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Development of Banana Peduncle Juice Extractor For Ethanol and Fiber Production

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ABSTRACT

Banana (Musa acuminata C.) peduncle is a waste byproduct of commercial banana plantations in the Philippines. Several studies proved the potential of utilizing this agricultural waste as raw material to produce ethanol, and the practical applications of its high-quality fiber. However, mechanical juice extraction was found to limit production as machines used are intended for other commodities, which may not meet functionality requirements for optimum performance. To meet the need, a juice extractor was developed to extract juice from banana peduncle without rupturing its fiber structure for the purpose of ethanol production and fiber recovery. The machine employed a system of crushing rolls as extraction mechanism and was studied under the effects of roll rotational speed (50, 70, and 90 rpm) and crushing load (0.8, 1.2, and 1.6 kN). Optimum performance of the machine was obtained under the optimal setting, 71.4 rpm and 0.8 kN, which resulted to input capacity (307.24 kg/h), juice extraction rate (82.92 kg/h), juice recovery (26.08%), extraction losses (4.21%), extraction efficiency (18.46%), fuel consumption rate (0.391 L/h), fiber extraction rate (54.83 kg/h), and fiber recovery (42.29%). ANOVA reveals that higher roll rotational speed and lower crushing load increases input capacity, juice and fiber extraction rates, and fiber recovery. Lower roll rotational speed and higher crushing load increases juice recovery and extraction efficiency. Higher roll rotational speed increases extraction losses while higher crushing load increases fuel consumption rate. No significant effect was found on the °Brix of extracted juice and on the tensile strength of the fiber. Ethanol analysis showed that the fermented juice contains 10-11% ethanol v/v while fiber tests showed tensile strength values approximate to 300 MPa.

Keywords: *banana peduncle, juice extractor, ethanol, fiber, bioconversion*

INTRODUCTION

The BP Statistical Review (2018) reported that one-third of all energy consumed in 2017 is oil, making it the world's dominant fuel. Aditiya et al. (2016) cited that 60% of worldwide oil consumption is attributed to the use of petroleum in the transportation sector. Balat (2011) previously projected that the global proved crude oil reserve will not be sufficient to match the increasing number of transportation vehicles by 2030. On the other hand, previous audits revealed that motorized vehicles contribute to more than 70% of global carbon monoxide emissions and 19% of global carbon dioxide emissions (Goldemberg, 2008). These issues on energy security and environmental detriment have led to a move towards renewable energy sources to partly replace fossil-derived fuels (Adekunle et al., 2016). Among other renewables, bioethanol is recognized as an important alternative fuel because it is a near carbon-neutral renewable bio-based resource (Kang et al., 2014). It contributes to about 60% of production growth of liquid biofuels in the transportation sector in 2017 (BP Statistical Review 2018). Despite this slight increase, worldwide production is still well below the average for the past 10 years. Pazmiño-Hernandez et al. (2017) concluded that the land requirements set by IEA for crops dedicated to energy generation cannot practically supply the growing demand and recommended to assess alternative biomass resources that are considered wastes, including by-products of agricultural production. It was pointed out further that processing of bioethanol from sugar and starch-based materials competes with the growing demand for human food (Talebnia et al., 2010) and that feedstock of bioethanol fermentation would be better if they are from nonfood sources such as agricultural wastes or lignocellulosic materials (Vohra et al., 2014).

Banana peduncle (*Musa acuminata* C.) is a waste byproduct of commercial banana plantations in the Philippines. It comprises about 13% by weight of harvested banana cluster and provides all the sugars for the banana fruit (Pazmiño-Hernandez et al., 2017). It is generated at roughly 2.3 MT every year and is either thrown as waste or turned into compost (BAR, 2013). While naturally biodegradable, this organic residue, when left to decompose in open landfills, emits gaseous pollutants that are harmful to the environment. Processing of this agricultural waste into value added products can solve problems on waste management, deter harmful environmental impact, and generate potential income for locales surrounding these plantations. Pazmiño-Hernandez et al. (2017) mentioned that banana peduncle may be an accessible resource for local production of bioethanol instead of being piled up as voluminous waste in banana packaging houses. The same conclusion was previously made by Ingale et al. (2014), citing that banana peduncle is a suitable sugar containing biomass which can be efficiently converted by microbes into bioethanol. Kusmiyati et al. (2018), further alluded that banana peduncle is a potential bioethanol feedstock because of its acceptable content of cellulose and lignin.

Aside from the promise of ethanol, chemical and mechanical properties of the banana peduncle fiber were found to be superior to other natural fibers (Bhatnagar et al., 2015). Some researchers have investigated the potential application of banana peduncle fiber from paper and eco-bags to reinforcement in polypropylene floor protection panels and polymer composite materials (Fagbemigun et al., 2016; Vinoth et al., 2018; Ramesh et al., 2014). Utilizing this natural organic residue to obtain an applicable, low cost, ecological and far less polluting product is a very useful practice that generates many advantages toward sustainable development.

To compliment with the various potentials of utilizing banana peduncle, more specifically on biofuel production and fiber recovery, appropriate mechanization is necessary. Extraction of peduncle juice without rupturing its fiber structure has become a major challenge in its processing. Extraction mills that employ cutting mechanism reduce its natural fibers to fine residues that would end up having little to no further economic benefits. On the other end, fiber decorticators are well-designed solely for fiber extraction and may be disadvantaged due to the thick rind and rather compact flesh of the peduncles. Crushing rolls used in sugarcane mills show promise in solving the problem, however, issues on design appropriateness, product rheology, and load and functionality requirements have to be considered. The aim of this study was to develop a banana peduncle juice extractor that can extract as much juice possible without rupturing the cellulosic fibers for the purpose of producing ethanol and recovery of fiber as co-product.

METHODOLOGY

Design Criteria

In the development of banana peduncle juice extractor, pertinent design criteria were considered. These include: (1) functionality, that is, the machine was designed to extract as much juice possible from banana peduncle without rupturing the cellulosic fibers – crushing rolls was selected as extraction mechanism; (2) materials and manufacturability, that is, the machine was fabricated using locally available materials and simple fabrication technologies; (3) safety and ease of operation, that is, sizes and dimensions of machine parts were well within capacity to overcome static and dynamic loading, all moving or rotating parts were enclosed or covered, and the machine was built with mounting provisions and/or adjustable operator platform to accommodate varying operator heights and arm span, as well as to provide allowance for female operators; and lastly (4) cost, that is, selection of materials was intended to minimize the overall cost of the machine without compromising material integrity.

Description of the Machine

The schematic drawing of the banana peduncle juice extractor is shown in Figure 1. It was composed of a main crushing roll which measures 400 mm by 400 mm and three smaller feeder rolls which measure 200 mm by 400 mm. One of the three feeder rolls was aligned horizontally with the main crushing roll at 330 mm effective center to center distance. The 30 mm space provided between the two rolls was based on the diameter of the lower section of banana peduncles and was intended to accommodate the feeding of samples into the juice extraction system through the hopper. The feeder roll was spring loaded, which makes the roll move back and forth along a horizontal confinement, causing an increase in the

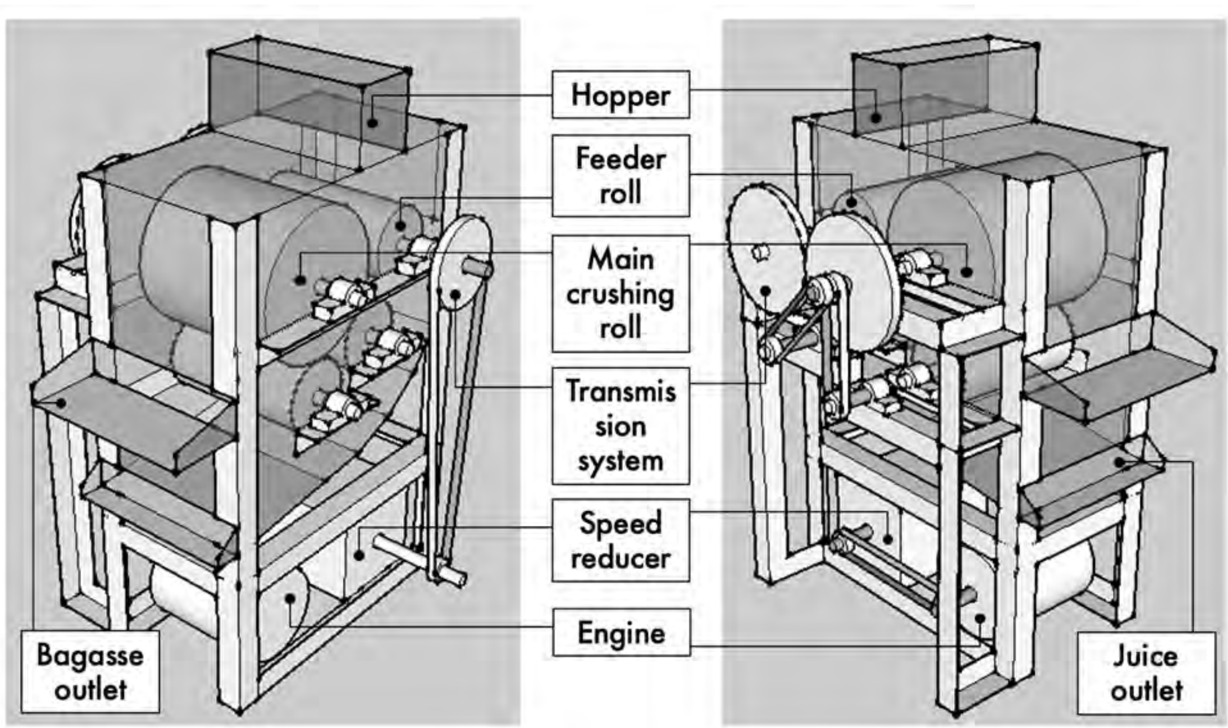

Figure 1. Schematic drawing of the juice extractor with major parts and components labeled accordingly

effective spacing to more than 30 mm and facilitate entry of bigger peduncle samples.

The second feeder roll was positioned at 45° below the main crushing roll with 320 mm effective center to center distance. The absence of a spring load mechanism made the roll offer greater pressure to effect deformation to the banana peduncles and further the crushing or juice extraction. The last feeder roll was positioned vertically below the main crushing roll with 310 mm center to center distance. The 10 mm space between the faces of the rollers was where the final extraction happens. The narrow spacing was enough only to let the banana peduncle bagasse (juice extracted) without complete shear of the fiber layers. The rolls were made of schedule 40 GI pipe filled with reinforced concrete for extra weight and wrapped with G20 SS304 stainless steel sheet to resist corrosion from contact with the banana peduncle juice.

The transmission system was composed of a reducer gearbox and a series of chains and sprockets. A 9-hp gasoline engine, equipped with a 75 mm pulley, drove an intermediate pulley with which sizes were varied from 100, 125 and 165 mm to effect variation in the rotational speed of the rolls. The intermediate pulley was then connected to the 4 inches drive pulley of a 1:10 reducer gearbox, which significantly reduced the speed of rotation. The other end of the gearbox was equipped with a 14-teeth no. 60 sprocket which was connected via chain to a 35-teeth no. 60 sprocket attached to the main crushing roll, further decreasing the speed of rotation. The main crushing roll was equipped with a second sprocket, which was connected to the three feeder rolls by chain. The four rolls rotate at the same rotational speed.

The main frame was made of 5 mm by 50 mm equal -leg angled bar. The rolls were mounted to the main frame by 50 mm diameter C1045 cold finish round bar, supported by 50 mm pillow block bearing. The hopper, exit chutes, and side covers were made of G16 GI sheet painted for corrosion protection and aesthetics.

Design Experiment

The performance of the machine was evaluated under two experimental variables: the roll rotational speed and the crushing load. The roll rotational speed was varied in three levels: 50, 70, and 90 rpm. Gbabo et. al. (2013) cited that speed recommendation for rolls in sugarcane juice extraction systems is between 60-80 rpm. Since banana peduncles have higher rupture force than sugarcane (Oriola et al. 2017) it was decided to extend speeds both lower and higher than that

Figure 1. Banana peduncle juice extractor, uncovered (left) and main crushing and feeder rolls with transmission system (right)

recommended for sugarcane. This was done by integrating a replaceable pulley in between the engine and the gearbox. Pulley sizes of 100, 125 and 165 mm were used to achieve the required roll rotational speed.

The crushing load was varied in three levels: 0.8, 1.2, and 1.6 kN. This was done by making use of the spring-loaded feeder roll. When the feeder roll is in original position, the spring is also in its original potential state. When the feeder roll is moved back or displaced horizontally by the exertion of rheological forces of the peduncles, the spring is stretched depending on the magnitude of rheological forces acting opposite the compressive action of the spring. By stretching the spring to a certain length, Hooke's law governs that stretching it further would require a greater amount of force. Using this principle, the other end of the spring was connected to an adjustable bar, which can be repositioned at 2 cm and 4 cm off the initial position. This stretches the spring and the magnitude of the compressive force that tends to restore the spring back to its original length was added to the weight of the feeder roll. This limits the possible displacement of the feeder roll caused by the exertion of rheological forces of the peduncles.

Each combination of factors was tested in 3 trials in a 2-factor, 3-level full factorial experiment, resulting to 27 test runs. The order of run is presented in Table 1.

Table 1. Randomized run order of the combination of factors

Run	Factor 1 A: Roll Rotational Speed (kph)	Factor 2 B: Crushing Load (kN)
1	50	0.8
2	70	1.2
3	70	1.6
4	50	1.2
5	50	1.2
6	70	0.8
7	90	1.2
8	50	1.6
9	70	1.6
10	50	1.6
11	90	0.8
12	70	1.2
13	90	0.8
14	70	1.6
15	90	1.6
16	90	1.2
17	90	1.6
18	70	0.8
19	90	1.2
20	90	0.8
21	70	1.2
22	50	0.8
23	90	1.6
24	50	1.2
25	50	0.8
26	70	0.8
27	50	1.6

Performance Evaluation

The machine was first subjected to preliminary tests to see if functionality requirements were met. The final testing was based on PAES 235:2008 (Multi-crop Juice Extractor – Method of Test) and PAES 229:2005 (Fiber Decorticator – Method of Test). The performance of the machine was evaluated in terms of the following machine performance index: input capacity, juice extraction rate, juice recovery, extraction losses, extraction efficiency, ˚Brix of extracted juice, fuel consumption, fiber extraction rate, fiber recovery, and fiber tensile strength. In each trial, roughly 40-kg sample of freshly-harvested, whole banana peduncles of the cavendish variety (*Musa acuminata* C.), was fed into the machine piece by piece. Each trial was timed, and the machine performance index were determined using the equations presented in Table 2.

The ˚Brix of the extracted juice was measured using a portable refractometer, which was calibrated using distilled water (Type II) per ASTM requirement. ˚Brix of the extracted juice was included as response variable since Bhagatt (2004) cited that juice extraction systems account for 35% total sugar losses. Gbabo, et. al. (2013), also explained that sugar recovery is proportional to the volume of juice extracted.

After the juice extraction, the peduncles were soak-

Table 2. Performance index measured during machine performance evaluation

No.	Performance Index	Equation	Legend
1	Input Capacity	$C_i = \frac{W_i}{T_i}$	C_i is the input capacity in kg/h, W_i is the weight of banana peduncle sample fed into the machine in kg, and T_i is the time it took from feeding the sample into the machine until it leaves the exit chute in hours.
2	Juice Extraction Rate	$E_r = \frac{W_f}{T_i}$	E_r is the extraction rate in kg/h and W_f is the weight of juice collected from the juice outlet in kg.
3	Juice Recovery	$R_o = \frac{W_f}{W_i} \times 100$	R_o is the juice recovery in percent.
4	Extraction Losses	$E_l = \frac{W_L}{W_{TJ}} \times 100$	E_l is the extraction losses in percent, W_L is the weight of juice collected other than from the juice outlet, W_{TJ} is the total weight of extracted juice ($W_f + W_L$).
5	Extraction Efficiency	$Eff = \frac{W_{TJ}}{PJC} \times 100$	Eff is the extraction efficiency in percent, PJC is the potential juice content or the initial moisture content in percent.
6	Fiber Extraction Rate	$F_r = \frac{W_d}{T_i}$	F_r is the fiber extraction rate in kg/h, W_d is the dry weight of clean and undamaged fiber extracted from banana peduncle sample after it has been extracted with juice, soaked in water, dried, and cleaned.
7	Fiber Recovery	$F_o = \frac{W_d}{W_i} \times 100$	F_o is the fiber recovery in percent.
8	Fuel Consumption	$FC = \frac{F_i}{T_i}$	FC is the rate of fuel consumption in L/h, F_i is the volume of fuel consumed in L.

washed with water daily for 14 days. This was done to dissolve the natural binders holding the fibers together and to detach or separate the rind from the fibers. The water used in soaking was replaced every day to effectively dissolve the natural binders and to prevent discoloration of the fiber strands. After the water soaking treatment, the wet fibers were weighed and sun-dried until no changes in weight was observed. The dried fibers were then cleaned and combed, removing the remaining dirt and impurities and the damaged or broken fibers.

The tensile strength of the fiber was determined by subjecting a dried sample of banana fiber to a universal testing machine. The test samples were submitted to the Mindanao Engineering Center of Central Mindanao University. The test was conducted using ASTM D3822-01 – Standard Test Method for Tensile Properties of Single Textile Fibers.

Figure 3. Fiber recovery from banana peduncle after crushing, soaking, and drying

Fermentation and Ethanol Analysis

The extracted juice from the 3 trials of each treatment was combined. The ˚Brix of the resulting combined juice was measured. The juice was placed in an open metal container over fire in a LPG burner stove to evaporate some of its moisture. The goal was to increase the sugar concentration of the extracted juice to a level that is conducive for microorganisms to thrive, reproduce and carry out metabolic processes of converting sugars into alcohol compounds and carbon dioxide. After 1 hour of boiling, the juice was left to cool down to room temperature before its ˚Brix was measured. The resulting concentrated juice from each treatment was placed in a fermenter jar. Five grams of yeast (*Saccharomyces cerevisiae*) was inoculated as catalyst for fermentation. Ackland (2015) reasoned that, five grams of yeast contains enough population to reproduce and carry out fermentation. It was cited that the critical tipping point is 5 grams of yeast for 5 gallons of mash. The fermenter jars were sealed tightly to ensure anaerobic process and were stored at room temperature for two weeks. After 2 weeks, a 100 mL sample from each fermenter jar was submitted to the UPLB-BioTech for ethanol analysis.

Figure 4. Fermentation of the extracted juice

RESULTS AND DISCUSSIONS

The two-factor interaction plot of the machine performance indices is presented in Figure 5. It can be observed that input capacity decreases with increasing crushing load for all levels of roll rotational speed. This decrease is attributed to the fact that the main crushing roll is more constrained at higher crushing load, restricting easy entry, which slows down the rate at which the peduncle samples pass through the rolls. On the other hand, higher input capacity is obtained by the machine at higher roll rotational speed. This is expected since it would take shorter time for the peduncles to pass through the rolls at higher roll rotational speed. It can be seen from Table 2 that the highest input capacity of 416.09 kg/h is achieved by the combination of 90 rpm and 0.8 kN while the lowest input capacity of 171.70 kg/h is obtained from 50 rpm and 1.6 kN combination. This difference shows that input capacity varies significantly with respect to the roll rotational speed $\{f(1) = 387.68, p<0.0001\}$ and the crushing load $\{f(1) = 169.66, p<0.0001\}$.

The two-factor interaction plot shows that juice extraction rate tends to decrease with increasing crushing load. Engaging the spring to increase crushing load restricts easy entry of the peduncle samples. While the amount of extracted juice increases with increasing crushing load, it also takes longer time for peduncle samples to pass through the rolls. This can result to decreasing rate of extraction. On the other hand, juice extraction rate increases as the roll rotational speed increases. It should be noted that at faster rotational speed, the time it takes for the peduncle samples to pass through the rolls is shorter. This can result to increasing rate of extraction. It is indicated in Table 2 that the highest juice extraction rate of 89.29 kg/h is achieved by the combination of 90 rpm and 0.8 kN while the lowest juice extraction rate of 62.83 kg/h is obtained from 50 rpm and 1.6 kN combination. This difference shows that juice extraction rate varies significantly with respect to the roll rotational speed $\{f(1) = 16.62, p<0.001\}$ and the crushing load $\{f(1) = 16.17, p<0.001\}$.

The two-factor interaction plot shows that juice recovery tends to increase with increasing crushing load. The pressure experienced by the peduncle samples at higher crushing load results to more crushing resulting to more juice extracted. On the other hand, lower juice recovery is obtained by the machine at higher roll rotational speed. With increased roll speed, the peduncles pass through the

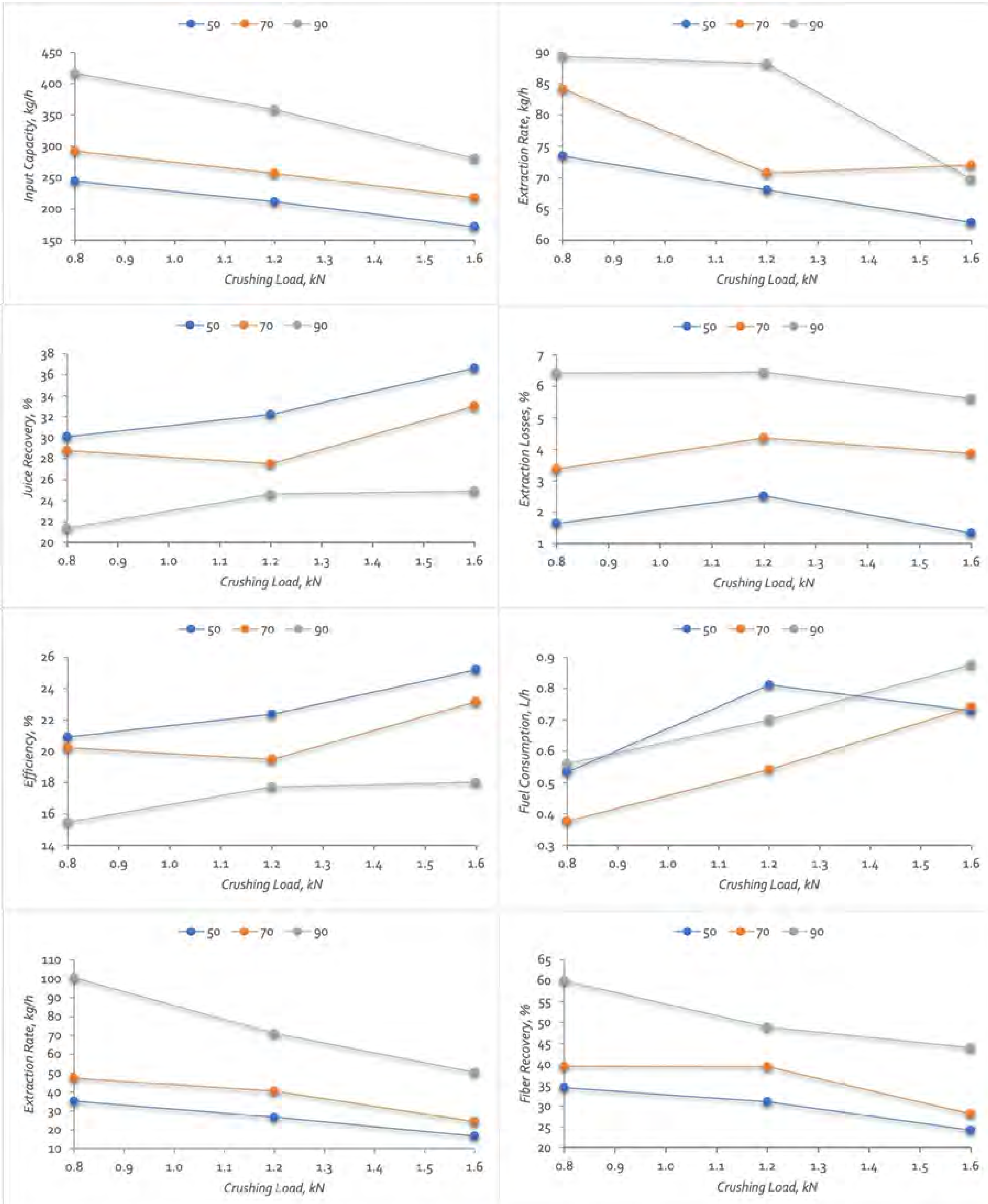

Figure 5. Two-factor interaction plot of machine performance indices

rolls quickly and leave the extraction chamber with juice extract still dripping from the sample. This uncollected juice may be considered as unextracted juice, resulting to lower juice recovery. It is indicated in Table 2 that the highest juice recovery of 36.63% is achieved by the combination of 50 rpm and 1.6 kN while the lowest juice recovery of 21.38% is obtained from 90 rpm and 0.8 kN combination. This difference shows that juice recovery varies significantly with respect to the roll rotational speed {f(1) = 71.85, p<0.0001}, and the crushing load {f(1) = 18.78, p<0.001}.

The two-factor interaction plot shows that extraction losses vary differently as crushing load increases. It tends to increase from 0.8 kN to 1.2 kN load and then decrease from 1.2 kN to 1.6 kN load. On the other hand, higher extraction losses are obtained by the machine at higher roll rotational speed. This can be attributed to the increase in centrifugal force deflecting more juice away from the rolls. It is indicated in Table 2 that the highest extraction losses of 6.45% is achieved by the combination of 90 rpm and 1.2 kN while the lowest extraction losses of 1.34% is obtained from 50 rpm and 1.6 kN combination. Analysis of variance shows that extraction losses varies significantly with respect to the roll rotational speed {f(1) = 55.87, p<0.0001} but no significant effect is observed from the crushing load. It is demonstrated by a significantly small value of the test statistic {f(1) = 0.126}, indicating a great probability that any observable change in effect of crushing load may be due to chance.

The two-factor interaction plot shows that efficiency tends to increase with increasing crushing load. It can be expected since efficiency is a function of the amount of juice extracted. At higher crushing load, peduncle samples are more likely to be successfully crushed resulting to more juice extracted. On the other hand, lower efficiency is obtained by the machine at higher roll rotational speed. It can be recalled that as roll rotational speed increases, juice recovery decreases while extraction losses increase. These translate to lower extraction efficiency. It can be seen from Table 2 that the highest extraction efficiency of 25.20% is achieved by the combination of 50 rpm and 1.6 kN while the lowest extraction efficiency of 15.48% is obtained from 90 rpm and 0.8 kN combination. This difference shows that extraction efficiency varies significantly with respect to the roll rotational speed {f(1) = 45.70, p<0.0001} and the crushing load {f(1) = 14.71, p<0.001}.

°Brix is a measure of the refractive index of a solution against dissolved sucrose (Considine et al., 2014) and is measured using a hand-held analogue refractometer. It is shown in Table 2 that the highest °Brix of 2.93 is achieved by the combination of 90 rpm and 1.2 kN while the lowest °Brix of 2.67 is obtained from 50 rpm and 1.6 kN combination. The distribution of the °Brix data points does not qualify for parametric analysis. This is to say that no variation exists between the group means and the overall mean. As the case, the analysis recommends the use of descriptive statistics or the use of the overall mean as predictor of the °Brix value.

The two-factor interaction plot shows that the rate of fuel consumption tends to increase with increasing crushing load, except for 50 rpm where it shows a drop in magnitude at 1.6 kN. Fuel consumption is subject to the power requirement of the engine. When the engine has to overcome bigger loads, it compensates by consuming more fuel. This may be the reason why fuel consumption is high at higher crushing load. On the other hand, fuel consumption tends to be lower at 70 rpm than at 50 rpm and 90 rpm. The rate of fuel consumption is directly proportional to the amount of fuel consumed and inversely proportional to the time it takes for its consumption. Any slight change in either of these parameters can bring about a significantly different value in the rate of fuel consumption. It is observed from Table 2 that the highest rate of fuel consumption of 0.88 L/h is achieved by the combination of 90 rpm and 1.6 kN. This may be because more fuel is consumed at overcoming the load of 1.6 kN and the fact that running at 90 rpm results to a shorter time of operation. Meanwhile, the lowest rate of fuel consumption of 0.38 L/h is obtained from 70 rpm and 0.8 kN combination. Analysis of variance shows that the rate of fuel consumption varies significantly with respect to the crushing load {f(1) = 96.59, p<0.0001}.

The interaction plot shows that fiber extraction rate tends to decrease with increasing crushing load. Fiber extraction rate is a function of the amount of clean extracted fiber – that is the fiber less all impurities and broken/damaged fiber strands. This explains the decrease in the rate of fiber extraction at higher crushing load. On the other hand, higher fiber extraction rate is obtained by the machine at higher roll rotational speed. Like the juice extraction rate, fiber extraction rate is also a function of time. It should be noted that at faster rotational speed, the time it takes for the peduncle samples to pass through the rolls is shorter. This can result to increasing rate of fiber extraction. It can be seen from Table 2 that the highest fiber extraction rate of 100.57 kg/h is achieved by the combination of 90 rpm and 0.8 kN while the lowest fiber extraction rate of 16.66 kg/h is obtained from 50 rpm and 1.6 kN combination. This difference shows that fiber extraction rate varies significantly with respect to the roll rotational speed {f(1) = 354.26, $p<0.0001$} and the crushing load {f(1) = 4211.17, $p<0.0001$}.

The two-factor interaction plot shows that fiber recovery tends to decrease with increasing crushing load. This decreasing trend may be attributed to the increased crushing pressure experienced by the peduncle samples at higher crushing load. The high crushing pressure may have resulted to unnecessary rupture of the cellulosic fibrils or the fiber structure of the peduncles. On the other hand, higher fiber recovery is obtained by the machine at higher roll rotational speed. This may be due to the immediate exit of the samples from the crushing rolls at higher roll rotational speed. It is indicated in Table 2 that the highest fiber recovery of 59.94% is achieved by the combination of 90 rpm and 0.8 kN while the lowest fiber recovery of 24.28% is obtained from 50 rpm and 1.6 kN combination. This difference shows that fiber recovery varies significantly with respect to the roll rotational speed {f(1) = 165.16, $p<0.0001$} and the crushing load {f(1) = 58.15, $p<0.0001$}.

Fiber tensile strength is equivalent to the maximum load that a single strand banana fiber can support without fracture when being stretched, divided by its original cross-sectional area. It was directly measured in a universal testing machine using ASTM D3822-01 – Standard Test Method for Tensile Properties of Single Textile Fibers. It is shown in Table 2 that the highest fiber tensile strength of 334.5 MPa was achieved by the combination of 50 rpm and 0.8 kN while the lowest fiber recovery of 286.7 MPa was obtained from 90 rpm and 1.6 kN combination. Analysis of variance reveals that the factors have no significant effect to the fiber tensile strength.

Table 4 shows the constraints for the optimization of individual response characteristics. It is desired that the machine maximizes the input capacity, juice extraction rate, juice recovery, extraction efficiency, fiber extraction rate, and fiber recovery while the opposite is true for extraction losses and fuel consumption. °Brix and fiber tensile strength were not included in the optimization since the two parameters do not vary statistically with respect to the factors.

The degree of importance for changing relative priorities to achieve the established goals were also assigned to each performance index. Both factors were assigned a default value of 3, which is a medium setting, to give equal importance to each of

Table 4. Constraints for optimization

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Roll Speed	is in range	50	90	1	1	3
B:Crushing Load	is in range	0.8	1.6	1	1	3
Input Capacity	maximize	163.80	454.98	0.1	10	2
Juice Extraction Rate	maximize	60.83	105.78	0.1	10	3
Juice Recovery	maximize	20.00	37.37	0.1	10	4
Extraction Losses	minimize	0.67	8.82	10	0.1	2
Extraction Efficiency	maximize	14.07	26.44	0.1	10	5
Fuel Consumption	minimize	0.328	0.924	10	0.1	1
Fiber Extraction Rate	maximize	15.00	104.64	0.1	10	3
Fiber Recovery	maximize	22.15	62.19	0.1	10	4

the factors. Extraction efficiency was assigned the highest importance of 5, extraction recovery for both juice and fiber was assigned the importance of 4, extraction rate for both juice and fiber was assigned the importance of 3, input capacity and extraction losses were assigned the importance of 2, and lastly, fuel consumption was assigned the lowest importance of 1.

The optimization presented in Table 5 yields eleven solutions based on a surface response methodology – optimal analysis for multiple responses performed using Design Expert 13 (Trial Version). The optimal setting for multiple responses is found to be the combination of 71.378 RPM and 0.8 kN. This setting has a desirability of 92.3%, which is similar to nine other solutions presented. However, since this is a multiple response optimization based on desirability function, it selects the most desirable responses relative to the individual responses under specified constraints. The optimal setting yields the input capacity of 307.242 kg/h, juice extraction rate of 82.916 kg/h, juice recovery of 26.084%, extraction losses of 4.206%, extraction efficiency of 18.461%, fuel consumption of 0.391 L/h, fiber extraction rate of 54.834 kg/h, and fiber recovery of 42.288%. Results of optimization, however, are not validated and rather depend only on the reliability of the full factorial experiment. Nonetheless, validation tests may be carried out to determine the variability of the actual performance from the predicted values. Table 6 shows the result of the ethanol analysis. The first two columns show the combination of the factors, roll rotational speed and crushing load. The third column is the volume of fermented juice while the percent ethanol content is shown in the fourth column. The mean is indicated plus/minus the standard deviation. The percent potential ethanol content of the slurry samples is within the range of 10.26% to 11.25% v/v. This means that on average, a 100 mL of slurry sample contains 10.72 mL of ethanol. Analysis of variance reveals that no significant difference was found in the percent ethanol content of the fermented juice from the juice extracted under the different factor combinations. This shows that alcohol conversion is proportional to the amount of sugar in the fermented juice. Since there is no significant difference in the °Brix of the extracted juice and provided that all other factors (yeast, temperature, time) are the same, it is expected that no significant difference can be observed in the percent ethanol content.

Table 5. Constraints for optimization

No.	Roll Speed	Crushing Load	Input Capacity	Juice Extraction Rate	Juice Recovery	Extraction Losses	Extraction Efficiency	Fuel Consumption	Fiber Extraction Rate	Fiber Recovery	Desirability
1	**71.378**	**0.800**	**307.242**	**82.916**	**26.084**	**4.206**	**18.461**	**0.391**	**54.834**	**42.288**	**0.923** **Selected**
2	71.206	0.800	306.466	82.855	26.124	4.187	18.486	0.391	54.547	42.179	0.923
3	71.540	0.800	307.975	82.974	26.046	4.224	18.438	0.391	55.107	42.390	0.923
4	71.040	0.800	305.696	82.791	26.164	4.169	18.510	0.391	54.261	42.073	0.923
5	71.791	0.800	309.110	83.062	25.988	4.251	18.402	0.391	55.529	42.550	0.923
6	70.753	0.800	304.410	82.687	26.232	4.138	18.552	0.391	53.786	41.895	0.923
7	71.995	0.800	310.013	83.129	25.943	4.273	18.374	0.391	55.865	42.678	0.923
8	71.590	0.806	307.655	82.891	26.069	4.228	18.454	0.394	54.972	42.372	0.923
9	72.178	0.800	310.893	83.201	25.898	4.293	18.346	0.391	56.195	42.800	0.923
10	70.997	0.805	305.040	82.689	26.204	4.163	18.537	0.394	54.005	42.004	0.922
11	66.999	0.800	288.619	81.351	27.106	3.732	19.090	0.398	48.094	39.751	0.922

Table 6. Percent ethanol content of the fermented slurry

Roll Speed, RPM	Crushing Load, kN	Fermented Slurry, L	% Ethanol v/v
50	0.8	11.95	11.08 ± 0.17
50	1.2	12.30	10.78 ± 0.07
50	1.6	15.60	10.68 ± 0.06
70	0.8	10.20	10.37 ± 0.11
70	1.2	9.80	10.77 ± 0.24
70	1.6	12.90	10.83 ± 0.11
90	0.8	6.15	10.70 ± 0.23
90	1.2	8.50	10.75 ± 0.07
90	1.6	8.75	10.50 ± 0.18

CONCLUSION

In conclusion, the banana peduncle juice extractor developed extracts juice without significant damage to the cellulosic fibers. The mechanism of crushing banana peduncles in a system of rolls was found to be significantly affected by roll rotational speed and crushing load. Higher roll rotational speed and lower crushing load increases the input capacity, the juice and fiber extraction rates, and the fiber recovery. Lower roll rotational speed and higher crushing load increases the juice recovery and extraction efficiency. Higher roll rotational speed increases extraction losses while higher crushing load increases the rate of fuel consumption. The optimal setting of 71.4 rpm and 0.8 kN yields the most desirable responses. Roll rotational speed and crushing load do not affect the ˚Brix of extracted juice and the percent ethanol content of the fermented juice, as well as the tensile strength of the fiber recovered. This means that the overall performance of the machine affects only the quantity and not the quality of extracted juice and recovered fiber.

RECOMMENDATIONS

At the rate in which ethanol and quality fiber can be produced, it has the potential to kickstart local communities to generate income, help address the waste disposal problem of banana plantation companies, contribute to the national mandate of increasing biofuels production, and support the global campaign of reducing our dependence to environmentally harmful fossil fuels.

Nonetheless, the following recommendations may be carefully considered for future studies:

1. Incorporate guide vanes and/or side guard within the rolls chamber to increase input capacity without the crushed peduncles entangling on the sides of the rolls, which increase friction when left unchecked.
2. Compare different kinematics of crushing roll systems and determine optimum roll diameter that can reduce the time of stay of peduncle within the extraction chamber and/or equip the rolls with horizontal grooves to increase friction between the rolls and the peduncles and prevent the peduncles from sliding into the side of the rolls.
3. Experiment on varying the rotational speed of rolls and determine optimum speed ratios between the main crushing roll and the feeder rolls that maximizes the juice extraction without significant damage to the fiber structure
4. Use prime movers with higher power rating and/or efficiency like diesel engine or electric motor to minimize fuel/power consumption.
5. Use transmission systems with higher efficiency like gears to maximize transmission of power.
6. Experiment on peduncles of other banana varieties to expand the applicability and serviceability of the machine.
7. Explore other mechanisms like mills or grinders to increase juice recovery and extraction efficiency. While this mechanism is destructive, the mill residue can be processed into briquettes, which may be another renewable fuel source.

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