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Original Article

Development Of Fabricated Laboratory Scale Extruder Machine For The Production Of Rice-Like Grains From Cassava (*Manihot Esculenta Crantz*) Dough

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Abstract - *Developing a laboratory scale extruder machine in producing rice-like grains from cassava dough was done to enhance the efficiency, recovery, and profitability in contrast to manual batch production using a pasta maker. Three screw speeds (40 rpm, 50 rpm, and 60 rpm) were evaluated to determine the optimum performance of the machine. The optimum performance was based on the result of the machine capacity and the physical properties of grains (size, width, shape, color, and hardness).*

The fabricated extruder machine has an efficiency that ranges from 88.38% to 93.86%, with an overall cassava dough recovery of 78.13%. Thus, the efficiency was enhanced by 2.33% to 8.67%, while the overall dough recovery was improved by 160.43% based on the capacity and throughput using the fabricated extruder machine in comparison with 86.37% efficiency and 30% overall recovery of the manual operation using pasta press. The optimum performance of the machine is at 40 rpm screw speed with desirability of 91.7%.

Furthermore, the economic analysis and value engineering of the machine showed that the machine is economically viable with an Internal Rate of Return of 45.87% for a period of 10 years and demonstrated a performance value that was greater than the cost of machine fabrication.

Keywords - *extrusion, single screw extruder, cassava, rice-like grains*

I. INTRODUCTION

Cassava (*Manihot esculenta Crantz*), locally known as *kamoteng kahoy* or *balinghoy*, is one of the major and important crops produced in the Philippines. Based on the data from Philippine Statistics Authority, in the first quarter of 2016, there was an increase of 7.3 percent in the production of cassava, from 541.39 thousand metric tons in 2015 to 580.82 thousand metric tons this year. Major contributors to this production are the regions from Mindanao like ARMM, SOCSKSARGEN, and Northern Mindanao. But this does not mean that the cassava industry in the Philippines is maximized because it has only minimal development support from the government. Thus, problems of cassava as highly perishable or having short shelf-life and lack of postharvest facilities are still prevailing until now. In the Philippines, the current farm gate price for cassava is PhP 5.15/ kg (Philippine Center for Postharvest Development and Mechanization (PHilMech), 2007). Comparing it to the prevailing market price for rice of PhP 45.00/ kg, cassava is more affordable for consumers. Aside from its economic advantage, this root crop is known as a good source of vitamin C, thiamine, riboflavin, and niacin (Food and agriculture organization of the United Nations, 2013).

With this study, the common goal is to secure food with uncompromised food safety and quality. Food security can be achieved by developing engineering technologies to lengthen the shelf life of the crops and have these foods be available to all sorts of consumers. The University of the Philippines – Los Baños, Institute of Human Nutrition and Food (UPLB-IHNF) developed a formulation to address micronutrient malnutrition through the utilization of the root crops like cassava as an alternative staple food. Cassava flour is converted into rice-like grains. However, the current method of production can only produce 100 grams per day (Hurtada, W. A., et al., 2016). Thus, a solution to mechanize the process is needed to enhance the production of rice-like grains. This study has the main goal of addressing the problem of doing manual preparation of rice-like grains through developing a laboratory-scale extruder that will mechanize the process. This study also aims to automate alternative food grain preparation of the country by monitoring the temperature during the process.

This study is pursued with the primary objective of mechanizing the production of rice-like grains by forming extrusion. Specifically, to develop a laboratory-scale extruder machine for rice-like grains from cassava dough, to evaluate the performance of the prototype extruder, and to determine the profitability of the laboratory scale operation.

II. METHODOLOGY

The material used in this study was cassava flour as the main component of the dough. The type of machine fabricated was a single screw-forming extruder (Figure 1). The 38.1mm diameter of the screw was designed based on the previously fabricated extruder of the author and the suitability of the size on a laboratory scale machine. Based on the recommendation of Adekola (2016), channel depth was designed at 9.525mm with a helix angle of 18º with respect to vertical and pitch of 38.1 mm. The design was based on the target capacity of 100 kg/h, motor power of 0.25 hp, and the rheology of the dough (viscosity and density). The machine is made of stainless steel was fabricated in CEAT Machine Shop, UPLB.

Testing of the machine and performance evaluation was done at ABPROD Laboratory, CEAT, UPLB. Performance criteria for the fabricated extruder were size, diameter or width, color, and hardness of the rice-like grains. The performance variables include the constant variables (operating temperature, screw configuration, and feed rate), while the running variable was the screw speed at 40 rpm, 50 rpm, and 60 rpm. Each screw speed was performed at four replicates. The operating temperature of the dough at each run was measured using the LabView Measurement application. Two thermocouples were placed along the screw length. The thermocouples were located 76.2mm from the start of the screw, while the other was located at 177.8mm from the start of the screw. The other end of the thermocouples was connected to NI 9213 16 channel thermocouple module, which is coupled to NI cDAQ-9174 (National Instruments, Hungary). Temperatures were measured every 5 seconds for each run. The testing procedure of the machine is shown in Figure 2.

Figure 1. Actual Design of the Extruder

After the grains were equilibrated from drying, grain size and grain diameter were measured using the digital caliper (General Tools & Instruments, New York USA) with an accuracy of ±0.02mm. There are 12 replicates. For each replicate, 100 grains were measured. From the data, grain shape was calculated as the ratio of the length to its width.

Grain color was measured using Konica Minolta CR-10 Color Reader (Konica Minolta, Inc., Osaka, Japan). For each run, five measurements were taken. Grain hardness, on the other hand, was measured using the Kiya Hardness Tester (Kiya Seisakusho Ltd., Tokyo, Japan). In this test, five measurements were taken for each replicate.

Interpretation and analysis of the data gathered were done using the Design Expert 7 software employing a one-factor response surface design. The single factor to be analyzed was the screw speed (40, 50, and 60 rpm), while the five responses were grain size, grain diameter, grain shape, grain color, and grain hardness. The economic viability and value engineering of the machine were evaluated. Costs and returns analysis, payback period, break-even point, benefit-cost ratio, and internal rate of return were calculated to assess the economics of the extruder machine. Partial budgeting was also included to show the benefits of mechanization as compared to manual operation on an annual basis. Value engineering is calculated to evaluate the performance of the individual parts to their respective costs.

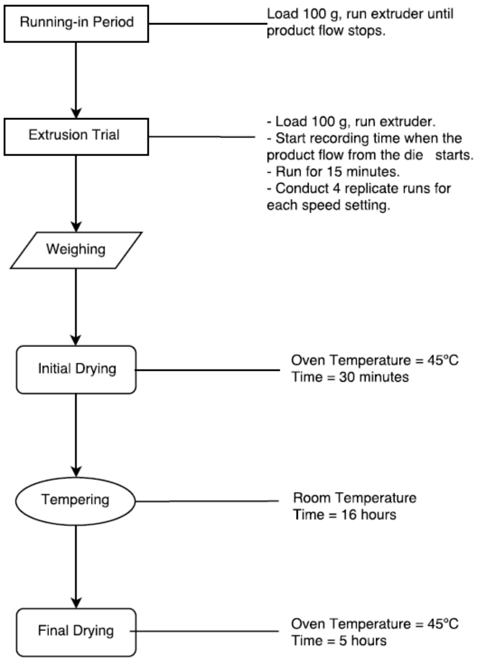

Figure 2. Flowchart for the Machine Testing Procedure

III. RESULTS

A. *Machine Performance*

Machine efficiency was measured in a kilogram of extrudate per kilogram of dough (kg/kg) times 100 (in percentage) tested into the extruder machine. Table I shows the summarized data of the machine efficiency and recovery of the extruder machine.

Data shows that as the screw speed increases, machine efficiency decreases. Higher screw speed means higher pressure drop along the screw (Abdel-Ghany, W.E. et al., 2015). This is due to the increase of pressure-flow that will overcome the increasing drag flow caused by the screw speed. Thus, resulting from a decrease in net extruder flow (Levine and Miller, 2006). A decrease in net extruder flow means that the throughput capacity of the machine decreases because of the mass build-up along the screw going through the die. Thus, slowing down the mass flow rate of the extrudate for a fixed period of time.

Tukey's HSD test shows that the machine efficiency on three screw speeds is not significantly different at a 95% Confidence Interval.

Table I
Performance Evaluation of Extruder

Screw Speed (rpm)	Machine Efficiency (%)		Recovery (%)	
40	93.86 ± 1.19	**a**	77.74 ± 3.47	**ab**
50	91.34 ± 4.50	**ab**	79.44 ± 2.69	**a**
60	88.38 ± 11.14	**abc**	77.19 ± 11.20	**abc**

Values represent the mean ± SD of 4 replicate runs. In a column, means with a common letter are not significantly different by Tukey's HSD test at α = 5%.

Recovery, on the other hand, is the percentage of the number of rice-like grains obtained to the amount of dough fed to the machine. According to the Institute of Human Nutrition and Food (IHNF), UPLB, cassava dough recovery from the pasta maker is 86.37%, while the overall recovery of their manual operation is 30%. Data shows that the cassava dough recovery of the fabricated machine is greater than the recovery of the manual operation. Table I shows that using the fabricated extruder machine, the overall cassava dough recovery has an average of 78.13%. This means that the process was enhanced based on the capacity and throughput using the fabricated extruder machine by 2.33% to 8.67%. Additionally, the overall dough recovery was improved by 160.43%.

B. *The temperature of the Dough along the Screw Length*

Temperature plays an important role in extrusion even in the absence of an external heat source because it is a determinant of viscous dissipation. This means that heating happens because of mechanical dissipation by viscous forces. Figure 3 shows the temperature behavior of the dough at screw speeds of 40 rpm, 50 rpm, and 60 rpm to Point A and Point B. At the screw speed of 40 rpm, the temperature behaviors both at Point A and Point B were at their peak measurements. It has a maximum temperature of 37.43ºC Point A and 44.56ºC for Point B. Thus, the explanation above about the pressure drop increase during the increase in screw speed is verified. The increase in temperature is caused by mechanical dissipation, as well as the pressure accumulation happening at the dead end. That is why Point B is always greater than Point A on all the runs because the pressure is at its highest on the dead end.

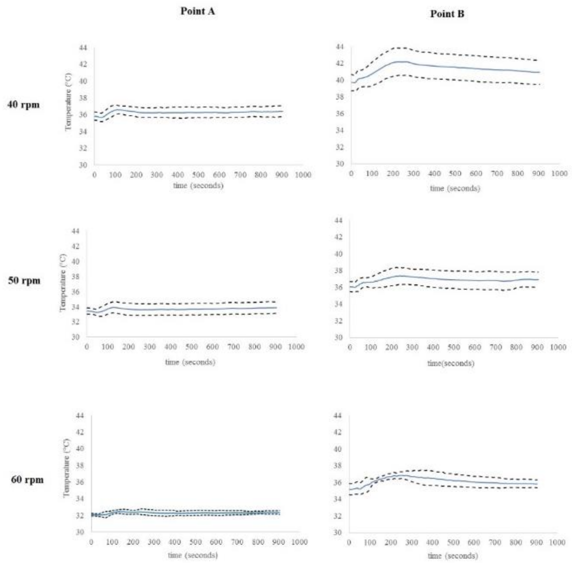

Figure 3. Temperature Behavior of the Dough. The solid line represents the mean of four replicates on each screw speed. Broken lines represent the ±standard deviation of the means.

On the other hand, temperature behavior for 60 rpm recorded the lowest temperature reading. The minimum reading is 31.55ºC for Point A and 34.07ºC for Point B. This temperature reading is logical because as the axial flow velocity of the dough is increased, the temperature on the dough surface is lower. Also, it shows some abrupt fluctuations in the readings because of a high screw speed set. The temperature also changes due to viscous dissipation. Viscous dissipation is primarily affected by the material property. Cassava dough exhibits a property of a pseudoplastic. It means that as the screw speed increases, the shear rate increases. As the shear rate increases, the viscosity decreases. As the viscosity decreases, heat through viscous dissipation also decreases. That is the reason why 40 rpm has the highest temperature reading while 60 rpm has the lowest temperature reading.

C. Physical Properties of the Grains

Physical properties are important indicators for grain quality since form and appearance greatly influence consumer acceptability of the produce. There were five physical properties studied, namely, grain size, grain width, grain shape, grain color, and grain hardness.

Table II
Physical Characteristics and Properties of Extruded Grains

Screw Speed (N)	Size (mm)	Width (mm)	Shape	Hardness
40	11.69 ± 2.16 **a**	2.81 ± 0.08 **a**	4.15 ± 0.76 **ab**	0.30 ± 0.08 **a**
50	11.43 ± 2.01 **ab**	2.69 ± 0.12 **b**	4.25 ± 0.76 **a**	0.11 ± 0.02 **ab**
60	10.84 ± 1.67 **c**	2.65 ± 0.15 **c**	4.10 ± 0.65 **ac**	0.06 ± 0.02 **abc**

Values represent the mean ± SD of 400 replicate extruded grains for size, width, and shape, and 10 replicate samples for hardness. In a column, means with a common letter are not significantly different by Tukey's HSD test at α = 5%.

Grain size is measured through the length of the grain. As observed, as the screw speed is increases, the grain size decreases. The results are acceptable since the motion of the cutter is dependent on the speed of the screw. When the screw speed is increased, the cutting rate also increases. On the other hand, the capacity or the throughput of the machine is not significantly different from each other, as shown in Table 1. Thus, at a constant capacity or output from the die, the size of the grain is shortest for the highest screw speed and longest for the slowest screw speed. Tukey's HSD test at 95% Confidence Interval illustrates that the grain size from 40 rpm has no significance to the grain size from 50 rpm. But the grain size from 60 rpm is significantly different from the grain size out from 40 rpm and 50 rpm screw speeds. Meanwhile, in comparison to the grains from manual operation, the grains produced from the fabricated extruder are more uniform in terms of size. They have a minimum size of 2.46 mm and a maximum size of 12.84 mm, and a standard deviation of 3.01 mm.

Grain width is measured through the diameter of the grain. This is important, especially on the die functionality with respect to the screw speed. It is observed that the screw speed of 40 rpm has the most evenly distributed grain width with the lowest standard deviation. Thus, the highest formability was achieved at the lowest screw speed of 40 rpm. Formability is defined as the compactness of the extrudate as it exits through the die. This difference in grain width versus the screw speed is due to the rheology of the cassava dough. Based on the preliminary studies of the researcher, cassava dough exhibits a shear-thinning property because it is a non-Newtonian fluid, specifically a pseudoplastic. As the velocity is increased, the formability is decreased. Thus, the results of the preliminary studies show that screw speed, as well as the screw pitch and dough rheology, contribute to the formability of the extrudate. Tukey's HSD test at 95% Confidence Interval shown in Table II illustrates that the grain width for the three screw speeds is significantly different. Comparing the grain width measurements from manual operation, the grains produced from the fabricated extruder are also more uniform in terms of width or diameter. This means that the formability of the grains was achieved using the fabricated extruder.

Grain shapes are based on the ratio of the grain length to the grain width in mm/mm. The grain shapes should not be significantly different from each other with respect to the screw speed. Because as the screw speed decreases, the grain size and grain width increase. The deviation might be due to a systematic error during measurement and also due to the property of the extrudate. It can easily be broken upon collection to the container. Comparing the grain shape measurements from manual operation, the grains produced from the extruder are more uniform in terms of shape. Since uniform size and desired formability was not achieved; thus, the shape was also uneven using the pasta maker.

Grain whiteness is another important physical property of grain. Rice consumers in the Philippines preferred white-colored grain; therefore, milling and polishing should be incorporated into the post-harvest process of rice production. The literature stated that there is no fixed standard of whiteness among varieties exists. Yet, for this study, the researcher used the milled Sinandomeng rice variety, as the standard whiteness, on the Konica Minolta CR-10 Color Reader. It has measurements of a = -1.2, b = +16.0, and L = 65.6. At the lowest screw speed, the grains have the most identical color compared to the standard, as shown in Table III. Thus, for the slow speed, the consistency of the dough is more uniform because the flour and the binder were properly mixed in the process.

Grain hardness is an important property for the handling and storage of grains. Typical values for breaking hardness are 4-7 kg, and crushing hardness is 7-10 kg for the rice grain (Juliano, 2007).

Table III
L*- a* - b* Measurement Summary Table

Screw Speed (rpm)	L*	a*	b*
40	57.275 ± 3.023 **a**	4.335 ± 1.627 **abc**	27.810 ± 5.140 **c**
50	52.960 ± 5.50 **b**	5.06 ± 1.183 **ab**	33.135 ± 3.137 **ab**
60	49.125 ± 4.466 **c**	5.245 ± 1.007 **a**	33.660 ± 2.756 **a**

Values represent the mean ± SD of 10 replicate samples. In a column, means with a common letter are not significantly different by Tukey's HSD test at α = 5%.

Table II shows that the highest screw speed has the lowest hardness measurement of 0.06, while the lowest screw speed has the highest measurement of 0.30. This property was affected by the formability and the length of the grain during the extrusion process. As observed in the previous discussions about grain size and grain width, lower speed resulted in higher formability and larger grain size. For these reasons, better hardness measurements will be obtained.

IV. CONCLUSIONS AND DISCUSSIONS

This study is pursued with the primary objective of developing a laboratory-scale extruder machine for rice-like grains from cassava dough. It has the specific objectives of enhancing the capacity and throughput using the fabricated extruder in comparison with manual operation, fabricating an extruder machine with high functionality measured in kilogram per power used (kg/kW), usability for the farmers, and at low cost, and testing the capacity and optimization of the performance of the machine. After the fabrication, testing, and evaluation, data shows that in comparison to manual operation, the cassava dough recovery of the fabricated machine has a better result. According to the Institute of Human Nutrition and Food (IHNF), UPLB, cassava dough recovery from the pasta maker is 86.37%, while the overall recovery of their manual operation is 30%. The fabricated extruder machine has an efficiency of 88.38% - 93.86%, while the overall cassava dough recovery after drying has an average of 78.13%. This means that the process was enhanced based on the capacity and throughput using the fabricated extruder machine by 2.33% to 8.67%. Additionally, the overall dough recovery was improved by 160.43%. After the physical evaluation of the extruded grains, data also showed a positive result on the grain size, grain width or diameter, grain shape, and grain color as compared to the grains produced from manual operation. The grains from the fabricated extruder are more uniform and whiter. In terms of the daily machine capacity, it can be able to produce up to 10 kilograms per day (kg/day) versus the 100 grams per day of the manual operation. Thus, the machine is considered highly functional and more usable. The fabrication costs only PhP 35,000.00. At this cost for an extruder machine, this is more affordable compared to the other single screw extruder machine available on the market. To identify the optimum performance of the machine, the experimental design was run using Design-Expert software. Data shows that the highest desirability for optimum response conditions can be obtained by implementing 40 rpm with desirability of 0.917. The economic viability and value engineering of the machine were also determined. After setting assumptions, it is shown that the machine is economically viable with an Internal Rate of Return of 45.87% for a period of 10 years. The value engineering of the machine also shows a positive result demonstrating that the performance value is greater than the cost of machine fabrication.

The results of the extruder performance matched the goal of the study. The machine can be further improved in a number of aspects. Firstly, the metering and cutting machine can be enhanced. Developing more sophisticated metering and cutting parts of the machine may greatly help the forming and the downstream process of the extruder. Secondly, it is observed that the fabricated machine can be used or applied to a broad range of feed materials, especially dough-based materials, which means that controlling the composition of the feed can affect the outcome of the extrusion process. For further study, it can be recommended that, in making a dough that is intended to produce a rice-like grain, the researcher can explore more options in defining the overall composition of the dough, controlling the binder to be used, and using other agents to enhance the extrudate. Also, instrumentation and process control elements can be integrated into the extruder machine. The researcher can use pressure and temperature transducers in order to monitor the overall behavior of the machine at a given time of operation. Process control and monitoring of the extruder can help the researcher to understand more the phenomena that occurs inside the extruder that can serve as the basis for further improvement and troubleshooting. Lastly, profitability for the pilot-scale production of cassava rice-like grains should be evaluated.

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