doi: 10.17221/70/2015-RAE

Effect of moisture and region of cut on cassava stalk properties in biomass applications

Nisanath Kaewwinud*, Porntep Khokhajaikiat, Apichart Boonma

Department of Industrial Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, Thailand

**Corresponding author: nisanathk@gmail.com*

Abstract

Kaewwinud N., Khokhajaikiat P., Boonma A. (2017): Effect of moisture and region of cut on cassava stalk properties in biomass applications. Res. Agr. Eng., 63: 23–28.

In an attempt to investigate the potential of using cassava stalk as a biomass material and determine the design requirements for developing a cutting machine, this study aims to investigate physical and mechanical properties of cassavas stalk, under the influence of moisture content and region of cut using statistical techniques. Moisture contents were ranged into three different levels; 54.19, 43.05 and 24.93% wet basis (w.b.) while cutting regions were classified as top (tip of cassava stalk), middle and bottom. Mechanical properties were represented by shearing stress. Physical properties, on the other hand, were represented by length, diameter, and mass. By decreasing moisture levels, all parameter values were reduced, except shearing stress. Moreover, it was found that shearing stress increased when lowering the cutting line. Maximum and minimum shearing stress occurred at bottom and top regions of the stalk, respectively. Most importantly, moisture content and region of cut both had a significant influence ($P < 0.05$) on shearing stress, although the latter had much larger impact.

Keywords: cassava; property; moisture; residue; biomass

Cassava (Manihot Esculenta, Crantz) is the third most important source of calories and the sixth most important crop cultivated in tropical and subtropical areas around the globe. The growth in cassava production is likely to accelerate over the current decade (FAO 2008; Burns 2010). In Thailand, cassava has been widely cultivated with a total area of approximately 8,975,865 Rai or 1,436,138.40 ha across the country, which results in annual production of around 30,022,052 t (OAE 2014). In traditional cassava harvesting, the stalks are cut and collected from the field, then the roots are pulled out from the soil either by hand or machine. About 30% of stalks are kept for cultivating in the next season, while the remaining 70% are abandoned in the field as agricultural residues (FAO 2008). These residues can be used as raw materials for biomass applications due to high volume of residues and heating value of 15.40 MJ/kg (DEDE 2009). This could help Thailand to reduce energy imports, carbon emission, improve energy sustainability, and also increase farmer income (Kronbergs, Smits 2009; Khongthong, Sudajan 2014). Despite the aforementioned benefits, biomass material produced from cassava usually suffers from low density and inconsistent size. This affects transportation costs considerably. To solve the problem, the cassava residues must be chopped by chopping machine before becoming biomass energy. As a result, a proper chopping machine must be developed. Also, physi-

Supported by the Center for Alternative Energy Research and Development and the Agricultural Machinery and Postharvest Technology Center, Khon Kaen University, Thailand.

doi: 10.17221/70/2015-RAE

cal and mechanical properties of cassava stalk must be studied in order to understand their reactions to cutting force and deformation (Dauda et al. 2014). These properties depend greatly on species, variety, stalk diameter, maturity, moisture content, cellular structure (Persson 1987; Chattopadhyay, Pandy 1999; Azadbakht et al. 2014; Dauda et al. 2014) and also differ at different heights of the plant stalk (I'nce et al. 2005). There are studies that have determined physical and mechanical properties of agricultural residues, including cotton stalk, maize stalk and sugar cane bagasse, in order to design appropriate machines which function efficiently (Amer Eissa 2008). Physical properties were normally determined as length, stem diameter and unit mass, while mechanical properties were determined as shearing force, shearing stress and shearing energy (Dauda et al. 2014). These properties were observed under different moisture content and cutting height (Esehaghbeygi et al. 2009). Such studies on canola, alfalfa and sunflower stalk residue have been reported as examples (I'nce et al. 2005; Kronbergs, Smits 2009; Hoseinzadah, Shirneshan 2012). However, to the best of our knowledge, there is no investigation focused on physical and mechanical properties of cassava stalk.

The main objective of this study was to determine physical and mechanical properties of cassava stalk residues at different moisture contents and region of cut. The physical properties were measured in terms of length, stalk diameter and unit mass, while the mechanical properties were represented by maximum shear stress. This knowledge is necessary for designing and improving the cutting machine used in the biomass material storage and preparation process.

MATERIAL AND METHOD

Kasatsart 50 was selected for this study because it is the most popular cassava variety cultivated in Thailand (Rojanaridpiched 2002; Thai Tapioca Development Institute 2006). Generally, the stalks of Cassava are cut off 40–60 cm above ground by hand, machete or machine and piled at the side of the field (GRACE 1977). In this study, the residues were collected by hand from the field during the harvesting period in the Khon Kaen province, located in the Northeast region of Thailand. The leaves and the twigs were stripped off. Only cassava stalks were used in physical and mechanical analysis. Stalk samples were taken from the field on the harvest day and kept at the storage area in the Industrial Engineering Faculty, Khon Kaen University. There were three groups of cassava stalk. Each group was classified by the amount of time the stalk samples in the group were kept until being analysed, i.e. 0, 10 and 20 days. Five stalk samples per group were randomly selected and examined for moisture content using an electrical drying oven (ASAE method; ASAE 1993). The moisture content of the first, second and third group were 54.19, 43.05. and 24.93% w.b., respectively.

Physical properties. To determine the physical properties of cassava stalks at three different moisture contents, thirty stalks from each group were selected for the analysis. First, the length of stalks, defined as the distance between the base and the top of the stalk, was measured using a measuring tape. Next, these stalks were cut into three equal pieces. The part closest to the root was identified as the bottom, the middle part was equidistant between extremes and the uppermost part was the top. After cutting, the diameter was measured at the midpoint of each sample using a digital Vernier microscope and the unit weight was examined using a digital balance.

Mechanical properties. All stalk specimens, with varying region of cut and moisture content, were examined for shearing stress. The laboratory test was done using a Universal Testing Machine (UTM) at the Agricultural Engineering Department, Khon Kaen University. A set of fixtures was developed and fixed firmly on the base platform by the use of a fabricated fixture under the cross-

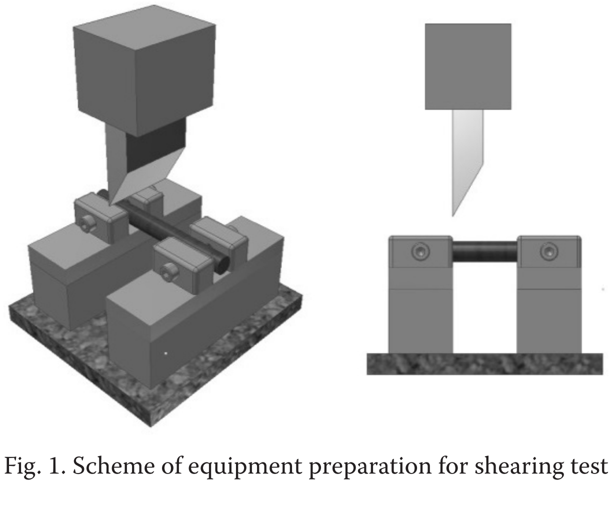

Fig. 1. Scheme of equipment preparation for shearing test

doi: 10.17221/70/2015-RAE

head with four bolts for support. The cross head of the machine was equipped with a flat knife (8 mm thick, 65 mm wide, and 120 mm long with bevel angle of 30 degree) which was aligned vertically to the length of stalk specimen (Fig. 1). The diameter of each stalk specimen was measured at the midpoint and the data were recorded by the UTM (LR50K; Ametek, Meerbusch, Germany). Then, an individual specimen was held at both ends by the fixtures with the help of the four bolt support clamps. Next, the cross head with flat knife moved downward and struck the specimen right at the midpoint. The shearing force required to cut the specimen was recorded against time by the UTM chart recorder.

Statistical test. In this study, there were two factors (moisture content and region of cut) affecting the shearing stress of the cassava stalk. In order to determine the level of influence of each factor, a statistical analysis is required. SPSS Statistics version 19.0 was selected for this task. The process started from investigating normal distributions for all combinations of each level of factors using the Shapiro-Wilk's test ($P > 0.05$). Then, analysis of variance (ANOVA) and comparative analysis were carried out. The confidence interval for statistical tests was set to be 95% ($a = 0.05$) in the study. Next, the correlation test was performed to define the linear association between two factors. Finally, Duncan's multiple range test was employed to compare the means of the three levels of moisture content and the means of the three regions of cut (bottom, middle and top).

RESULTS AND DISCUSSION

Physical properties (defined as length, diameter, and unit mass) and mechanical properties (defined as shear stress) were related to performance of the cassava cutting tools which were investigated at three levels of moisture content. The obtained results are presented and discussed below.

Table 2. Maximum shearing stress of each part of cassava stalk at different moisture contents

Moisture content (% w.b.)	Maximum shearing stress (MPa)		
	bottom	middle	top
54.19	4.06	2.87	1.59
43.05	4.93	3.25	2.06
24.93	5.57	3.82	2.38

Physical properties of cassava stalks

Length and mass of stalk samples at varying moisture contents and regions of cut were measured. Then, the diameter of each sample was observed and recorded. The results are presented in Table 1.

Mechanical properties of cassava stalks

Mechanical property was defined as a shearing stress related to the cutting process in biomass material preparation. Loads were applied on the midpoint of stalk samples to examine the shearing stress. As the results in Table 2 show, at every level of moisture content, the shearing stress appeared to increase from the top of stalk to the bottom. For example, at a moisture content of 54.19% w.b., shearing stresses of 1.59, 2.87, and 4.06 MPa were read at the top, middle, and bottom of the stalk, respectively. This finding is similar to those described in previous research (Pearson 1987; Amer Eissa 2008; Khidhathong et al. 2014). Shearing strength in "bottom" samples is usually higher than in other parts of the cassava stalk due to the fol-

Table 1. Physical properties of cassava stalks at different moisture contents

Physical property	Moisture content (% w.b.)					
	54.19		43.05		24.93	
	range	mean	range	mean	range	mean
Length of sample before cut (mm)	1,815.00–3,040.00	239.09	1,900.00–2,920.00	2,348.00	1,795.00–2,605.00	2,088.10
Weight of sample (g)	180.40–802.10	454.75	166.00–596.00	302.16	102.10–385.10	248.81
Bottom region diameter (mm)	18.29–31.71	24.53	13.96–33.51	22.18	10.24–27.05	20.93
Middle region diameter (mm)	14.60–27.03	20.84	10.77–26.20	19.39	13.51–24.55	18.40
Top region diameter (mm)	8.20–22.30	16.05	8.17–22.62	14.96	7.71–21.04	14.47

doi: 10.17221/70/2015-RAE

Table 3. Statistic data and normal distribution of maximum shearing stress of cassava stalk

Moisture content (% w.b.)	Shearing Stress						
	region	N	min.	max.	mean	s.d.	Shapiro-Wilk's test ($P > 0.05$)
	Bottom	30	2.09	4.06	3.12	0.53	0.770
54.19	Middle	30	1.47	2.87	2.16	0.35	0.936
	Top	30	0.71	1.65	1.13	0.22	0.449
	Bottom	30	1.88	4.93	3.45	0.84	0.265
43.05	Middle	30	1.36	3.25	2.17	0.40	0.839
	Top	30	0.54	2.06	1.29	0.32	0.874
	Bottom	30	2.46	5.57	3.94	0.94	0.091
24.93	Middle	30	1.80	3.82	2.55	0.50	0.144
	Top	30	0.64	2.39	1.33	0.39	0.488

N – sample size

lowing reasons; (1) the bottom part has more fiber and thicker stem wall than the top, and (2) stalk diameter is larger at the bottom region than the top. In addition, the strength of the outer layer of the stem increases with age of the crop due to gradual accumulation of lignin in the stem wall. For each region of cut, shearing stress increases with decreasing moisture content. For example, in the bottom region, the shearing stresses were found to be 4.06 MPa, 4.93 MPa and 5.57 MPa with moisture contents of 54.19% w.b., 43.05% w.b. and 24.93% w.b., respectively. This finding is consistent with previous research (Amer Eissa 2008).

Statistical analysis

This analysis was performed in order to determine which factor has a statistical effect on the shearing stress. Based on the statistical analysis by SPSS Statistics 19.0, max. shearing stresses at varying moisture contents and regions of cut were normally distributed, as shown in Table 3. A two-way analysis of variance (ANOVA) for the data obtained from the cassava stalk samples was carried out at the 95% confidence interval. There were two factors in the analysis: moisture content and a region of cut. The factors were considered separately and aggregately. According to the analysis, the moisture content, region of cut, and their interactions had significant effects on the shearing stress as shown in Table 4. This means cassava stalks should be cut at a proper time and at a proper position to minimize the energy required to prepare biomass raw material. Thus, if one wants to design a chopping blade, these factors must be taken into account. Next, the correlation coefficient was used to identify a relationship between the two factors. The results show that the effects of moisture content and region of cut on shearing stress were related in a negative linear sense. This means

Table 4 Two-way analysis of variance (ANOVA) test of the effect of moisture content and region of cut on the shearing stress (dependent variable: shear_stress)

Source	Sum of squares	df	Mean square	F	P-value
Corrected model	241.695[a]	8	30.212	101.083	0.000
Intercept	1,490.746	1	1490.746	$4.988E^3$	0.000
Moisture	10.296	2	5.148	17.225	0.000
Region	227.742	2	113.871	380.990	0.000
Moisture × region	3.657	4	0.914	3.059	0.017
Error	78.008	261	0.299		
Total	1,810.450	270			
Corrected total	319.704	269			

[a]R squared = 0.756 (adjusted R squared = 0.749)

doi: 10.17221/70/2015-RAE

Table 5. Correlation of moisture content and region on shearing stress

		Shear_stress	Region	Moisture
Shear stress	Pearson Correlation	1	–0.843**	–0.179**
	Sig. (2-tailed)		0.000	0.003
	N	270	270	270
Region	Pearson Correlation	–0.843**	1	0.000
	Sig. (2-tailed)	0.000		1.000
	N	270	270	270
Moisture	Pearson Correlation	–0.179**	0.000	1
	Sig. (2-tailed)	0.003	1.000	
	N	270	270	270

Sig. – significant; N – sample size; **correlation is significant at the 0.01 level (2-tailed)

Table 6. Duncan's multiple range test of moisture content and region of cut

N	Duncan's multiple range test on moisture content.			Duncan's multiple range test on region		
	subset			subset		
	54.19 % w.b.	43.05 % w.b.	24.93 % w.b.	top	middle	bottom
90	2.1369			1.2540		
90		2.3038			2.2937	
90			2.6086			3.5016
Sig.	1.000	1.000	1.000	1.000	1.000	1.000

Sig. – significant; N – sample size

shearing stress decreased with increasing moisture content. Also, at the top region, the shearing stress was lower than that at the bottom region of stalk. Moreover, it appeared that the relationship between region and shearing stress was much stronger than that between moisture content and shearing stress (0.843 > 0.179) as shown in Table 5. Finally, the Duncan's multiple range test was applied in this experiment to compare the range of a subset of the shearing stress on moisture content and the range of a subset of the shearing stress on region of cut. The obtained results are tabulated in Table 6. Duncan's multiple range test for shearing stress on moisture content and region of cut showed that there are significant differences in shearing stress among all pairs of moisture contents at the 95% confident interval. Similar findings were found in all pairs of regions of cut at the 95% confident interval. This means that cassava stalks with high moisture require less cutting energy than those with low moisture. Similarly, the top part of the stalk requires less cutting energy than is needed for the bottom part.

CONCLUSION

This study presents an investigation of physical and mechanical properties of cassava stalks under the effects of moisture content and region of cut. Average length, mass, and diameter of cassava stalk all decreased with decreasing moisture. Statistical analysis indicates that both moisture content and region of cut significantly affect shearing stress. The stress increased with decreasing moisture content. The stress also increased when the region of cut was shifted from top to bottom of the stalk thereby increasing stalk diameter. However, compared to moisture content, region of cut appeared to have a much larger impact on shearing stress. The impact ratio of region of cut to moisture content is 0.843 to 0.179 or approximately 4.71 to 1. Therefore, cutting the cassava stalk right after harvesting, or at the higher moisture content, is recommended to minimize cutting energy. In practice, the date of cutting or chopping is very important for biomass and agricultural activities.

doi: 10.17221/70/2015-RAE

References

Amer Eissa A.H., Gomaa A.H., Baiomy M.H., Ibrahim A.A. (2008): Physical and mechanical characteristics for some agricultural residues. Misr Journal of Agricultural Engineering, 25: 121–146.

ASAE (1993): ASAE standards: standards, engineering practices and data adopted by the American Society of Agricultural Engineers. ASAE, USA.

Azadbakht M., Esmaeilzadeh E., Esmaeili-Shayan M. (2015): Energy consumption during impact cutting of canola stalk as a function of moisture content and cutting height. Journal of the Saudi Society of Agricultural Sciences, 14: 147–152.

Burns A., Gleadow R., Cliff J., Zacarias A., Cavagnaro T. (2010): Cassava: the drought, war and famine crop in a changing world. Sustainability, 2: 3572–3607.

Chattopadhyay P.S., Pandy K.P. (1999): Mechanical properties of sorghum stalk in relation to quasi-static deformation, Journal of Agricultural Engineering Research, 73: 199–206.

Dauda S.M., Ahmad D., Khalina A., Jamarei O. (2014): Physical and mechanical properties of kenaf stems at varying moisture contents. Agricultural and Agricultural Science Procedia, 2: 370–374.

DEDE (2009): Spatial biomass potential of Thailand in 2009. Available at http:// www.dede.go.th

Esehaghbeygi A., Hoseinzadeh B., Khazaei M., Masoumi A. (2009): Bending and shearing properties of wheat stem of alvard variety, World Applied Science Journal, 6: 1028–1032.

FAO (2008): Cassava. Available at http://www.fao.org/ag/agp/agpc/gcds/index_en.html

Grace M.R. (1977): Cassava processing: FAO Plant Production and Protection Series, No. 3. Available at http://www.fao.org/docrep/x5032e/x5032e01.htm

Hoseinzadeh B., Shirneshan A. (2012): Bending and shearing characteristics of canola stem, American-Eurasian American-Eurasian Journal of Agricultural & Environmental Sciences, 12: 275–281.

I'nce A., Ugurluay S., Guzel E., Ozcan M. T. (2005): Bending and shearing characteristics of sunflower stalk residue. Biosystems Engineering, 92: 175–181.

Khidhathong P., Wangjiranira W., Suriyawon A. (2014): A study on spatial potential of biomass for electricity generation. Journal of Energy Research, 11: 63–76.

Khongthon N., Sudajan S. (2014): Some physical and mechanical properties of sugarcane trash relating to the criteria design of a sugarcane trash chopping machine. Advanced Materials Research, 931–932: 1574–1581.

Kronbergs E., Smits M. (2009): Cutting properties of common reed biomass. In: Engineering for Rural Development, Jelgava.

OAE (2014): Agricultural statistics of Thailand 2014. Available at http://www.oae.go.th

Persson S. (1987): Mechanics of Cutting Plant Material. Michigan, ASAE.

Rojanaridpiched C., Vichukit V., Sarobol E., Changlek P. (2002): Breeding and dissemination of new cassava varieties in Thailand. In: Proceedings of the seventh regional workshop, Thailand, Oct 28–Nov 1, 2002: 67–76.

Thai Tapioca Development Institute (2006): Kasetsart 50 (KU 50). Available at http://www.tapiocathai.org/English/K2_e.html

Received for publication December 27, 2015
Accepted after corrections March 15, 2016