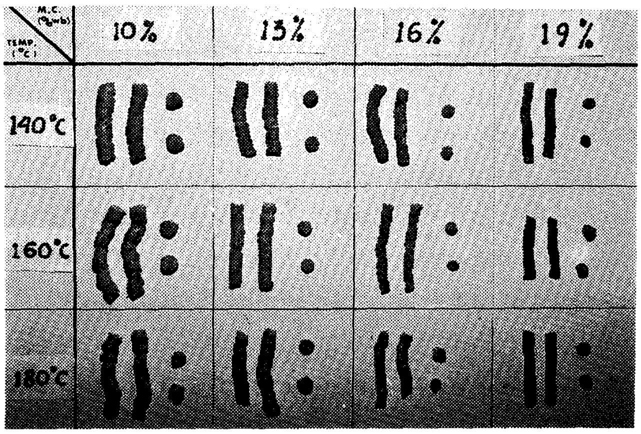

Fig. 1. The effect of process temperature and feed moisture content on physical appearances of product.

Product Properties

The appearances of extrudates are widely different for each levels of process temperature and feed moisture content (Fig. 1). The dark and brown colour of extrudate produced when process temperature increased and feed moisture content decreased. This result was consistent with general term of cooking process, and those over cooking occured if materials with low moisture content cooked on high temperature. The good apppearance of product produced at process temperature of 140° and 160℃ with feed moisture content of 13 and 16 % w.b.

The bulk density increased as the feed moisture content increased for each of the process temperature tested (Fig.2a). Some researchers found a similar relationship between bulk density and feed moisture content and it could be fitted in general pattern. Apparently, at low feed moisture content, heat energy directly increases the product temperature. As the product temperature increase, the materials are more fully cooked and become more plastic. This condition and high flashing moisture in the die caused the product to expand more (Fig.2b), reduced its bulk density (Fig.2c) and product moisture content (Fig.2d).

The statistical analysis (Table 1 and 2) indicated that process temperature was not significant ($P>0.05$) and feed moisture content was significantly correlated for individual correlation, but multiple correlation indicated that both temperature and feed moisture content significantly correlated with bulk density, expansion ratio and product moisture content. The similar effect was observed by Falcone et al[5] for cowpea and sorghum and Chinnaswamy and Hana[2] for corn starches. Surprisingly, those process temperature, in individual term, had no relation with expansion ratio

(P>0.05). It was contrass with result observed by Taranto et al[11] for glandless cottonseed and Chinnaswamy and Hana[2] for corn starches. Some researchers noted that expansion ratio of starchy material had different behaviour depend on variety of starch.

Darnoko and Artz[4] wrote that the water absorption was one of the parameters that had been used to monitor changes that occured in starch as a result of extrusion. The effect of feed moisture content and process temperature on water absorption was illustrated in Fig. 2e. Regression analysis showed that, in individual term, only feed moisture content significantly correlated with water absorption. It was similar with the result observed by Darnoko and Artz[4]. Comparing Fig. 2d with Fig. 2b and can be seen in Table 3, it is apparent that water absorption increases as expansion ratio increases. These relationship are not surprisingly, since the product is more porous it can hold more water.

It is also shown that only feed moisture content effected to the shearing strength of the extrudate (Fig. 2f and Table 1 and 2). Comparing Fing. 2f with previous figures and as shown in Table 3, the shearing strength is positivelly related with product moisture content and bulk density, and negativelly correlated with expansion ratio and water absorption.

Processing Characteristics

As shown in Fig. 3a and with statistically analysis (Table 2), for the same feed rate, product rate did not depend on both feed moisture content and process temperature. The high product rate with good appearence occured

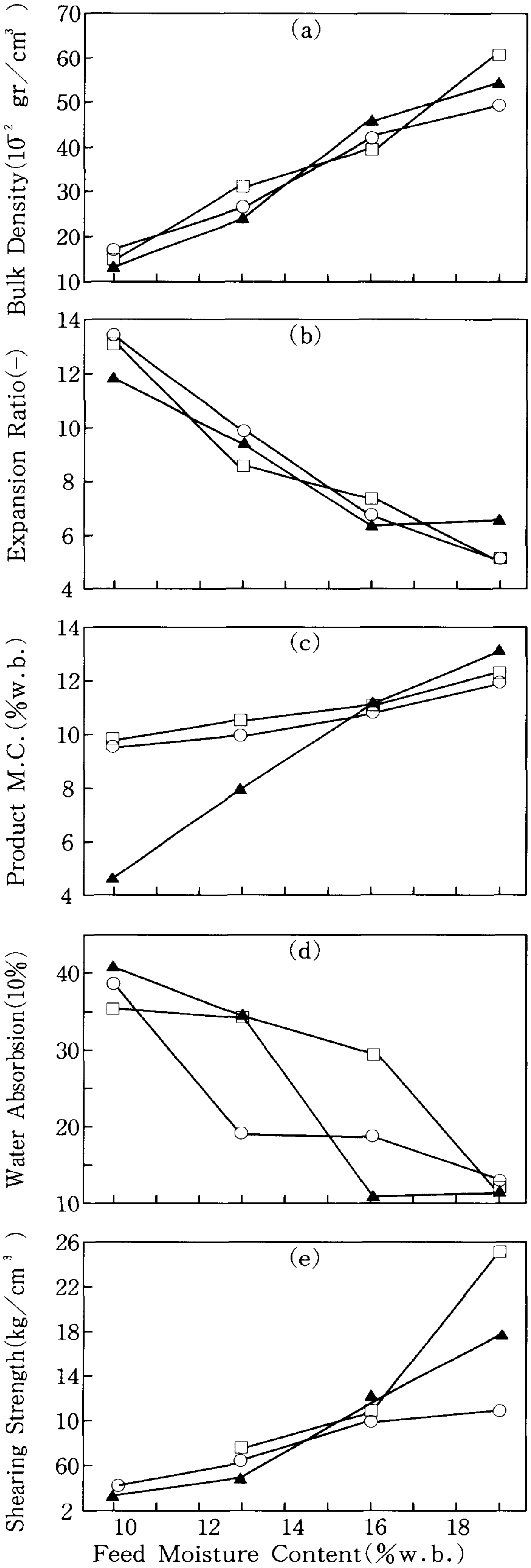

Fig. 2. The effect of process temperature and feed moisture content on product properties.
The process temperature was calculated as the average of second section and die head of barrel temperature
Legend: —□—□— : 140℃ —○—○— : 160℃ —▲—▲— : 180℃

at process temperature of 160℃ for 13% and at140℃ for 16% w.b. of feed moisture content.

Torque was highly significant in correlation with feed moisture content ($P<0.001$), but not consistent on process temperature. The extruder used in this study have limit torque operation of 10000 m-gr. Thus, it is very dangerous to operate the extruder at low feed moisture content. For all level process temperature, safe operation was on 13 and 16 % feed moisture content.

Pressure decreased as feed moisture content increased for each level of proces temperature (Fig. 3c and Table 2). The highest pressure occured at process temperature of 140℃ and the lowest was at 160℃ for each level of feed moisture content.

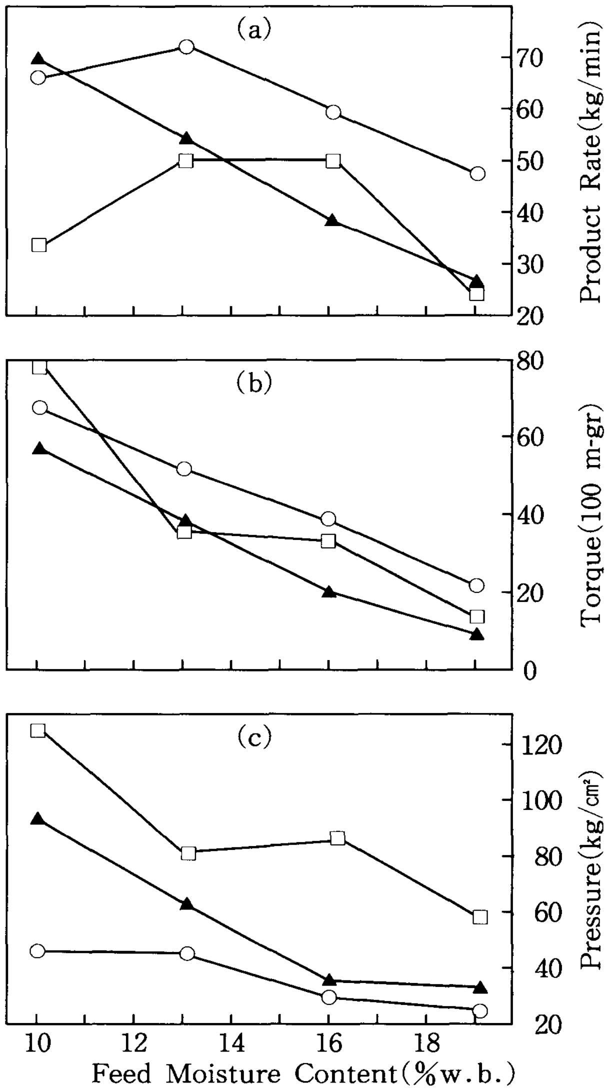

Fig. 3. The effect of process temperature and feed moisture content on processing characteristics.
The process temperature was calculated as average of second section and die head of barrel temperature.
Legend : —□—□— : 140℃ —○—○— : 160℃ —▲—▲— : 180℃

Table 1. The result of regression coefficient

Dependent variables	Constanta	X_1	X_2	R^2
Bulk density	-0.19	-0.00*	0.04***	0.96
Expansion ratio	20.48	0.00*	-0.83***	0.92
Product M.C.	9.40	-0.04*	0.51***	0.72
Water Absorp.	832.54	-0.98*	-29.50***	0.79
Shearing strength	-5.22	-0.06*	1.63***	0.78
Product rate	58.53	0.72*	-2.64**	0.36
Torque	15991.10	-25.27*	-565.27***	0.88
Pressure	264.50	-0.79*	-5.48**	0.57

X_1 : Process temperature, X 2 : Feed moisture content
R^2 : Coefficient of determination
* : not significant ($P>0.05$)
** : significant with $P<0.05$
*** : significant with $P<0.01$

Table 2. Result of correlation coefficient of dependent and indepedent variables

Dependent variables	Process Temperature	Feed moisture content	Multiple (R)
Bulk density	-0.07*	0.98***	0.98**
Expansion ratio	0.00*	-0.96**	0.96**
Product M.C.	-0.31*	0.79**	0.85**
Water absorp.	-0.14*	-0.88***	0.89**
Shearing strength	-0.15*	0.87***	0.88**
Product rate	0.19*	-0.57*	0.60*
Torque	-0.20*	-0.92***	0.94**
Pressure	-0.43*	-0.62*	0.76*

a : not signification (P>0.05)
* : significant with P<0.05
** : significant with P<0.01
*** : highly significant with P<0.001

Table 3. Result of correlation coefficient between extrudate properties.

	Expansion ratio	Product m.c.	Water absorp	Shearing strength	Bulk density
Exp. ratio	—				
Product m.c.	-0.69*	—			
Water absorp.	0.83***	-0.76**	—		
Shearing strength	-0.80**	0.72**	-0.77**	—	
Bulk density	-0.95**	0.82**	-0.88***	0.93***	—

* : significant with P<0.05
** : significant with P<0.01
*** : highly significant with P<0.001

Conclusion

The present investigation has shown that two parameters studied during extrusion process of cassava, i.e. the extrusion process temperature and feed moisture content significantly correlated with extrudate's properties in combination analysis term. On the other hand, the individual analysis indicated that only feed moisture content significantly correlated with all product properties. However, the physical appearance of extrudates clearly showed that both process temperature and feed moisture content produced wide varieties of extrudate. The good appearance produced at process temperature of 140 – 160℃ for feed moisture content of 13 –16 % w.b. The experiment also showed that there were intercorrelation between product properties.

The feed moisture content was critical parameters on operation of the extruder used in this experiment, and combination with process temperature showed highly related to torque and pressure, but no relation with product rate. For all level of process temperature, the safe operation conducted for feed moisture content of 13 -16 % w.b.

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キャッサバの加熱押出し加工特性とその生成物の性質に与える含水量及び温度の影響

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キャッサバは東南アジアあるいは南米などで重要な食料あるいは飼料とされているが、タンパク質含量が低く栄養価は高くない。筆者らはその栄養価を高めるために、加熱押出し加工によって多孔質物質を作りこれを固体発酵させて高タンパク質含量の飼料を製造する技法について報じてきたが、本報ではその加工特性及び生成物の性状に及ぼす加工温度と材料の含水量の影響について検討した。

即ち、キャッサバ粉を10,13,16,及び19各%の含水量に調質し、バレル温度140,160及び180各℃で1軸イクストルーダで加熱押出し、生成物の膨化率、吸水量、外相、剪断強度などの性質と、加工時のトルク、圧力、及び噴出速度を求めて、それらの間に次の関係があることを見出した。

(1)試料の含水量とバレル温度は生成物の性状に有意な関係を持っていたが、主要因は含水量であった。

(2)試料の含水量が13～16%の範囲ではバレル温度140～160℃の時に優れた外観の生成物が得られた。

(3)本実験に用いたイクストルーダでは含水量が制限因子であり、温度は加工時の所要トルクとバレル内圧力には関係しているものの生成速度との関係は見られなかった。

以上を総合してキャッサバのイクストルーダ加工には含水量13～16%の材料を用いるのが適当と判断した。

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