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Effects of Process Variables on the Physical Properties of Taro Extrudate

[1]Budi Nurtama and [2]Jenshinn Lin

[1]Department of Tropical Agriculture and International Cooperation
[2]Department of Food Science,
National Pingtung University of Science and Technology, Pingtung 91201, Taiwan

Abstract: Extrusion technology is known to be a versatile, low cost and very efficient process in food production. However, this state-of-the-art technology is a little bit complicated and needs to be studied further for better understanding and control. The quality of extrusion product (extrudate) can vary considerably depending on extrusion process variables. Taro (*Colocasia esculenta* L. Schott) is one of the most important tuber crops grown in Africa and Asia. The edible corm has higher starch content than either potato or sweet potato. Its flour is considered good for baby food and is recommended for gastric patients. This study investigates the effects of extrusion process variables on the physical properties of taro extrudate. The design of experiment was a factorial design 2x2 consisting of two factors, each with two levels (moisture content of feeding 10% and 13% and extrusion screw speed 30 Hz and 50 Hz). The dried taro was milled and the moisture contents of the powder were adjusted before fed into the collet extruder. After extrusion, the samples of extrudate were collected and the color (measured in *L*, *a* and *b* values), moisture content and density of samples were measured. The data were analyzed using analysis of variance (ANOVA). The results showed that moisture content of feeding significantly affected the *a* value ($p<0.05$), moisture content ($p<0.01$) and density ($p<0.01$) of extrudate. The screw speed only had a significant effect on the *L* value ($p<0.05$). The interaction factor did not affect on these properties except the density ($p<0.05$). Therefore, it can be concluded that moisture content of feeding was the most important factor on taro extrusion.

Key words: Extrusion · Taro · Edible corm · Collet extruder

INTRODUCTION

Commercial extrusion processing of food and feed has been practiced for over 50 years [1]. Extrusion technology has become very popular for many reasons including versatility, low cost, energy efficient, high productivity and environmental concerns. Food industries have been applying extrusion technology to produce various products such as pasta, ready-to-eat cereals, meat analogs, flat bread and puffed snacks. Extrusion is simply a technique used to form shapes by forcing a material through a region of high-temperature and/or pressure and then through a die to form the desired shape [2]. The raw materials, which are developed in the extruder to form the extrudate, play an active role in determining the magnitude of processing variables such as pressure, temperature and motor load [3]. Starchy materials from different kinds of cereals, legumes and tubers are commonly used in extrusion process.

Taro (*Colocasia esculenta* L. Schott) is a member of the Arum Family (*Araceae*). This plant is known with several names, including dasheen, eddoe, cocoyam, or tannia [4, 5]. It is also has different names in different place such as taro tru (Papua New Guinea), dalo (Fiji), gabi (Philippines), keladi (Malaysia), talas (Indonesia) and yù tou (Taiwan). Taro is one of the important tuber crops that widely planted in Africa and Asia. According to FAO [6], in the year of 2007 the production of taro in the world is 11,949,300 metric tonnes (m.t.), Africa: 9,506,170 m.t. and Asia: 2,039,175 m.t. while that for Taiwan is 42,472 m.t [7]. Taro has high starch content and can be considered higher than either potatoes or sweet potatoes [4]. Its flour digestibility is good for baby food and also can be recommended for gastric patients. Taro is an important staple food in some countries. The edible corms are consumed fresh after boiling or baking. It is also processed into a distinct nutty flavor chips. Corms are sliced thinly and fried in hot oil, resulting in a product

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Corresponding Author: Jenshinn Lin, Department of Food Science, National Pingtung University of Science and Technology, Pingtung 91201, Taiwan

similar to potato chips. Taro is processed into flour to make noodles, cake, infant food, pasta and ice cream.

Extrusion technology plays an important role in food production. However, it was only limited information in extrusion of taro. The present study was done to investigate effects of moisture content of feeding and screw speed of extruder on the physical properties of taro-based snack food.

Literature Review: There are many definitions about extrusion. Heldman and Hartel [8] defined extrusion as "forcing a pumpable product through a small opening to shape materials in a designed fashion." Rossen and Miller [9] have offered the practical definition as follows: "Food extrusion is a process in which a food material is forced to flow, under one or more variety of conditions of mixing, heating and shear, through a die which is designed to form and/or puffdry the extrudate." Food extruder is considered a high-temperature short-time bioreactor that transforms a variety of raw ingredients into modified intermediate and finished products [1]. Various operations are involved in extruders including grinding, mixing, homogenizing, cooking, cooling, vacuumizing, shaping, cutting and filling operations [2]. Several different types of extruders are available on the market. According to Riaz [2], collet extruders are high-shear machines with grooved barrels and screws with multiple shallow flights that have been used for making puffed snacks from defatted com grits. The temperature of dry ingredients (12% moisture) is raised rapidly to over 175°C and the resulting mass loses moisture and puffs immediately upon exit through a die to form a crisp, expanded curl or collet. This type of machine initially was characterized by an extremely short screw (length: diameter = 3: 1), but longer L/D (1: 10) machines that rely heavily on friction-induced heat have been developed.

Taro flour can be extruded into noodle by adjustment of dough temperature and moisture content. Mung bean flour or soy protein were added to enrich protein content [10]. Maga *et al.* [11] evaluated the role of extrusion temperature on certain physical properties of taro extrudate. The maximum expansion ratio was found at the extrusion temperature of 120°C which was also effective for gelatinization (the water absorption was more than 500%). Increasing the extrusion temperature resulted in decreasing extrudate breaking strength. According to the results of Onwulata and Konstance [12], extrudate from taro flour mixed with whey products expanded more, but less absorbed water and less soluble than taro alone. The peak viscosities of the blends were lower than taro flour.

In extrusion of corn starch, Thymi *et al.* [13] found that the density, porosity and expansion ratio of the product were depended on the feed moisture content and were not affected by the screw speed.

The textural parameters of ready-to-eat (RTE) corn ball snack, such as maximum force, number of major peaks, energy for compression, Young's modulus and firmness, were shown as a function of moisture content [14]. The maximum force is an indication of the peak resistance offered by corn ball during compression; an increase in moisture content increases maximum force. The number of major peaks showed a decreasing trend with increasing moisture content. It indicated that at a high moisture content, the same snack would not appear to be brittle or crisp. The energy for compression and Young's modulus showed an increasing trend with moisture content. These results indicated that a snack having high moisture content needs more energy to bite and/or chew as its elastic limit increases. A decreasing trend in firmness of corn balls has been observed above a moisture content of 4.5% and marked decrease occurs beyond 7%.

Perez, *et al.* [15] used response surface methodology to study the effects of extrusion conditions on extrudate properties, taking grits moisture (14-18%) and extrusion temperature (155-185°C) as factors. Specific mechanical energy consumption, radial expansion, specific volume and product texture were determined on each extrudate sample and the viscosity of the dispersion from extrudate flour was measured at different solids concentrations. For the maize/soybean mixture, a softer maize endosperm gave a more expanded product than the harder one. Texture scores were directly related with specific volume. The best extrusion conditions to obtain expanded products and precooked flour from an 88/12 maize/soybean mixture were 170°C and 14% moisture.

Pansawat *et al.* [16] studied the effects of extrusion conditions on secondary extrusion variables and physical properties of fish, rice-based snacks. Primary extrusion variables were temperature (125-145 °C), screw speed (150-300 rpm) and feed moisture (19-23 g/100 g db). Response surface methodology was used to study the effects of extrusion conditions on secondary extrusion variables (product temperature, pressure at the die, motor torque, specific mechanical energy (SME) and mean residence time) and physical properties of the extrudates. Change of extrusion conditions, especially, screw speed and feed moisture affected the secondary extrusion parameters and physical properties of extruded rice flour, fish powder and menhaden oil formulation. The highest

SME was observed at medium barrel temperature, high screw speed and low feed moisture. The products with high expansion ratio and low product density, which generally are good characteristics of extruded snack, were produced at medium extrusion temperature, high screw speed and low feed moisture.

MATERIALS AND METHODS

Taro Preparation: Fresh taro were bought and packed in a plastic bag from the local market at Kaohsiung. Taro corms were thoroughly washed with tap water and the skin were peeled manually with a knife. The peeled taro was sliced into small rod-shaped pieces using the fruit and vegetable slicing machine. A closed-type air dryer was used to dry the sliced taro at 45°C for 24 hours.

Extrusion Processing: The dried taro was extruded directly using a collet extruder made by Seng Din Industrial Co. Ltd., Taiwan. The heater temperature was setup at 120°C. The feeding material (the dried taro) was milled into powder (30-40 mesh) and the moisture contents of the powder were adjusted before fed into the extruder. The cutter speed was in the range of 130-180 rpm. Figure 1 shows the processing steps of taro extrusion.

Experimental Design: The experiment was designed using a factorial design 2 x 2 consisting of two factors, each with two levels (moisture content of feeding 10% and 13% and extrusion screw speed 30 Hz and 50 Hz). The extrudate samples from the four treatments were collected after extrusion in sealed plastic bags and kept in refrigerator during waiting for analysis. The statistical program Statistica version 8 was used for data analyzing on Analysis of Variance (ANOVA) and Fisher's Least Significance Difference (LSD) test.

Determination of Moisture Content: Oven drying method was used to determine the moisture contents of extruded taro samples. Each 5 g sample was placed in the Aluminum paper dish that has already dried for 24 hours and then the sample was dried with the oven at 105°C for 24 hours. Three replications were done for each taro sample. The moisture content is calculated as follows:

$$\text{Moisture content}\,(\%) = \frac{W_W - W_d}{W_W} \times 100\%$$

W_w : Weight of wet sample (g)
W_d : Weight of dry sample (g)

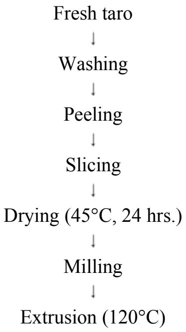

Fig. 1: Flow diagram of taro extrusion

Color Measurement: The colors of extruded taro samples were measured by L, a and b values using HunterLab - Color Quest XE. Those values were recorded two times for each sample and were replicated three times.

Determination of Density: The densities of extruded taro samples were determined with Micromeritics-Multivolume Pycnometer. It used Helium gas and a medium chamber was selected for the samples. Three replications were done for each taro sample.

In each test, the P_1 and P_2 pressures were recorded and then V_s was calculated using this formula:

$$V_S = 36.143 - \frac{20.471}{(P_1/P_2) - 1}$$

The sample was weighed using a balance and the density was calculated as follows:

$$\text{Density (g/cm}^3) = \text{Weight of sample} / V_s$$

RESULTS AND DISCUSSION

Figure 2 shows the product of taro after slicing, drying and extrusion. The changes of color and texture appeared significantly different. From white and soft sliced taro changed slightly into darker and harder dried taro and finally became dark brown, small puff and porous like popcorn.

Table 1, 2 and 3 showed the results of analysis of variance for *L*, *a* and *b* color values, respectively. The extrusion variable of screw speed affected significantly on *L* value while moisture content of feeding had a significance effect on *a* value. No extrusion variables affected the *b* value of the extrudate. LSD test results showed both variables had significant difference effects of their levels at $p < 0.05$ significance level (Table 6 and 7).

Table 1: ANOVA result for *L* value of extrudate

Source	df	SS	MS	F	p
Moisture Content (MC)	1	2.76	2.76	0.437	0.521159
Screw Speed (SS)	1	34.28	34.28	5.434	0.037995
MC*SS	1	0.01	0.01	0.001	0.970451
Error	12	75.70	6.31		
Total	15	112.75			

Table 2: ANOVA results for *a* value of extrudate

Source	df	SS	MS	F	p
Moisture Content (MC)	1	0.8236	0.8236	7.293	0.019289
Screw Speed (SS)	1	0.1388	0.1388	1.229	0.289369
MC*SS	1	0.5148	0.5148	4.559	0.054055
Error	12	1.3551	0.1129		
Total	15	2.8322			

Table 3: ANOVA result for *b* value of extrudate

Source	df	SS	MS	F	p
Moisture Content (MC)	1	0.170	0.170	0.217	0.650013
Screw Speed (SS)	1	3.303	3.303	4.204	0.062832
MC*SS	1	0.037	0.037	0.047	0.831730
Error	12	9.429	0.786		
Total	15	12.940			

Table 4: ANOVA result for moisture content of extrudate

Source	df	SS	MS	F	p
Moisture Content (MC)	1	9.0313	9.0313	267.593	0.000082
Screw Speed (SS)	1	0.0013	0.0013	0.037	0.856765
MC*SS	1	0.0312	0.0312	0.926	0.390415
Error	4	0.1350	0.0338		
Total	7	9.1988			

Table 5: ANOVA result for density of extrudate

Source	df	SS	MS	F	p
Moisture Content (MC)	1	0.005253	0.005253	45.531	0.002515
Screw Speed (SS)	1	0.000325	0.000325	2.818	0.168515
MC*SS	1	0.000903	0.000903	7.828	0.048921
Error	4	0.000461	0.000115		
Total	7	0.006943			

Table 6: LSD Test for Screw Speed on *L* values

Factor	Level	Mean ± Std. Dev. *)
SS	30 Hz	49.49 ± 2.37^a
SS	50 Hz	46.56 ± 2.36^b

*) Values with different letters are significantly different at $p < 0.05$

Table 7: LSD Test for Feed MC on *a* values, MC extrudate and density

		Mean ± Std. Dev. *)		
Factor	Level	*a* value	MC extrudate	Density
MC	10 %	4.92 ± 0.38^a	3.88 ± 0.19^a	0.14 ± 0.01^a
MC	13 %	4.47 ± 0.38^b	6.00 ± 0.14^b	0.20 ± 0.02^b

*) Values with different letters are significantly different at $p < 0.05$

Figure 3 illustrated the color of the extruded taro measured by *L*, *a* and *b* values which were plotted in three dimensional space. The *L* (lightness) axis: 0 (black) to 100 (white), *a* (red-green) axis: positive values are red, negative values are green and 0 is neutral, while *b* (blue-yellow) axis: positive values are yellow, negative values are blue and 0 is neutral. The *L* values of the four extrudates were in the range of 46.17-49.92, the *a* values were 4.20-5.01 and the b values were 8.95-10.07 or in general it could be said that the color was a medium dark that tended to more red and yellow.

The moisture content of feeding has also high significantly affected the moisture content of extrudate (Table 4) and the density of extrudate (Table 5). The interaction of two extrusion variables only showed a significant effect on the density of extrudate. LSD test results in Table 7 supported the significantly different of effects between 10% and 13% moisture content of feeding on moisture content and density of extrudate.

The densities of the four extrudates were in the range of 0.14-0.21 g/cm^3. According to Colonna *et al.* [3], depending on starch composition and heat treatment, bulk densities can be in the range of 0.04-0.38 g/cm^3.

Fig. 2: Sliced (A), dried (B) and extruded (C) taro

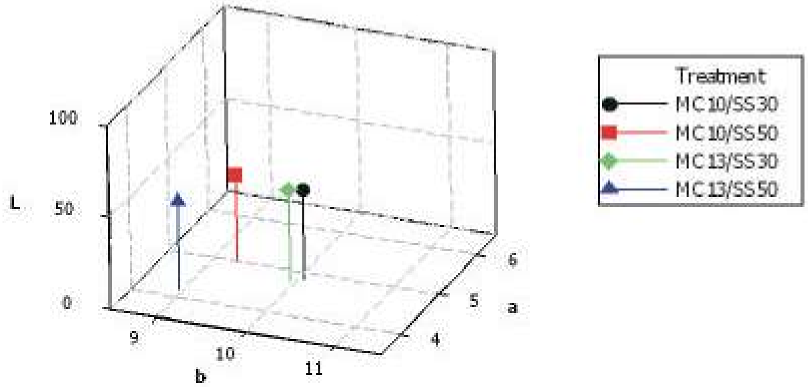

Fig. 3: *L*, *a*, and *b* values of taro extrudate in x-y-z coordinates

For all of the observed physical properties, it could be summarized that the moisture content of feeding was the more important variable comparing with the screw speed variable. This result was similar with other results from different studies [13-16].

CONCLUSIONS

It Can Be Concluded from this Study:

- The moisture content of extrusion feeding significantly affected the color (*a* value), moisture content and density of taro extrudate.
- The screw speed of extruder significantly affected the *L* value of the extrudate color.
- The interaction factor significantly affected the density property.
- Both variables, moisture content of extrusion feeding and screw speed of extruder, were not significantly affected the *b* value of the extrudate color.

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