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A study of cassava physical behavior for a design of cassava combine harvester

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Abstract

The research objective was to study physical behaviors of cassava parameters for a design of cassava combine harvester. The cassava used in this study was of variety Kasetsart 50. The study of the cassava stem shape found the highest percentage number of cassava stems to belong to the shape groups T2, T1 and T3 with the average of 76.0%. For the groups T2, T1 and T3, the stem decisive behavior of cassava was an upright stem with a few branches that fit the gripping unit of the cassava combine harvester. The study of tilt angle behavior of cassava stem tilting at angle with its rhizome horizontal plane, revealed the highest amount of cassavas to belong to the angle in the range 60°-90°, followed by the 30°-59° angle range, with averages of 75.9% and 18.1% respectively. The angle ranges of 60°-90° and 30°-59° were considered as good condition for an upright stem being easily pulled off the soil and therefore suitable for the design. Further study of tilt angle behavior of cassava tuber tilting at angle with its rhizome horizontal plane, revealed the highest amount of cassavas tested to belong to the angle range of 60°-90°, followed by that of 30°-59°, with averages of 74.6% and 13.9% respectively. Consequently, the cutting blade had to be designed as a cylindrical shape, considered to be more suitable for the tilt angle behavior within ranges of 60°-90° and 30°-59°.

Keywords: Cassava rhizome, Combine harvester, Physical behavior

1. Introduction

Cassava (*Manihot esculenta*) is one of the most important economic crops in Thailand with a total cultivated area of 1.37 million hectare with crops yield of 30 million ton/year (fresh tuber) in 2016-2018, distributed over almost all regions of Thailand. Most cultivation areas are located in the northeast region, followed by the central and the northern regions. The most cultivated variety of cassava is of variety Kasetsart 50. In Thailand, farmers begin to cultivate the cassava in early rainy season from March to May, and mid-dry season from November to February. Therefore, the crop can be harvested throughout the year, especially from December to July. All yields of fresh cassava tuber from every region of the country were processed into various raw materials supplying various industries, for example, cassava flour for paper and textile industries, cassava pellets for animal feed industries, cassava chips for ethanol industries, and material for other industrial sectors, etc. [1,2]. Currently, a general harvesting method of cassava begins with stem cutting that leaves 30 cm of stem above ground, then unearthing and gathering by labors or a puller machine. Later, tubers are cut and separated from their rhizomes by hand. The only way to assemble harvested tubers is by labors gathering tubers in baskets and loading onto a truck. This process consumes time and requires manpower, about 7-10 person for each operation Currently, human labor is still required, with chopping capacity 300-340 kg/h/person or 160-165 rhizomes /h/person. There was a loss of 0.17-0.20 %. The ability to separate the tubers from the rhizomes by machine 400 kg/h. Tapioca lost 0.18%. [3-6]. Consequently, the harvest cost is relatively high, as well as, an issue of labor shortage progressively increases in the agricultural sector [7]. Many researchers have proposed various guidelines to develop and research on cassava cutting and harvesting machinery, for examples, a sawing blade cutting, a pressured cutting, and a combine harvester machine which the prototype is still in the early stage of development in various operation principles [8-11]. A significant physical behavior with respect to shape of cassava stem and rhizome is a factor affecting amount of product loss and harvesting efficiency. However, all previous studies have collected data only on the purpose of machinery testing, but pre-testing physical behavior of cassava has yet to be studied.

Therefore, this research aims to study the physical behavior of cassava in order to collect more information for the design of cassava combine harvester, especially for the part of stem gripping unit and cutting set to separate the cassava tuber from its rhizome. For example, the maximum diameter of the rhizome and the stem was designed to design a cylindrical cutter blade and a cassava stem gripper. The width of cassava root distribution was determined, the size and structure of the cassava grappling device.

2. Materials and methods

The study divided a testing procedure into 2 phases; procedure 1 consisting of 3 measurements, physical behavior of cassava stem shape, tilt angle of stem tilting at angle with its rhizome horizontal plane, and tilt angle of tuber tilting at angle with its rhizome horizontal plane. The procedure 2 was a study of physical properties of cassava rhizome and tuber. The cassava used in this study was of variety Kasetsart 50, plant age of 12 months, from 5 study plots with 200 sample individuals per plot, and planted in Khon Kaen Province. A random sampling method was used to collect the cassava from the study plots. The processes and methods of this study were as follows;

2.1 A study of the physical behavior of cassava stem shape

For the pre-harvested cassava, the physical behavior of stem shape could be classified into 6 groups; group T1 was a single stem without branch, group T2 a single stem with 2 branches, group T3 a single stem with 3 branches, group T4 a two-stem type, group T5 a multiple-stem type, and group X a miscellaneous-stem type, as shown in Figure 1 the classification basis for grouping T1, T2, T3, T4, T5 etc. A significant physical behavior with respect to shape of cassava stem and rhizome is a factor affecting amount of product loss and harvesting efficiency.

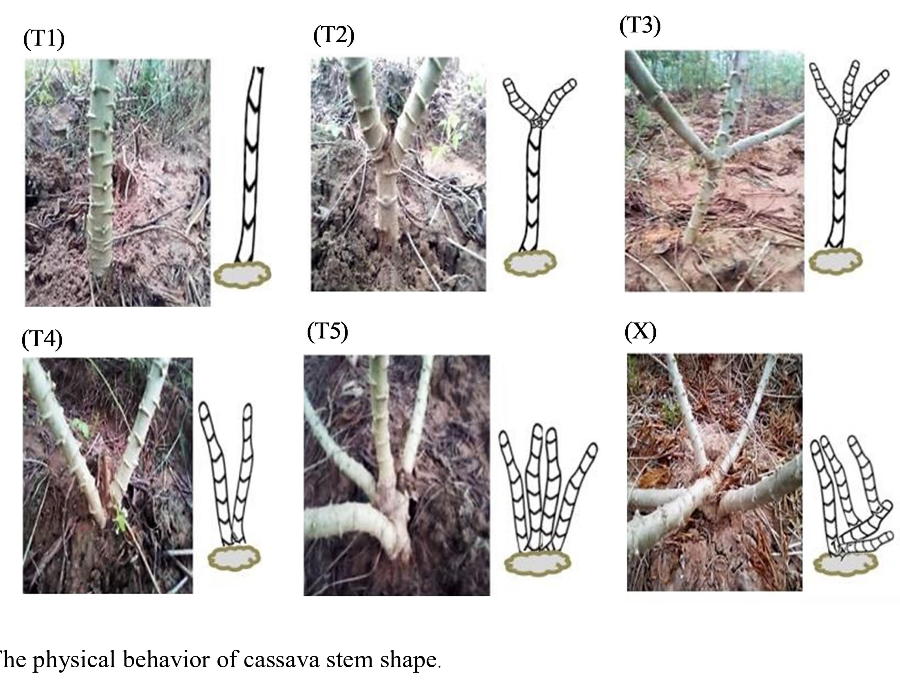

Figure 1 The physical behavior of cassava stem shape.

2.2 A study of tilt angle behavior of cassava stem tilting at angle with its rhizome *horizontal plane*

The cassavas in this test were directly dug from the study plots. The study of tilt angle behavior was conducted only on cassavas in groups T1, T2 and T3 of stem shape, due to the potential of 'single stem' of these groups being utilized in the design of gripping unit of the harvester. The tilt angle was classified into 3 stem levels, an upright stem in the range 60°-90°, a semi-lean stem in the range 30°-59°, and a lean stem in the range $<30^{\circ}$. Equipment and methods for the measurement of tilt angle followed the method by Junsiri et al. [12], as shown in Figure 2.

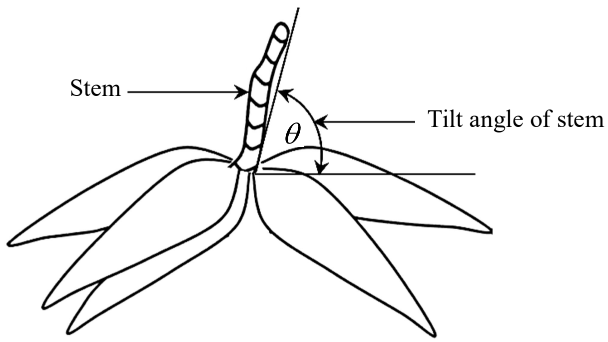

Figure 2 The tilt angle measurement of stem tilting at angle with its rhizome horizontal plane.

2.3 A study of tilt angle behavior of tuber tilting at angle with its rhizome horizontal plane

The cassava tubers were directly dug from the study plots. The study of tilt angle behavior of the tuber tilting at angle with its rhizome horizontal plane*,* was conducted on the same groups T1, T2 and T3 as in 2.1.2 The tilt angle was one of the factors affecting harvesting loss, especially in the process of cutting tuber off its rhizome. In case of the angle being too large, tubers might not be completely cut off or leave some remnants. The tilt angle was classified into 4 tuber levels; an incomplete cutting angle in the range $>90^{\circ}$, a complete cutting angle in the range 60°-90°, a semi-complete cutting angle in the range 30°-59°, and a partial cutting angle in the range $<30^{\circ}$. The measurement method was used, as shown in Figure 3.

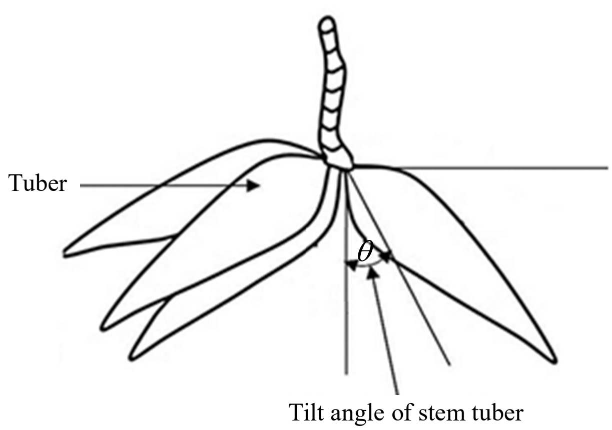

Figure 3 The tilt angle measurement of tuber tilting at angle with its rhizome horizontal plane.

Data were collected from all measurements of stem shape, the tilt angle behaviors of stem and tuber tilting at angle with each rhizome horizontal plane, and then were analyzed.

2.4 A study of the physical properties of cassava rhizome and tuber

The study of physical properties of cassava rhizome and tuber aims to obtain additional information for the design of cassava combine harvester. The physical properties in this study focused on width of tuber distribution around its rhizome, rhizome's height, rhizome's diameter, total weight of rhizome and tuber, and moisture content of fresh tuber. The moisture content was determined by the cassava rhizomes used in this study were directly dug from study plots. A measuring position was based on the method by Jengsooksawat et al.[13]; Langkapin et al. [9], as shown in Figures 4 and 5. The data were recorded and analyzed for average values, and the lowest and the highest values.

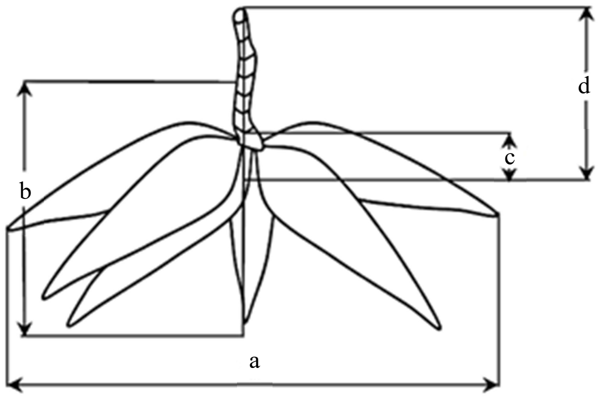

Figure 4 The measurement positions of tuber distribution width and rhizome's height.

Where,
a = the width of tuber distribution (cm).
b = the height of tuber to the middle of stem (cm).
c = the height of rhizome (cm).
d = the height of rhizome to the stem end (cm).

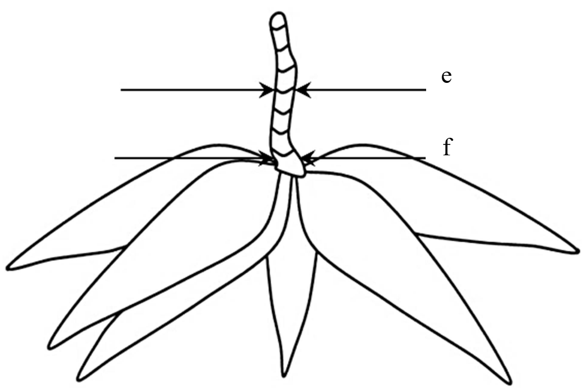

Figure 5 The measurements of rhizome's diameter and stem's diameter.

Where,
f = rhizome's diameter (cm)
e = stem's diameter (cm)

3. Results and discussion

3.1 The results of stem shape

The tilt angle behavior of stem tilting at angle with its rhizome horizontal plane and the tilt angle behavior of tuber tilting at angle with its rhizome horizontal plane could be summarized in each procedure as follows:

3.1.1 The study of stem shape was conducted on cassavas

Having be obtained from 5 study plots, 200 rhizomes per plot, by classifying into 6 groups, T1, T2, T3, T4, T5 and X. The result revealed the most common stem shape to belong to group T2 with an average of 34.0%, followed by groups T1 and T3 (25.4% and 16.6% respectively). The stems of these 3 groups could be easily held by the gripping unit which was considered suitable for the design of the harvester. The shapes in groups T4, T5 and X were not fit for the gripping unit due to multiple stems and branches that might affect the amount of loss during harvesting. Therefore, the shapes in groups T1, T2 and, T3 would potentially be more fit for the gripping unit and tools than groups T4, T5 and X. In addition, the summed amount of stems in groups T1, T2 and T3 was over 76.0±8.6%, whilst that of groups, T4, T5 and X was only 24.0%±4.9, a factor affecting amount of product loss and harvesting efficiency. as shown in Figures 6 and 7.

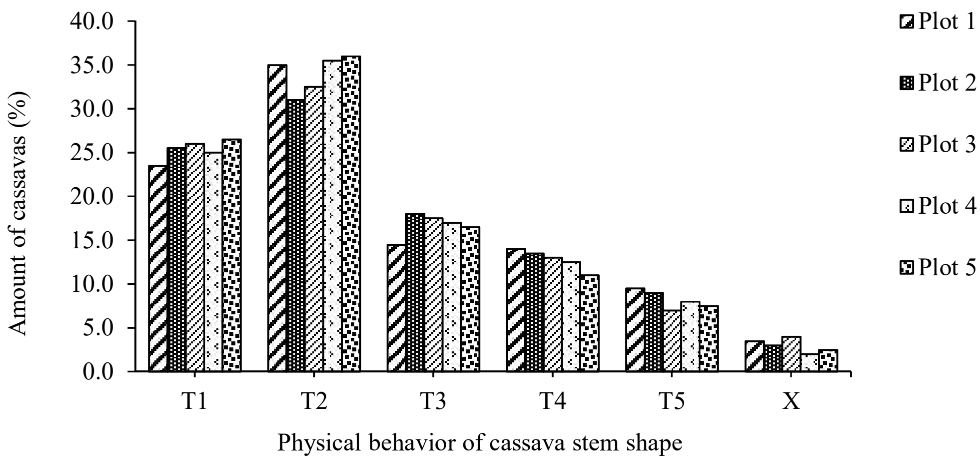

Figure 6 Percentage of cassavas found for each stem shape in each plot.

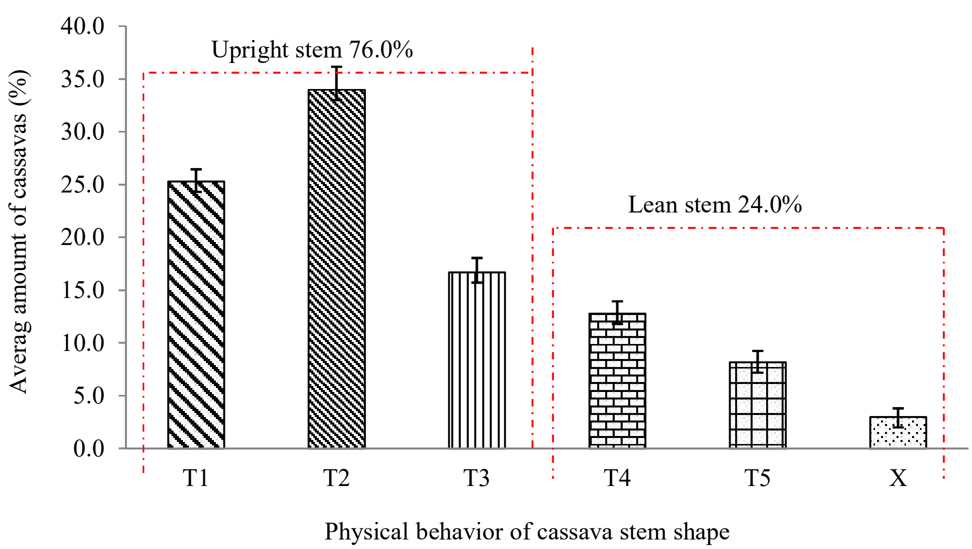

Figure 7 The average percentage of cassavas found for each stem shape in overall 5 study plots.

3.1.2 The tilt angle behavior of cassava stem

The classification for 3 levels, 60°-90°, 30°-59° and <30°, from 5 study plots, 200 cassavas per plot. The results found that cassavas with tilt angle in the range 60°-90° were the most common with an average of 75.9±1.8%, followed by those in the range 30°-59° with an average of 18.1±1.3%, whilst the least amount belonged to the tilt angle in the range <30° with an average of 6.0±0.7%. For the design of cassava harvester, the tilt angles in the ranges 60°-90° and 30°-59° were considered suitable for the design because upright stems would be easily held and pulled off the soil by the gripping unit, whilst the stem with tilt angle less than 30° was too lean for the gripping unit to efficiently unearth the tuber, resulting in faulty grip and more amount of loss during harvesting. Therefore, the tilt angles in the ranges 60°-90° and 30°-59° could be utilized for the design of tools and gripping unit, better than the lean angle in the range <30°, as shown in Figures 8 and 9.

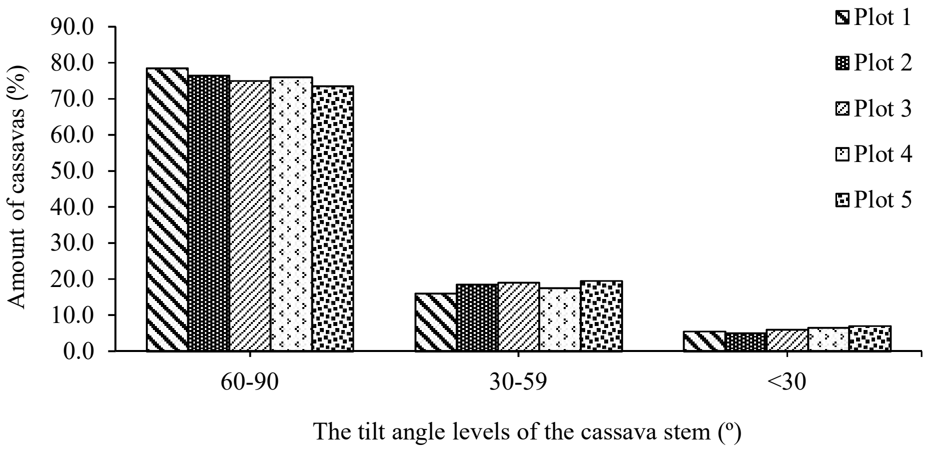

Figure 8 The percentage of cassavas found for each tilt angle in each plot.

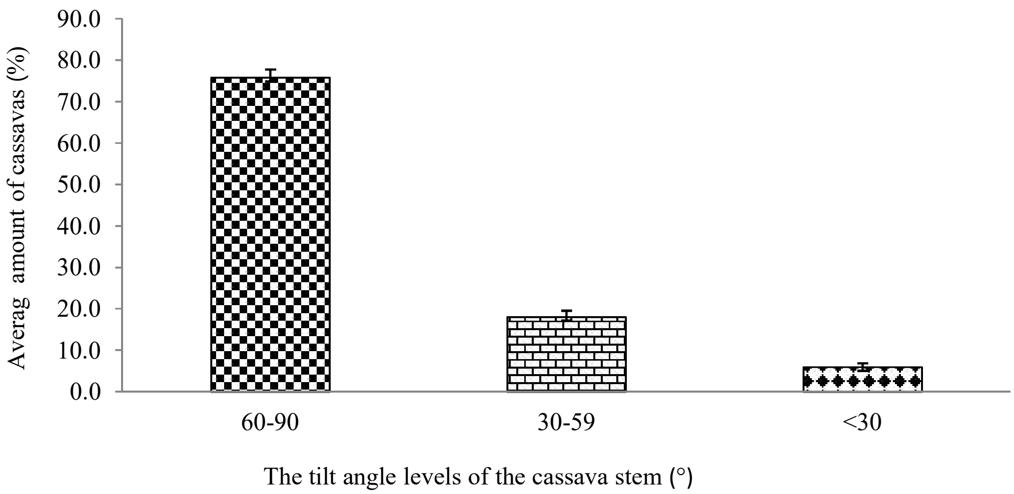

Figure 9 The average percentage of cassavas found for each tilt angle in overall 5 study plots.

3.1.3 The study of tilt angle behavior of cassava tuber

From 5 study plots, 200 cassavas per plot, by classifying into 4 levels of tilt angle, >90°, 60°-90°, 30°-59° and <30°. The results found that the highest amount of cassavas with tilt angle in the range 60°-90° had an average of 74.6±0.7%, followed by tilt angle in the range 30°-59° an average of 13.9±1.9%, whilst the least amount of cassavas with tilt angles in the ranges >90° and <30° had averages of 6.0±0.8% and 5.5±1.0% respectively. For the design of cassava harvester, a cutting blade was considered an important tool to separate the tuber from its rhizome. Moreover, the tilt angle between tuber and its rhizome was one of the factors affecting complete or incomplete cutting during the harvesting process. Consequently, the cutting tool should be designed as a cylinder-shape blade in order to fit with the tilt angle behavior of the tuber and rhizome so that they would be easily separated. The levels of tilt angle suitable for the cutting tool were in the ranges 60°-90° and 30°-59°, because such positions would enable the tubers to be easily accessed and cut. The tilt angles of >90° and <30° gave the positions that the tubers would be difficultly cut off and/or incompletely cut, causing additional amount of loss during harvesting. Therefore, the tilt angles in the ranges 60°-90° and 30°-59° were considered more suitable for the design of cylindrical-shape cutting blade for the harvester in cutting the tuber off its rhizome, as shown in and Figures 10 and 11.

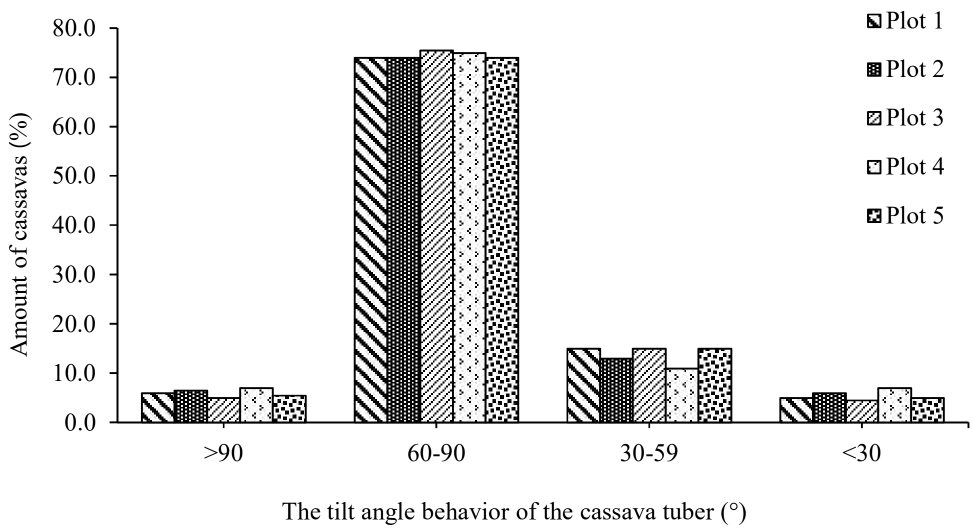

Figure 10 The percentage of cassavas found for each tilt angle level in each plot.

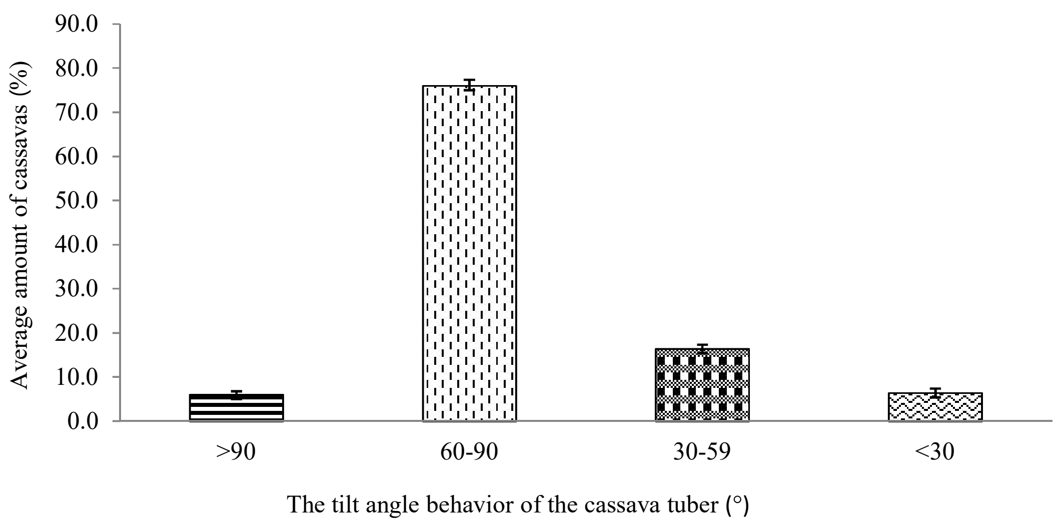

Figure 11 The average percentage of cassavas found for each tilt angle level in overall 5 study plots.

3.2 The results of physical properties of the cassava rhizome and tuber

The physical properties of the cassava rhizome and tuber were studied using cassavas directly dug from 5 study plots, 200 cassavas per plot. The measurements consisted of tuber distribution width, height and diameter of tuber and rhizome, total weight of rhizome and tuber, and moisture content of fresh tuber. The results revealed the width of tuber distribution to be in the range 21.3-54.0 cm, whilst, the rhizome's height in the range 21.2-29.0 cm for the tuber-middle part, 14.6-17.6 cm for the rhizome part, and 29.3-32.7 cm for the rhizome-end part. The rhizome's diameter was in the range 2.8-5.6 cm for the rhizome part, and 1.9-3.3 cm for the middle part. The total weight of tuber and rhizome was in the range 1.9-6.6 kg, as shown in Tables 1. The average moisture content of fresh tuber was 61.8% wb. These results provided useful information base for the design of the cassava combine harvester, for example, the largest diameter of the rhizome and tuber could be applied for the design of cutting blade and gripping unit, whilst the width of tuber distribution could be applied for the structural design of gripping unit to pull the tuber off the soil, etc., in accordance with engineering design principle.

Table 1 The result of physical properties, width of tuber distribution, rhizome's height and diameter, total weight of rhizome and tuber, by overall average values of 5 study plots. The average values of physical properties of overall 5 study plots.

Properties	Width of tuber distribution (cm) (a)	Rhizome's height (cm)			Rhizome's diameter (cm)		Total weight of rhizome and tuber (kg)
		Tuber-middle (b)	Rhizome (c)	Rhizome-end (d)	Rhizome (e)	Middle (f)	
Max.	54.0	29.0	17.6	32.7	5.6	3.3	6.6
Min.	21.3	21.2	14.6	29.3	2.8	1.9	1.9
Avg.	35.0	24.3	16.5	31.0	3.3	2.5	3.8
SD(±)	8.0	1.5	0.6	0.7	0.5	0.6	1.4

*The numbers represented mean values and ± indicated the standard deviation.

The study of cassava physical behavior for the design of combine harvester could be first summarized that the stem shapes of group T2, T1 and T3 were the most common, with an average of highest number of cassava stems of 76.0±8.6%. A single stem with a few branches within these 3 shape groups could easily be held by gripping unit. The study of tilt angle behavior of stem tilting at angle with its rhizome horizontal plane revealed the highest amount of cassava stems to belong to the angle in the range 60°-90°, followed by the 30°-59° angle range, with averages of 75.9±1.8 and 18.1±1.3% respectively. For these 2 ranges of angle, the cassava stem was quite upright which would be easily held and pulled off the soil. Therefore, the amount of loss from harvesting would be minimized. This result of study was similar to the study of Junsiri et al. [12] on rice, who had studied the physical tilt angle of rice stalk occurring during the harvesting process which was an important cause of loss. If the rice stalk inclined, the spokes could not reap all the rice to be cut.

The study of tilt angle behavior of tuber tilting at angle with its rhizome horizontal plane, found that most cassavas had the tilt angle in the range 60°-90°, followed by the 30°-59° angle range, with averages of 74.6±0.7% and 13.9±1.9% respectively, which was similar to the study of Junsiri et al. [12] who had studied the physical properties of agricultural materials according to the natural form. The study of Junsiri et al. [12] used radius gauges according to the technique of testing agricultural materials. The results have been used as important information for designing machinery, process, structure, and control. The obtained results suggested a cylindrical-shape of cutting blade to be suitable for enabling the tuber to be cut off more easily.

For the physical properties of cassava rhizome and tuber, the width of the tuber distribution was in the range 21.3-54.0 cm, the rhizome's height was in the range 21.2-29.0 cm for the tuber–middle part, 14.6-17.6 cm for the rhizome part, and 29.3-32.7 cm for the rhizome-end part. The rhizome's diameter was in the range 2.8-5.6 cm for the rhizome part, and 1.9-3.3 cm for the middle part. The total weight of rhizome and tuber ranged from 1.9 kg to 6.6 kg. The moisture content of fresh tuber was averagely at 61.8% wb, which was similar to the results of the study of Langkapin et al. [9] who studied the physical characteristics of rhizome and tuber, aged 10 months. According to the gauging physical characteristics of rhizomes, it was found that the width of the tuber distribution was in the range 34.0-72.0 cm, the rhizome's height was in the range 22.0-37.2 cm, the rhizome's diameter was in the range 2.4-5.0 cm, the total weight of rhizome and tuber ranged from 1.6 kg to 4.2 kg, and the moisture content was at 57.4% wb. The data obtained from the gauging were consistent with the data of this study.

Ultimately, the results of important physical properties would be utilized in the design of the cassava combine harvester. For example, the maximum diameter of the rhizome and the stem was designed to design a cylindrical cutter blade and a cassava stem gripper. The width of cassava root distribution was determined, the size and structure of the cassava grappling device. in order to reduce the issue of labor shortage and to help researchers in the development of agricultural machinery for effective cassava harvesting in the future.

4. Conclusion

The results of the study of cassava physical behavior for a design of cassava combine harvester showed that the highest number of cassava stems belonged to the shape groups T2, T1 and T3 with the average of 76.0%, followed by groups T4, T5 and X with the average of 24.0%. The study of tilt angle behavior of cassava stem tilting at angle with its rhizome horizontal plane, revealed the highest amount of cassavas to belong to the angle in the range 60°-90°, followed by the angle in the range 30°-59°, whilst the least amount was from angles $<30^{\circ}$, with averages of 75.9%, 18.1%, and 6.0% respectively. The study of tilt angle behavior of cassava tuber tilting at angle with its rhizome horizontal plane, revealed the highest amount of cassavas to belong to the angle in the range 60°-90°, followed by the angle in the range 30°-59°, with averages of 74.6% and 13.9% respectively. The least amount belonged to angles >90° and <30°, with averages of 6.0% and 6.4% respectively. Finally, for the physical properties of cassava's rhizome and tuber, it was found that the width of tuber distribution was in the range 21.3-54.0 cm whilst the rhizome's height in the range 21.2-29.0 cm for the tuber-middle part, 14.6-17.6 cm for the rhizome part, and 29.3-32.7 cm for rhizome–end part. The rhizome's diameter was in the range 2.8-5.6 cm for the rhizome part and 1.9-3.3 cm for the middle part. The total weight of rhizome and tuber was in the range 1.9-6.6 kg while the moisture content of fresh tuber was 61.8% wb.on the average.

5. Acknowledgements

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