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Some physical properties of cassava and evaluation of the performance in cutting cassava tubers from their rhizomes using manual labor

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Abstract

This research was conducted to determine some physical properties of cassava and evaluation of the performance in cutting cassava tubers from their rhizomes using manual labor. The study of physical properties of cassava showed the ranges of diameters of cassava tubers (at base, middle and end sections) were 4.2-8.5, 3.1-6.7 and 2.1-5.3 cm respectively. The cassava tubers' lengths ranged between 2.2-4.4 cm, their weights ranged between 0.2-1.0 kg and their average density was 820.83 kg/m^3. The coefficient of static friction was in the range 28.0°-30.0°. The performance in cutting cassava tubers from their rhizomes using manual labor an average working rate of 352.53 kg/hr/person, resulting from 163.05 rhizomes/hr/person, and the average cutting loss was 0.22%.

Keywords: cassava, physical properties, cassava tuber, cutting of cassava tubers from their rhizomes

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1. Introduction

Cassava (Manihot esculenta (L.) Crantz) is one of the essential economic crops in Thailand, ranked after sugarcane and rice. Thailand is the second-largest cassava producer in the world after Nigeria. In 2018/19, the area of cassava plantations in Thailand was approximately 8.6 million rai, with an average yield of 30 million tons / year (fresh cassava). Cassava is planted in various areas of Thailand, except the southern region. The region with the largest cassava plantation is the north-eastern region, followed by the central and northern areas. The most popular cultivar grown in Thailand is Kasetsart 50. Cassava can be harvested throughout the year, especially from December until July. Fresh cassavas produced in the country is processed as raw materials for several industries, such as cassava starch for the paper and textile industry, pellet form for the animal feed industry, tapioca for the ethanol industry, and other industrial sectors. About 25-28 percent of cassava production are used domestically, while the remaining 75-80 percent are exported. Thailand's major export markets are mainly Asia, especially China. [1, 2] The current method of harvesting cassava begins with cutting stem and leaving the remaining stem about 30 cm from the ground. Then the ground-attached stems are pulled by human workers or dug by machine and gathered in pile. Cassava tubers are cut and separated from their rhizome by human labors or a cutting machine. The only method for loading harvested cassava tubers into trucks is relying on human labors to gather the tubers, put in the basket and weight in to the truck. It needs about 7-10 people to operate each time [3, 4, 5, 6]. Since fresh cassava must be delivered to the factory daily to avoid the rapid deterioration, which causes decreasing of starch yield and affects the buying price of fresh cassava tubers [7]. The cassava harvesting, especially the procedure of cutting cassava tubers from their rhizomes, has been studied by many researchers. They presented the guideline for development and research about cutting and harvesting machinery, such as saw blade cutting, pressure cutting or pile harvesting machines. The prototypes of these machines are in the initial development and have different working principles [8, 9, 10]. Necessary physical behaviors such as the shape of stems, rhizomes and tubers affect the loss and efficiency in cassava harvesting. The research has not studied the physical properties of cassava regarding the shape of cassava stems, but could be found in machine's data collection only. Therefore, the research and design of agricultural machinery for cutting cassava tubers is very important, especially the process of cutting cassava tubers from their rhizomes that relies on human labors. This research focused on some physical properties of cassava and evaluation of the performance in cutting cassava tubers from their rhizomes using manual labor. Moreover, the results from this research will be useful for further research in developing tools for cassava tubers separation and cassava harvesting machinery for agriculture in Thailand.

2. Materials and methods

The determination of some physical properties of cassava and evaluation of the performance in cutting cassava tubers from their rhizomes using manual labor were carried out for designing the tuber-cutting machine and cassava harvester. Preliminary study on physiological activity indicated that the shape of cassava stem in the planting plot before harvesting could be categorized into 6 groups: T1 – single stem without side branches, T2 – single stem with two side branches, T3 – single stem with three side branches, T4 – a two-stem type, T5 – a multiple-stem type, and X – a miscellaneous-stem type. From physiological activity, the stem shapes of T1, T2 and T3 were found to be more than 76.0 percent, whereas stem shapes of T4, T5 and X were just 24.0 percent. Thus, the focused study was performed on the stem shapes of T1, T2 and T3 and separated into two experiment steps: 1st step – studying physical properties of cassava tubers, and 2nd step – testing and evaluating the performance in cutting cassava tubers from their rhizomes by manual labors. Cassava cultivar of Kasetsart 50 and 10-month-old tubers grown in Khon Kaen Province were selected for the study's experiment as shown with details and methodology as followed.

2.1 Physical properties of cassava tubers

This step was the study on physical properties of T1, T2 and T3 tubers, including the number of tubers per rhizome, size of tuber, density of tuber and coefficient of static friction.

2.1.1 The number of tubers per rhizome

Cassava rhizomes were separated into 4 levels: 1-5, 6-10, 11-15, and more than 15 tubers/rhizome. 1,000 rhizomes with the stem shapes of T1, T2 and T3 (Figure 1) were randomly sampled from allover 5 plots (200 rhizomes per plot). The data on tuber number were analyzed for mean and percentage values according to the experiment template.

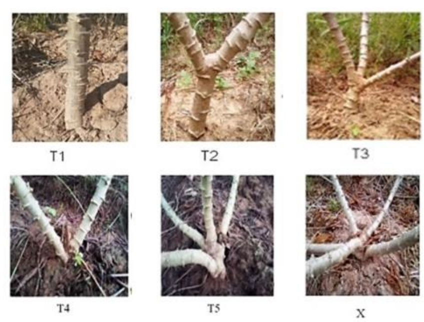

Figure 1 Physiological difference of cassava stem shapes in T1, T2, T3, T4, T5 and X groups.

2.1.2 Size of tubers

The data of this step were used as a ggideline for considering a design and outlet of tubers after cutting for continuous feeding. 200 tubers per plot

(5 plots) were randomly measured for their diameter (at base, middle and end part), length and weight (Figure 2). The data were analyzed for mean, minimum and maximum values. Measurement tape, vernier caliper and digital scale were used for data collection.

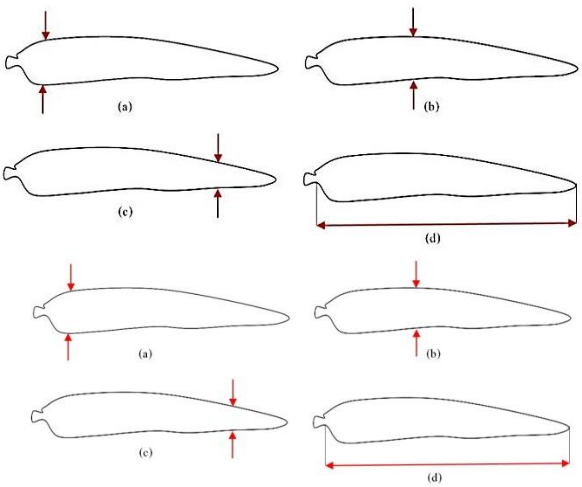

Figure 2 Size measurement of cassava tuber. (a) base; (b) middle; (c) end part; (d) length.

2.1.3 Density of tubers

Bulk density was defined by the ratio of fresh-tuber mass to container volume. A cubic container of 20 x 20 x 20 cm sides was weighed to measure mass of container, and weighed again after filling with fresh cassava tubers. Mass of fresh tuber was obtained by deducting the weight of empty container from the weight of container filled with tubers. Triple repetition of measurement was done and the data were used to analyze for the density of cassava tuber (Equation 1).

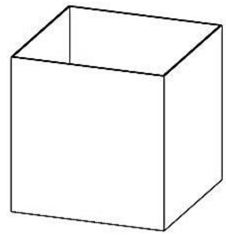

Figure 3 Container of 0.008 m^3 volume for defining the bulk density.

$$\sigma = \left(\frac{M}{V}\right) \tag{1}$$

where σ = Density of cassava tuber (kg/m^3)

M = Mass of cassava tuber (kg)

V = Volume of container (m^3)

2.1.4 Coefficient of static friction of tubers

This step was needed for designing the angle of outlet for continuous flow of post-cut cassava tubers. Tools with four components used in the experiments included an oriented strand board, steel sheet, stainless steel sheet and rubber sheet. 10 repetitions per sample were performed with two experiments (tranversal and longitudinal modes) according to Mohsenin's method [11]. Data were recorded and analyzed.

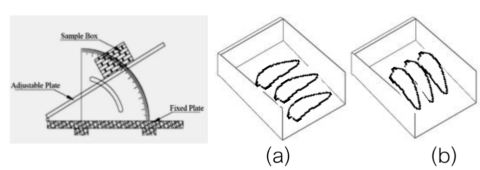

Figure 4 Tools for measuring coefficient of static friction. (a) transversal, (b) longitudinal.

2.2 Experiment and performance evaluation in cutting tubers from their rhizomes by using manual labor

Cutting tubers from rhizome by human labors was generally done by farmers. The experiment was separated into 3 steps: Step1 – picking pre-cut tubers from a pile, Step 2 – separating tubers from rhizome with blade, and Step 3 – disposing of post-cut tubers. The experiment was done by three persons with 100 rhizomes per person. Data on working rate and cutting loss after tuber-rhizome separation (Equations 2 and 3) were collected throughout the experiment and then calculated and analyzed respectively. The experiment items included 300 cassava rhizomes, stopwatch and digital scale.

Figure 5 Cutting cassava tubers from rhizome by human labors, a general method for farmers.

$$C_p = \frac{m_1}{t \times n} \quad (2)$$

Where $C_p =$ Working rate (kg/hour/person).

$m_1 =$ Total weight of post-cut tubers (kg).

$t =$ The total working time of cutting (hour).

$n =$ The number of working persons (person).

The cutting loss after separating tubers from rhizome according to Nasr et al. [12] can be calculated as

$$L_s = \frac{m_2}{m_1 + m_2} \times 100 \quad (3)$$

where $L_s =$ Cutting loss (%).

$m_1 =$ The total weight of post-cut tubers (kg).

$m_2 =$ The total weight of unsuccessful cuts (tubers incompletely cut from rhizome, kg).

3. Results and discussion

The physical properties of three tuber groups (T1, T2 and T3) from 5 plots (200 rhizomes per plot) showed that the stem shape of T2 provided the highest average number of tubers (43.4%), and cutting machine, whose actual usage would followed by T1 and T3 (33.6% and 23.0% respectively) (Table 1 and Figures 6, 7). A lower number of tubers in T1 and T3 could be due to cassava cultivar, soil conditions and environmental factors. The high tuber number or high rhizome weight could cause post-harvest loss when using stem-picking and cutting machine, whose actual usage would need further studies and researches on this factor.

Table 1 Percent of tubers per rhizome of stem shapes T1, T2 and T3.

Physical behavior of stem shape (group)	Number of tubers (tubers/rhizome)	Plot						
		Plot no. 1 (percent)	Plot no. 2 (percent)	Plot no. 3 (percent)	Plot no. 4 (percent)	Plot no. 5 (percent)	Mean (percent)	Total mean (percent)
	1-5	11.0	12.5	13.0	18.0	16.5	14.2	
	6-10	70.0	68.0	71.5	69.5	73.0	70.4	33.6
T1	11-15	35.0	47.0	37.5	46.0	40.5	41.2	
	> 15	9.0	8.0	10.0	8.5	9.5	9.0	
	1-5	12.0	15.5	17.0	21.0	18.5	16.8	
	6-10	84.0	87.0	85.5	87.5	89.0	86.6	43.4
T2	11-15	55.0	57.0	67.5	56.0	66.5	60.4	
	> 15	10.0	9.0	11.0	9.5	10.5	10.0	
	1-5	9.0	10.5	11.0	13.0	12.5	11.2	
	6-10	54.0	57.0	60.5	55.5	56.0	56.6	
T3	11-15	25.0	27.0	28.5	26.0	24.5	26.2	23.0
	> 15	7.0	6.0	7.0	7.5	7.5	7.0	

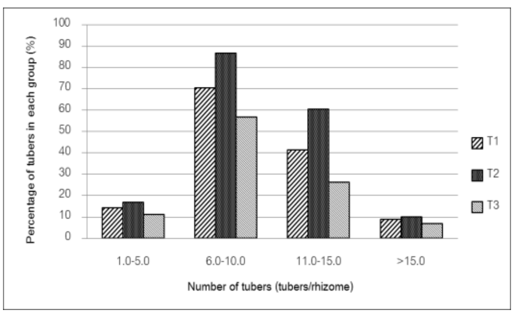

Figure 6 Number of tubers per rhizome in groups T1, T2 and T3 of each plot.

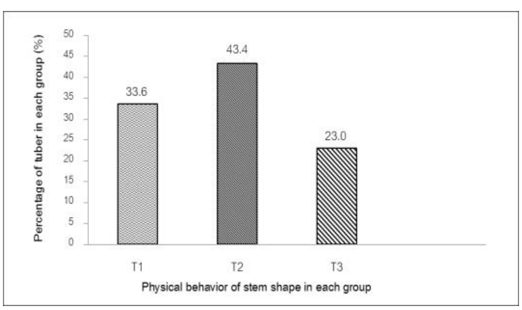

Figure 7 Average number of tubers per rhizome of groups T1, T2 and T3.

The study on size of cassava tubers showed the following results: diameters of three tuber sections (base, middle and end part) were 4.2-8.5, 3.1-6.7 and 2.1-5.3 cm respectively. Their lengths ranged between 2.2- 4.4 cm and their weights ranged between 0.2- 1.0 kg (Table 2). Average density of cassava tubers was 820.83 kg/m^3. (Table 3).

Table 2 Tuber average sizes from 5 plots.

Properties	Diameter (cm)			Length (cm)	Tuber weight (kg)
	Base	Middle	End		
Maximum	8.5	6.7	5.3	4.4	1.0
Minimum	4.2	3.1	2.1	2.2	0.2
Mean	5.6	4.8	3.4	3.0	0.6
SD(±)	0.7	0.7	0.7	0.5	0.5

*The numbers represent mean values and ± indicates the standard deviation

Table 3 Average density of cassava tubers.

Replication	Box's weight (kg)	Box's weight + Tuber weight (kg)	Tuber weight (kg)	Bulk density (kg/m^3)
1	3.04	9.44	6.40	800.00
2	3.04	9.54	6.50	812.50
3	3.04	9.84	6.80	850.00
Mean	3.04	9.60	6.56	820.83

Fresh cassava tuber on rubber sheet surface had the highest coefficient of static friction (40.0-42.0 degrees), followed by oriented strand board and steel sheet surfaces (35.0-38.0 and 28.0-30.0 degrees respectively). The lowest coefficient of static friction was found for fresh tuber with transversal and longitudinal drive modes on stainless steel sheet (25.0-27.0 degrees). Therefore, steel sheet with 28.0-30.0 degrees was considered suitable for actual usage in designing machine outlet for long-term usage and high strength (Table 4), according to the principle of engineering design of Shigley and Mischke [13] and the principle of agricultural machinery design of Krutz et al. [14].

Table 4 Average coefficient of static friction for fresh tuber on various material surface

Coefficient of static friction				
Longitudinal/transverse direction	Oriented Strand Board (^{O})	stainless sheet (^{O})	Steel sheet (^{O})	Rubber sheet (^{O})
Longitudinal	35.0	25.0	28.0	40.0
Transverse	38.0	27.0	30.0	42.0

Experiment and performance evaluation of cutting tubers from the rhizome by using human labors indicated that farmers usually dug tubers or pulled tubers out of soil and then separated tubers from rhizome using a knife. The sampling rhizomes had an average weight of 2.50 kg/rhizome with an average tuber number of 9.56 tubers/rhizome. The result showed an average working rate of 352.53 kg/hr/person or 163.05 rhizome/hr/person and average cutting loss of 0.22% (Table 5). The three experiment steps showed that Step 2 consumed the longest average time (7.55 seconds/rhizome), followed by Step 1 and Step 3 (2.56 and 0.65 seconds/rhizome respectively) (Table 6). Step 2 needed longer time than other steps because of the difference in rhizome size and higer tuber number which would take longer operation time for cutting, 3-8 times per rhizome.

Table 5 Average working rate and post-cutting loss for tuber separation from rhizome by manual labor, in accordance with farmer practice.

Person	Working rate		post-cutting loss (percent)
	(kg/hour/person)	(rhizomes/hour/person)	
1	360.50	168.21	0.25
2	350.34	170.31	0.22
3	346.77	150.65	0.20
Mean	352.53	163.05	0.22

Table 6 Average operation time of tuber separation from rhizome by manual labor, in accordance with farmer practice, classified by procedural steps in each operation.

Operation procedure	Person			Average time (seconds/rhizome)	SD(±) (seconds/rhizome)
	1	2	3		
1. Taking pre-cut rhizomes from stock pile	2.56	2.55	2.56	2.56	1.52
2. Cutting tubers from rhizomes by blade	7.55	7.53	7.56	7.55	1.30
3. Disposing of post-cut rhizomes	0.64	0.65	0.66	0.65	0.21
Total time				10.76	3.03

(a)

(b)

Figure 6 (a) Post-cut rhizomes by human labors, and (b) post-cut tubers by human labors.

4. Conclusion

The study of physical properties of cassava among 3 stem shapes, T1, T2, and T3 from 5 plots, with 200 rhizomes each, indicated the highest tuber number belonging to shape T2 with an average of 43.4 %, followed by stem shape T1 and T3 with 33.6 and 23.0 % respectively. As for the tuber size, the diameters of tuber for all 3 sections were 4.2-8.5 cm for base part, 3.1-6.7 cm for middle part, and 2.1-5.3 cm for end part. Tuber lengths ranged from 2.2-4.4 cm and the weight was between 0.2-1.0 kg. Average bulk density of tubers was 820.83 kg/m^3. The coefficient of static friction for the steel sheet in the longitudinal and transversal directions was between 28.0^{o} - 30.0^{o}. performance in cutting cassava tubers from their rhizomes using manual labor an average working rate of 352.53 kg/hour/person or 163.05 rhizomes/hour/person, with an average of 0.22 % post-cutting loss. Among 3 steps of operation procedure, Step 2 was the most time-consuming operation in each cycle. The reason for the longer cutting time taken in this step was because of the large number of tubers to be cut and separated, at values about 3-8 cutting times for one rhizome or an average of 7.55 seconds per rhizome, whilst Steps 1 and 3 spent averagely 2.56 and 0.65 seconds/rhizome respectively.

5. Acknowledgements

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