Effects of moisture content and blade cutting speed on the chopping and size distribution of sugarcane leaves for the production of fuel biomass

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Abstract: The objective of this study was to determine the effects of moisture content and blade cutting speed on the chopping and size distribution of sugarcane leaves. The experiments were conducted using 4 different moisture content percentages of 19.74%, 30.97%, 44.52% and 50.12% w.b. and at the blade cutting speeds of 380, 630 and 880 rpm. The results revealed that moisture content and blade cutting speed significantly affected working capacity, weight and geometric mean particle length of the sugarcane leaves, and the results were statistically significant with confidence levels of 95%. The interaction of the two factors had a significant effect on the working capacity but did not affect the percent weight and geometric mean particle length of the sugarcane leaves. Working capacity, percent weight and geometric mean particle length all decreased when the cutting speed was increased and the moisture content decreased. This resulted in an increase in the distribution of "small size" leaves. At the blade cutting speed of 880 rpm and moisture content of 19.74% w.b., the percent weight was 98.54% and geometric mean particle length was 9.18 mm. Size distribution of leaves {(<10) (10-20) (20-30)} mm in length had a total size distribution of 86.67%. The distribution of particles less than 10 mm in length was the highest at 48.57%, followed by the distribution of particles 10-20 mm and 20-30 mm in length, recorded at 24.52% and 13.57%, respectively.

Keywords: sugarcane leaves, chopper, size distribution, fuel biomass

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1 Introduction

Sugarcane (*saccharum officinarum,* belonging to the *Poaceae or Gramineae* family) is cultivated in over 200 countries in both the tropics and sub-tropics. Almost 180 million metric tons of sugar from sugarcane is produced per year. Thailand is the fourth largest producer after Brazil, China, and India and is the second largest sugar exporter after Brazil (FAO, 2018). Thailand has a total sugarcane plantation area of about 1.94 million hectares, with a yield of 67.63 tons / hectare, and a total production of 130.97 million metric tons per year; this is divided into fresh sugarcane for crushing (about 50.94 million metric tons) and burnt sugarcane (about 80.03 million metric tons) (OCSB, 2018). The sugarcane that is harvested consists of sugarcane tops (8%), fresh leaves (15%), sugarcane stems (70%) and dry leaves (7%); the remaining non-

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sugar product is called “sugarcane trash” (Ashfaq et al., 2015). The amount of sugarcane leaves and shoots depend on the species and maintenance (De Landel et al., 2013). Approximately one-third of the total sugarcane, or about 60 percent of leaves and sugarcane tops, comprising 18 million metric tons per year, is often burnt, which causes pollution and environmental damage (Jenjariyakosoln et al., 2013). These types of biomass, such as bagasse, can be recycled as alternative energy to be used in the sugar production industry, as supplementary fuel in a combined cycle powerplant or as fuel in biomass powerplants. Leaves and the tops of sugarcane at a dry-30% moisture content w.b. have energy values in the range of 12.0 to 18.3 MJ kg^{-1} (Smithers, 2014), and can be used to produce electricity for 1,647 MW. Some types of agricultural waste cannot be used straight away as they need to be modified to be suitable for use. In the material preparation process before energy production, there is a necessity to reduce material size due to the low density and high humidity (13.5% – 70% w.b.) of sugarcane leaves and tops, specifically, due to the fact that it causes transportation and storage problems (Hassuani et al., 2005). Moreover, the length of material causes problems regarding fuel conversion efficiency, incomplete burning and heat transfer efficiency (Ghaly et al., 2013).

Chopping is an important part of the production process that reduces material size so as to increase surface area between particles and reduce friction of material flow rate (Jezerska et al., 2016). Particles with a wide distribution will provide various material characteristics that could make it more difficult to create briquettes compared to using particles with a close distribution or better homogeneity. Therefore, the distribution of particles is an important factor in the briquette-making process (Nunes et al., 2016). The report of Sun and Cheng (2002) stated that after chopping, the size of the material should be 10-30 mm and after hitting, it should be 0.2-2 mm in length. Naimi et al. (2006) suggested that the ideal material size for the production of pellets is less than 3.2 mm; for briquettes production, 6-8 mm; and ethanol production, 1-6 mm. Jorapur and Rajvanshi (1997) studied the mixture of sugarcane leaves (10-100 mm in size) and bagasse (less than 50 mm in size) as fuel in a gasification system. Kurt (2006) used sugarcane leaves and tops, measuring 10-50 mm, to generate heat and energy and found increased efficiency. Therefore, material size is important for utilization or product transformation, including product design. Choosing an appropriate chopper unit (or chopping machine) can help achieve suitable and consistent material size while reducing energy consumption in the biomass preparation process.

In relation to the above information about the factors that affect chopping and the distribution of material after chopping, a study by Ghaly et al. (2013) reported that increasing cutting speed caused straw length to be reduced and created a high percentage of small material, while other variables remained unchanged (Abdallah et al., 2011). Moisture content also significantly affected the size of material. The higher the moisture content of the materials, the thinner the material would be. While material with particles of a smaller size requires more energy to reduce the size (Hernández and Boulanger, 1997; Kratky and Jirout, 2011). Chopping speed and moisture content of materials could affect the performance of a chopping machine and the size of the chopped material for use as fuel. Therefore, the objective of this study was to study the effects of moisture content and blade cutting speed on the chopping and size distribution of sugarcane leaves for the production of fuel biomass. The results of this study can be used as guidelines for choosing the optimal size of chopped sugarcane leaves for fuel production.

2 Materials and methods

2.1 Sample preparation

The sugarcane leaves used in this study are Khon Kaen 3 cultivar grown in Khon Kaen province in the north-eastern region of Thailand (16°25'50"N / 102°37'0"E). This is the most popular cultivar among farmers in the region. The sugarcane harvesting season runs annually from December through May. The sugarcane structure consists of fresh leaves, dry leaves and tops residues before harvesting. Fresh leaves are green and yellow, while dry leaves are brown. The tops are part of the stem between the topmost tip and the last stalk-node (Canilha et al., 2012). Dry leaves will gradually degrade as they age, eventually becoming mulch. The leaves sample used in this study was comprised of leaves from 12-month-old sugarcane harvested by laborers (Figure 1). In harvesting, the farmers cut off and discarded the fresh leaves and the tops, while the stalks were tied together (15-20 stems) and transported to the sugar factory. This experiment used fresh leaves and tops in order to obtain data with different moisture content in each sample group. Samples were divided into four groups, consisted of group 1: freshly harvested sugarcane leaves; while group 2, 3 and 4 were sun-dried leaves (daytime temperature between 32°C -37°C, relative humidity between 55%-65%). The results showed that the moisture content percentages of the sugarcane leaves were 50.12%, 44.52%, 30.97% and 19.74% w.b., respectively. The average moisture content of sugarcane leaves was measured. Samples were weighed at 30 g and oven-dried at 105°C for 24 hours and then weighed again (ASAE, 2006). Moisture content of sugarcane leaves was calculated using the following Equation 1:

$$MC\ (\%w.b.) = \frac{(w_w - w_d)}{w_w} \times 100 \qquad (1)$$

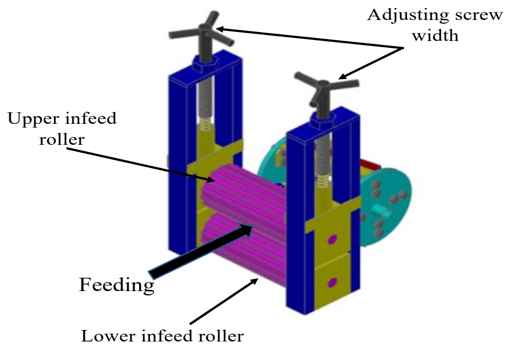
where MC is the moisture content, wet basis (%), w_w is the initial mass of sample (g); w_d is the final mass of dry sample (g).

Figure 1 Sugarcane Khon Kaen 3 cultivar being harvested by laborers

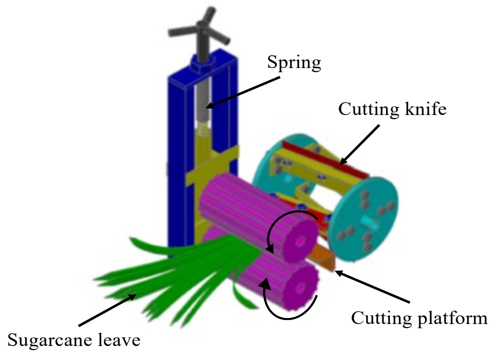
Figure 2 The prototype dump chopper unit developed for chopping sugarcane leaves

2.2 Test equipment

This study used a dump chopper unit developed for chopping sugarcane leaves (Figure 2) belonging to the Postharvest Technology Innovation Center at Khon Kaen University. This dump chopper unit utilizes the following components: infeed roller, adjusting screw width, chopper head, cutting knife and cutting platform.



(a)



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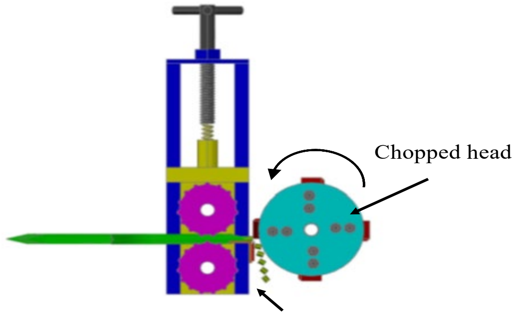

(c)

Figure 3 Working principle of sugarcane leaf chopping unit (a) material feeding position,(b) pulling material into the chopping unit, and (c) cutting characteristics

The working principle of the dump chopper unit starts with the upper and lower infeed rollers having a diameter of 10 centimeters and 22.5 centimeters respectively, both rotating in opposite directions at the same speed (The size ratio between the infeed rollers and chopper head is 1:4). The distance between the upper and lower roller can be adjusted by screws. The feed rollers pull the sugarcane leaves into the chopper head, which has a diameter of 16 cm (measured from the tip of the blade). The chopper head holds 4 blades positioned at an incline of 10 degrees to the chopper shaft. The chopper head securely holds 4 blades at an angle of 10 degrees to the chopper shaft. The chopper head causes the blade to spin, and it is swung round to cut the sugarcane leaves that are fed in, using the shearing chop principle to cut platform. The chopped sugar cane leaves are broken into pieces and then fall down through the exit, as shown in Figure 3.

2.3 Test methods

The variables in this study were: (1) blade cutting speed at three levels; 380, 630 and 880 rpm (3.18, 5.28 and 7.38 m s^{-1}), and (2) moisture content at four levels; 19.74%, 30.97%, 44.52% and 50.12% w.b. Other factors to note was the cutting blade, which had four blades, and the input rate, which was set at 200 kg h^{-1}. The engine prime mover used in this study obtained from tractor connect with power take off. Each of the working conditions was tested accordingly. Chopped sugarcane leaves were weighted. Working capacity was recorded. Chopped leaves were sorted into different sizes using sieves. The materials that were collected in each sieve were weighed and the length of the leaves were measured using a Vernier Caliper. The indicators in this study were:

2.3.1 Working Capacity (kg h^{-1})

It is the weight of the product per set operation time (h). This can be calculated using Equation 2:

$$C_{wc} = \frac{W_p}{T_o} \quad (2)$$

where, C_{wc} is the working capacity (kg h^{-1}); W_P is the weight of product (kg); T_O is the time of operation (h)

2.3.2 Percent Weight (%)

It is ratio of the weight of chopped material to the weight of material before being chopped, as shown in Equation 3:

$$W_{pw} = \frac{(W_i - W_{uc})}{W_i} \times 100 \quad (3)$$

where, W_{PW} is the percent weight (%); W_{uc} is the weight of uncut materials (kg); W_i is the weight of input materials (kg)

2.3.3 Geometric mean particle length (mm)

The particle size of the chopped sugarcane leaves was determined according to ASAE standard S424.1 DEC01 (ASAE, 2003) for chopping forage materials. The samples of chopped sugarcane leaves were placed into the top screen of the Ro-Tap sieve shaker. The sieve sizes used in the experiment were numbered 1, 2, 3, 4 and 5 (nominal openings of 19, 12.7, 6.3, 3.96 and 1.17 mm, respectively) using the sieve set as shown in Table 1 for sifting the chopped material. After sieving, the mass retained in each sieve was weighed. Sieve analysis was repeated four times for each sample of chopped leaves. The geometric mean particle lengths (x_{gs}) of the samples were calculated according to ASAE Standard S424.1 (Wilcox et al., 1970; Lisowski et al., 2018). This can be calculated using Equation 4:

$$x_{gs} = log^{-1}[\sum(m_i \log x_{si})/\sum m_i] \quad (4)$$

where, x_{gs} is the geometric mean particle length(mm); m_i is the mass of the material left in the *i*-th sieve(g); and x_{si} is the geometric mean particle length in the *i*-th sieve determined from the Equation 5 below (mm):

$$x_{si} = \sqrt{x_i x_{i-1}} \quad (5)$$

where, x_i is the holes diagonal of *i*-th sieve(mm) and $x_{(i-1)}$ is the diagonal of sieve hole which is above the *i*-th sieve(mm).

Table 1 Dimension of square sieve used for measuring the length of chopped materials.

Sieve	Nominal opening (mm)	Diagonal (mm)	Sieve thickness (mm)	Sieve size (%)
1	19.00	29.60	12.70	45
2	12.70	18.00	6.90	33
3	6.30	8.98	4.80	33
4	3.96	5.61	3.10	39
5	1.17	1.65	0.64	41.5
tray	-	-	-	-

2.3.4 Size distribution (%)

Data obtained from measuring the length of chopped leaves that remained in the sieve of 6 parts, 100 samples of each part. There was a total of 7,200 samples. The distribution of lengths of the chopped leaves were (<10), (10-20), (20-30), (30-40), (40-50) and (>50) mm, respectively. The distribution of the leaves can be grouped for appropriate use.

2.4 Experimental design and statistical analysis

This study was a 3×4 factorial analysis. Each treatment had 4 replicates. Data were analyzed using a two-way variance analysis (ANOVA) in SPSS software (IBM Crop. Released, 2019). Mean values were compared using least-significant difference (LSD) analysis at the significance level of 0.05

3 Results and discussion

The analysis of variance of the data indicated that the effects of the moisture content (A) and blade cutting speed (B) had significant effects on the working capacity, percent weight and geometric mean particle length of the sugarcane leaves. The interaction effect of moisture content and blade cutting speed (AB) had significant effects on the working capacity but the effect on the percent weight and geometric mean particle length was not statistically significant (p>0.05) (Table 2). The details of each indicator are explained as follows:

Table 2 Analysis of variance on the effects of moisture and blade cutting speed

Source	Dependent Variable	Df	Mean Square	F-value	p-value
Moisture content (A)	Working capacity	3	1114.143	179740.807	0.000
	Percent weight	3	34.964	24.715	0.000
	Geometric mean of particle length	3	9.559	209.403	0.000
Blade cutting speed (B)	Working capacity	2	0.542	87.416	0.000
	Percent weight	2	13.968	9.873	0.000
	Geometric mean of particle length	2	7.059	154.652	0.000
AB	Working capacity	6	0.055	8.820	0.000
	Percent weight	6	0.957	0.676	0.670
	Geometric mean of particle length	6	0.032	0.693	0.657
Error	Working capacity	36	0.006		
	Percent weight	36	1.415		
	Geometric mean of particle length	36	0.046		

3.1 Working capacity

The mean values of the working capacity on the chopping of sugarcane leaves at different moisture contents and blade cutting speed are compared. The average working capacities were significantly different (p<0.05). The working capacity of the chopping of sugarcane leaves decreased when moisture content was increased; and, the working capacity of the chopping of sugarcane leaves increased when the blade cutting speed was increased (Table 3). The average values for the working capacity varied from 92.97 to 71.52, 93.04 to 71.91 and 93.09 to 72.10 kg h^{-1}, by increasing the moisture content from 19.74% to 50.12% w.b., and blade cutting speed at 380, 630 and 880 rpm, respectively. This showed that the working capacity at the lowest moisture content was approximately 1.3 times higher than that of the highest moisture content.

Table 3 Effects of moisture content and blade cutting speed on the working capacity of the chopping of sugarcane leaves

Independent variable	Blade cutting speed, rpm		
Moisture content, % w.b.	380	630	880
	Working capacity, kg h^{-1}		
19.74	92.97^{a}_{B}	93.04^{a}_{AB}	93.09^{a}_{A}
30.97	84.72^{b}_{B}	84.85^{b}_{A}	84.95^{b}_{A}
44.52	74.83^{c}_{C}	75.03^{c}_{B}	75.35^{c}_{A}
50.12	71.52^{d}_{C}	71.91^{d}_{B}	72.10^{d}_{A}

Note: The same letter in Column (Lowercase letter), Row (Capital letter) indicates non-significant difference at LSD test (α=0.05)

Figure 4 shows that as moisture content increased from 19.74% to 50.12% w.b., the working capacity continuously decreased at all blade cutting speeds. And as the blade cutting speed was increased from 380 to 880 rpm with a moisture content of 19.74%, 30.97%, 44.52% and 50.12% w.b., the working capacity tended to increase slightly. When looking at the blade cutting speed from 380 to 880 rpm, the moisture content of 19.74% w.b. had the highest working capacity of all other tested moisture contents. Because as fresh leaves, which contained numerous heavy fiber bundles and fully structured, developmentally mature, moisture-rich mesophyll cells, exhibited a significantly higher resistance to failure. Similar results were also reported by Mou et al. (2013) for leaf sheath of sugarcane. The cutting speed increased, sugarcane leaves were chopped in larger quantities in the same amount of time, which caused the increasing of working capacity. The maximum working capacity was 93.09 kg h^{-1} with a blade cutting speed of 880 rpm and moisture content of 19.74% w.b. Similar results were also obtained by Adgidzi (2007), who reported the average working capacity of dry materials was 24.00 kg h^{-1} and fresh materials was 15.60 kg h^{-1}. Furthermore, Ajav and Yinusa (2015) stated that moisture content significantly affected the working capacity of a machine. This is because when materials are chopped at a high speed, the centrifugal force of the blade creates wind that causes dry material to be blown out of the chamber, whereas this is more difficult when materials have a high moisture content.

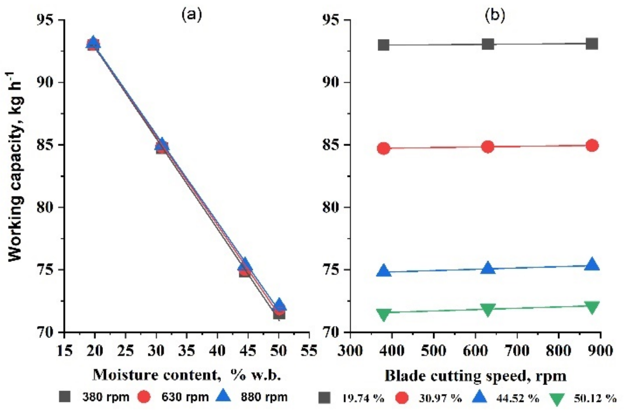

Figure 4 Working capacity, with (a) effect of moisture content and (b) effect of blade cutting speed.

3.2 Percent weight

A comparison of the mean values of the percent weight of chopped sugarcane leaves at different moisture contents and blade cutting speeds are presented in Table 4. It is evident from Table 4 that as the moisture content of the sugarcane leaves increased, the percent weight of chopped sugarcane leaves decreased, with increasing moisture content of sugarcane leaves from 19.74% to 50.12% w.b. the mean value of their percent weight decreased by a factor of 1.04 (from 97.01% to 92.92 %). The average values for the percent weight were found to be 92.92%, 94.62%, 95.50% and 97.01% for moisture contents of 50.12%, 44.52%, 30.97% and 19.74% w.b., respectively.

The test results showing the difference between the effects of moisture content at the level of 50.12% and 19.74% w.b. with all other levels were significant for the percent weight at a 5% probability level, while there was no significant difference between the effect of moisture contents of 30.97% and 44.52% w.b. (Table 4). The percent weight of chopped sugarcane leaves increased in line with the increased blade cutting speed (Table 4), showing a positive correlation. The average values for the percent weight were found to be 94.17%, 94.87% and 96.02% at blade cutting speeds of 380, 630 and 880 rpm, respectively. The difference between the effects of the blade cutting speed at the level of 880 rpm with all other levels was significant for the percent weight at a 5% probability level, while there was no significant difference between the effect of blade cutting speeds at 380 and 630 rpm (p<0.05).

Table 4 Comparison of percent weight and geometric mean of particle length in relation to the interaction effect between moisture content and blade cutting speed

Independent variable		Dependent Variable	
		Percent weight (%)	Geometric mean of particle length (mm.)
Moisture content, % w.b.	19.74	97.01a	9.91d
	30.97	95.50b	10.65c
	44.52	94.62b	11.48b
	50.12	92.92c	11.92a
Blade cutting speed, rpm	380	94.17b	11.51a
	630	94.87b	11.22b
	880	96.02a	10.24c

Note: The same letter indicates non-significant difference at LSD test (α=0.05)

Figure 5 shows that as moisture content increased from 19.74% to 50.12 % w.b., the percent weight tended to decrease at all blade cutting speeds. As the cutting speed increased from 380 to 880 rpm, percent weight increased as well. Similar results were also reported by Khope and Modak (2013) for forage cutter. At the blade cutting speed of 880 rpm and moisture content of 19.74% w.b., the percent weight was higher than all other tested levels. This is because the sugarcane leaves with a low moisture content were dry and fragile. Therefore, a higher quantity could be chopped compared to those with a high moisture content, of which the leaf structure had strongly attached fibers. The maximum percent weight was 98.54% at the blade cutting speed of 880 rpm and moisture content of 19.74% w.b.. The minimum percent weight was 92.28% at the blade cutting speed of 380 rpm and moisture content of 50.12% w.b.. Similar results were also obtained by Adgidzi (2007) who reported that percent weight of wet materials and dry materials was 86% and 92% respectively for forage cutter.

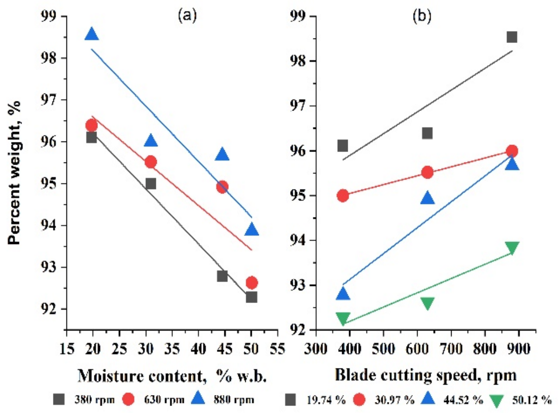

Figure 5 Percent weight, with (a) effect of moisture content and (b) effect of blade cutting speed.

3.3 Geometric mean of particle length

Results revealed that the geometric mean particle length of sugarcane leaves after chopping also decreased when moisture content decreased; likewise, it decreased with increased blade cutting speed (Table 4). The average geometric mean particle length of sugarcane leaves after chopping varied from 11.92 to 9.91 mm when the moisture content changed from its lowest value to its lowest amount in this study (Table 4). According to the results, the geometric mean particle length was at its lowest point with a statistically significant difference (p<0.05) for the three lowest moisture contents of 19.74%, 30.97% and 44.52% w.b., with a mean value of 10.68 mm. This is compared with a mean value of 11.92 mm for the other moisture content (50.12% w.b.). The average values for the geometric mean particle length were found to be 11.51, 11.22 and 10.24 mm at the blade cutting speeds of 380 630 and 880 rpm, respectively. The geometric mean particle length at the blade cutting speed of 380 rpm was statistically different from the blade cutting speeds of 630 and 880 rpm (p<0.05).

Figure 6 shows that as moisture content increased from 19.74% to 50.12% w.b., the geometric mean particle length tended to increase at all blade cutting speeds. As the blade cutting speed increased from 380 to 880 rpm, the geometric mean particle length tended to decrease. The geometric mean particle length at the moisture content of 19.74% w.b. was shorter than lengths at other tested moisture contents. This is because the sugarcane leaves with a low moisture content were dry and fragile, therefore, they were more prone to tearing than those with a high moisture content, of which the leaf structure had strongly attached fibers. After sorting and measuring the geometric mean particle lengths, the lengths of the leaves with a low moisture content were shorter than those with a high moisture content. The maximum geometric mean particle length was 12.47 mm at a blade cutting speed of 380 rpm and moisture content of 50.12% w.b. Similar results were also reported by Ajav and Yinusa (2015), who found that the average length of the leaves was shorter according to the reduction of moisture content.

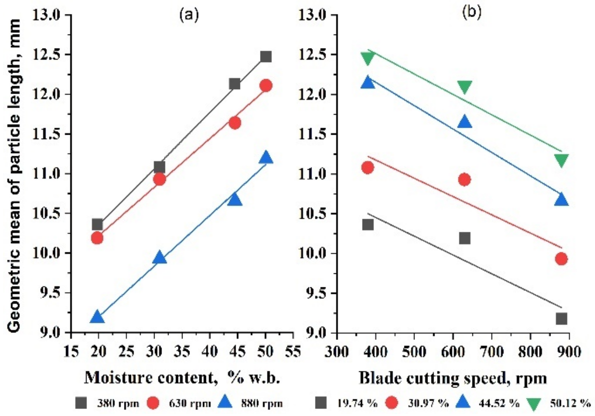

Figure 6 Geometric mean of particle length, with (a) effect of moisture content and (b) effect of blade cutting speed.

3.4 Size distribution

The results of chopped sugarcane leaf size distribution show the length of sugarcane leaf size distributed as follows: (<10) (10-20) (20-30) (30-40) (40-50) and (> 50) mm, respectively. The distribution of life sizes were grouped into two groups: leaves with the length of {(<10), (10-20) and (20-30)} mm as "small size", and leaves with the length of {(30-40), (40-50) and (> 50)} mm as "large size". The theoretical length of chopped sugarcane leaf particles 19.64 mm. Figure 6 shows how different cutting speeds change the leaf size distribution. It revealed that when the cutting speed increased, the percentage of "small size" leaves increased, while the percentage of "large size" leaves decreased.

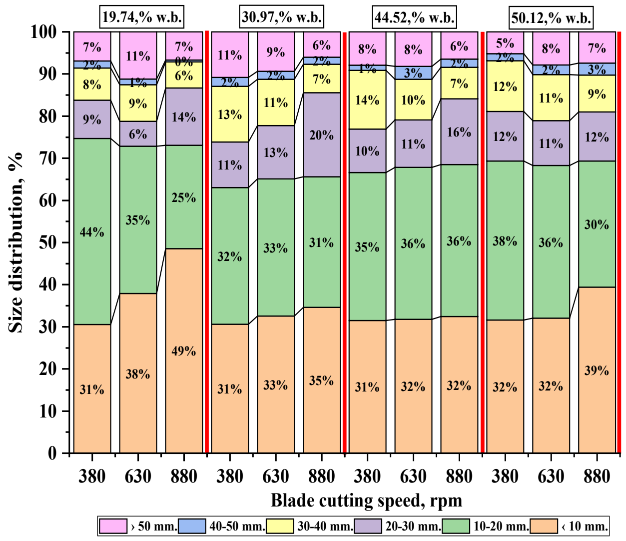

Figure 6 Size distribution for different blade cutting speed

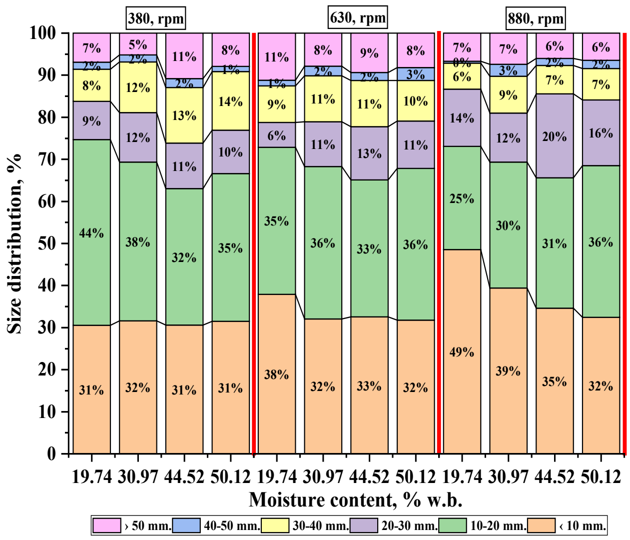

Figure 7 Size distribution for different moisture content

Figure 7 shows the effect of moisture content on leaf size distribution. When the moisture content increased, the variation of the percent size distribution was almost in a straight line, which means that the percent size distribution of "large size" leaves gradually increased as well. Similar results were also reported by Abdallah et al. (2011). The highest share of sugarcane leaves size distributed "small size", which was coherent with theoretical length of cutting (19.64 mm). Similar results were also reported by Lisowski et al. (2009) for plants chopping. Leaf size distribution of {(<10), (10-20) and (20-30)} mm at the moisture content level of 19.74% w.b. and blade cutting speed of 880 rpm resulted in a leaf size distribution of 86.67%. Leaf sizes of less than 10 mm had the highest distribution of 48.57%, followed by 24.52% and 13.57% for leaf sizes of 10-20 mm and 20-30 mm, respectively. Leaf sizes of {(30-40), (40-50) and (> 50)} mm at the moisture content level of 50.12 % w.b. and blade cutting speed of 380 rpm had the highest leaf size distributions of 13.94%, 1.20% and 7.93%, respectively or 23.08% in total.

Therefore, if the "small size" leaves are needed, sugarcane leaves should have low moisture content and the cutting speed should be increased. “Small size” leaves are suitable for grinding in order to make fuel products in the form of pellets and briquettes, or for the production of ethanol. When “large size” leaves are needed, the cutting speed should be reduced to obtain a greater distribution of “large size” leaves, but the percent weight may be reduced. This group is suitable for instantly used fuel.

4 Conclusion

This study investigated the cutting of leaves and size distribution of sugarcane leaves using a dump chopper, taking into consideration working capacity, percent weight, average leaf length and size distribution. The variables involved in this study were moisture content and blade cutting speed. Working capacity, percent weight and average length tended to decrease as cutting speed increased and moisture content decreased. Therefore, this affected the leaf size distribution, i.e., the amount of leaves categorized in the "small size" group increased. At a blade cutting speed of 880 rpm and moisture content 19.74 % w.b. with a percent weight of 98.54%, the geometric mean particle length was 9.18 mm and the leaf size distribution was {(<10), (10-20) and (20-30)} mm. The total size distribution was 86.67 %. Leaves with a length of less than 10 mm were distributed the most at 48.57 % followed by distributions of 24.52 %

and 13.57 % for leaves 10-20 mm and 20-30 mm in length, respectively. Reducing the cutting speed caused an increase in leaves in the “large size” group. Sugarcane leaves with a high moisture content have strong and heavy fibers, therefore, reducing the cutting speed left some of the sugarcane leaves uncut. This study can be used as an initial reference and for suggestions about relevant additional factors. Increasing the cutting speed may result in an increase of energy consumption. Reducing the size of chopped materials also relates to other factors, such as how the number of blades used in the cutting machine and the material input rate will affect the size distribution and energy required for cutting. Therefore, further studies should focus on ways in which energy consumption can be minimized for the production of fuel biomass using suitably sized sugarcane leaves.

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References

Abdallah, R., S. Auchet, and P. J. Méausoone, 2011. Experimental study about the effects of disc chipper settings on the distribution of wood chip size. *Biomass and Bioenergy*, 35(2): 843–852.

Adgidzi, D. 2007. Development and performance evaluation of a forage chopper. *Journal of Agricultural Engineering and Technology*, 15: 12-24.

Ajav, E. A., and B. Yinusa. 2015. Factors affecting forage chopper performance. *Agricultural Engineering International: CIGR Journal*, 17(3): 112–116.

ASAE Standards, 48nd Ed. 2003. S424.1. Method of determining and expressing particle size of chops forage materials by screening. St. Joseph, MI; American Society of Agricultural Engineers.

ASAE Standards, 52nd Ed. 2006. S358.2: 1:1 measurement - forages. St. Joseph, MI: ASABE.

Ashfaq, S., A. Ghafoor, M. Ahmad, and Q. Yaqub. 2015. Performance evaluation of sugarcane stripper for trash recovery. *Pakistan Journal of Agricultural Sciences*, 52(2): 489–494.

Canilha, L., A. K. Chandel, T. S. dos Santos Milessi, F. A. F. Antunes, W. L. da Costa Freitas, M. das Graças Almeida Felipe, and S. S. da silva. 2012. Bioconversion of sugarcane biomass into ethanol: an overview about composition, pretreatment methods, detoxification of hydrolysates, enzymatic saccharification, and ethanol fermentation. *Journal of Biomedicine and Biotechnology*, 2012: 989572.

De Landel, M. G. A., M. S. Scarpari, M. A. Xavier, I. A. dos Anjos, A. S. Baptista, C. L. de Aguiar, D. N. da Silva, M. A. P. Bidóia, S. R. Brancalião, J. A. Bressiani, M. F. de Campos, P. E. M. Miguel, T. N. da Silva, V. H. P. da silva, L. O. S. anjos, and B. H. Ogata. 2013. Residual biomass potential of commercial and pre-commercial sugarcane cultivars. *Scientia Agricola*, 70(5): 299–304.

FAO (Food and Agriculture Organization of the United Nations). 2018. Country fact sheet on food and agriculture policy trends. Available at: http://www.fao.org. Accessed 15 September 2019.

Ghaly, A. E., A. Ergudenler, S. Al Suhaibani, and V. V. Ramakrishnan. 2013. Development and evaluation of straw chopping system for fluidized bed gasifiers. *The International Journal of Engineering and Science*, 2(10): 97–110.

Hassuani, S. J., M. R. L. V. Leal, and I. de Carvalho Macedo. 2005. *Biomass Power Generation: Sugar Cane Bagasse and Trash*. Brazil: Programa das Nacoes Unidas para Desenvolvimento; Centro de Tecnologia Canavieira.Hernández, R. E., & Boulanger, J. 1997. Effect of the rotation speed on the size distribution of black spruce pulp chips produced by a chipper-canter. *Forest Products Journal*, 47(4), 43–49.

Hernández, R. E., and J. Boulanger. 1997. Effect of the rotation speed on the size distribution of black spruce pulp chips produced by a chipper-canter. *Forest Products Journal*, 47(4): 43–49.

IBM Crop. Released. 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk. Armonk, NY: IBM Corp.

Jenjariyakosoln, S., B. Sajjakulnukit, and S. Garivait. 2013. Energy and greenhouse gas emissions reduction potential of sugarcane field residues power generation in Thailand. *International Journal of Environmental Science and Development*, 4(2): 182-186.

Jezerska, L., O. Zajonc, J. Vyletelek, and J. Zegzulka. 2016. Mechanical material properties effect on pelletization. *Wood Research*, 61(2): 307-320.

Jorapur, R., and A. K. Rajvanshi. 1997. Sugarcane leaf-bagasse gasifiers for industrial heating applications. *Biomass and*

Bioenergy. 13(3): 141-146.

Khope, P. B., and J. P. Modak. 2013. Development and performance evaluation of a human powered flywheel motor operated forge cutter. *International journal of scientific and technology research*, 2(3): 146–149.

Kratky, L., and T. Jirout. 2011. Biomass size reduction machines for enhancing biogas production. *Chemical Engineering and Technology*, 34(3): 391–399.

Kurt, W. 2006. Sugar cane trash processing for heat and power production. M.S. thesis, Lulea University of Technology.

Lisowski, A., M. Kostrubiec, M. Dąbrowska-Salwin, and A. Świętochowskil. 2018. The characteristics of shredded straw and hay biomass: part 2-the finest particles. *Waste and Biomass Valorization.* 9(1): 115–121.

Lisowski, A., T. Nowakowski, M. Sypuła, D. Chołuy, G. Wiśniewski, and O. Urbanovičová. 2009: Suppleness of energetic plants to chopping. *Annals of War-saw University of Life Sciences SGGW, Agriculture (Agricultural and Forest Engineering)*, 53: 33–40.

Mou, X., Q. Liu, Y. Ou, M. Wang, and J. Song. 2013. Mechanical properties of the leaf sheath of sugarcane. *Transactions of the ASABE*, 56(3): 801–812.

Naimi, L. J., S. Sokhansanj, S. Mani, M. Hoque, T. Bi, A. R. Womac, and S. Narayan. 2006. Cost and performance of woody biomass size reduction for energy production. In CSBE/SCGAB Paper No. 06-107. 2006 Annual Conf., Edmonton, Alberta: CSBE/SCGAB.

Nunes, L. J. R., J. C. O. Matias, and J. P. S. Catalão. 2016. Biomass combustion systems: A review on the physical and chemical properties of the ashes. *Renewable and Sustainable Energy Reviews*, 53: 235–242.

OCSB (Office of the cane and sugar board). 2018. Annual Report 2018. Available at http://www.ocsb.go.th. Accessed 15 September 2019.

Smithers, J. 2014. Review of sugarcane trash recovery systems for energy cogeneration in South Africa. *Renewable and Sustainable Energy Reviews*, 32: 915–925.

Sun, Y., and J. Cheng. 2002. Hydrolysis of lignocellulosic materials for ethanol production: a review. *Bioresource Technology*. 83(1): 1–11.

Wilcox, R. A., C. W. Deyoe, and H. B. Pfost. 1970. A method for determining and expressing the size of feed particles by sieving. *Poultry Science*, 49(1): 9–13.