Physical and mechanical properties of sweet corn plant

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Abstract: Physical and mechanical properties are important issues to be studied due to its importance in the design of agricultural equipment and its relationship to the production operation. The average physical properties for weight, length, diameter, volume, porosity, repose angle, and angle of friction of sweet corn cobs and some of their components were measured. Moreover, the average mechanical properties for pulling force at three different angles (0, 45 and 90 degree) where at 90 degree gave the lowest value of pulling force of corn cobs which was 51.14 ± 1.97 N, compression force at vertical 497.56 ± 63.14 N; at horizontal 2801.26± 346.10 N, shearing force at two different angles (0 and 45) degree where at 45 gave the lowest value of shearing force of corn cobs which was 448.27± 34.03 N, and penetration 1.633± 0.144 N of sweet corn cobs and some of their components were measured. In addition, the physical properties of sweet corn plant for height of plant 211.70 ± 3.62 cm, width of plant 96.00 ± 2.17 cm, diameter of stalk at 20 cm from ground 2.21 ± 0.09 cm, weight of complete plant with root 0.833 ± 0.049 kg, leaves 0.077 ± 0.002 kg, stalk 0.318 ± 0.009 kg, corncobs 0.420 ± 0.032 kg and roots 0.068 ± 0.002 kg, moisture content of leaves 56.22% ± 5.10%, stalk 79.54% ± 2.14% and roots 62.33% ± 3.85%, and the average mechanical properties for pulling force at 0 degree 549.32 ± 6.27 N; at 45 degree 400.19 ± 3.05 N; 90 degree 334.00 ± 3.09 N, and shearing force at 0 degree 205.45 ± 20.59 N; at 45 degree 167.15 ± 25.10 N of the plant were conducted. These outcomes indicated possibility its utilization in design agriculture machine to determine standards of design machine.

Keywords: physical properties, mechanical properties, shearing force, penetration force, sweet corn.

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1 Introduction

Corn (*Zea mays* L) ranks as the third most important cereals in the world. Asian countries are significant producers of sweet corn and more than 62% of their corn production is consumed in the form of animal feed, while the balance is for human consumption. While sweet corn has been traditionally a popular vegetable in the USA, China and Brazil, it has in recent gained popularity in many other Asian countries including Malaysia. Corn is the staple food of a large population of the world's communities and one of the most economically principal food crops in the world.

Physical properties and especially mechanical properties of biological materials produced by agriculture have long been the object of scientific interest. The growing level of mechanization of work in agriculture and in food processing required that type of knowledge, necessary for

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the machine design engineers creating machines and equipment that are more and more aggressive in their operation. To design of technological processes, there is need to know all properties of mechanisms on biological materials (Szymanek et al., 2006). One approach to diminish damages in production is to explore the physical and mechanical properties of agricultural crops. The physical and mechanical properties of agricultural items have a powerful part in deciding the nature of the items, lessening the potential harm caused by transportation and in the long run outlining the equipment utilized as a part of the handling of the items (Sadeghi et al., 2010; Gholami et al., 2012; Mirzabe et al., 2012; Mirzabe et al., 2013; Li et al., 2016 and Jahanbakhshi, 2018).

Ertek and Kara (2013) reported that the plant height was 142.5-182.4 cm and stem diameter values 12.4-12.5 cm, cob length 15.8-16.9 cm and cob diameter values 40.2-40.5 mm, a number of kernels per cob 487.9-496.9, cob weight 207.4-211.7 g for fresh sweet corn during the years of 2011 and 2012 respectively. However, the cob length 22.21 cm and cob diameter values 49.4 mm, the number of kernels per row 28.05, number of kernel rows 14.72 in the study were all noted to establish the sweet corn's quality of some physicochemical properties (Szymanek, 2011). However, it has been reported by Saleh et al. (2002) in their study that with some sweet corn varieties their plant height was found to be in the range between 88 and 177.3 cm, cob weight, 89.9-203.4 g, cob length, 11.9-17 cm, and cob diameter, 32.2-44.5 mm. Nevertheless, Xu et al. (2014) found the plant height in between 190.43 to 202.27 cm, cob height, 57.40-62.60 cm, cob length, 17.17-18.04 cm, kernel rows, 13-13.72, and kernels per row, 36.03-38.66.

It was mentioned by Seifi and Alimardani (2010) that the porosity can be beneficial in planning the size of grain hoppers and storage facilities. Additionally, porosity of corn grains increased linearly from 43.2% to 51% when moisture content was raised from 4.73% to 22% wet basis, which were similar to the findings of Coşkun et al. (2006). The porosity of sweet corn seeds was seen to increase from 57.48% to 61.30% when moisture content was raised from 11.54% to 19.74% dry basic. These findings were the same as those of Karababa and Coşkuner (2007) for sweet corn kernel, and supported the findings of Seifi and Alimardani (2010), and Sobukola et al. (2013) for seed corn. To the best knowledge of these researches, there are no existing findings on the porosity of sweet corn cobs.

Coşkun et al. (2006) were determined a static coefficient of friction on four surfaces (elastic, aluminum, stainless steel, and galvanized iron) with a different moisture content of sweet corn seeds. It was observed that the static coefficient of friction was affected by increasing the moisture content of a material to all surfaces. Due to the high moisture content of the seeds was affected in the adhesion strength between the seeds and the surfaces. At all moisture contents, the stainless steel showed the lowest static coefficient of friction compared with others. This could be attributed to surface of stainless-steel polished and smooth. Similar results were found by Karababa and Coşkuner (2007) for sweet corn kernels.

Anderson and Bern (1984) reported that measurements of a repose angle made of corn cobs piles were found the mean angle for placed was 36°. However, Pradhan et al. (2008) stated that the repose angle of corn seeds was the increase of seed moisture content from 8.56% to 22.22%. The values were observed to rise from 27.69° to 37.33°. The tendency towards the repose angle with moisture content takes place because of the surface layer of moisture around the particles, which holds the total seeds together by surface tension. Similar results were indicated for sweet corn kernel by Karababa and Coşkuner (2007).

It was claimed by Akritidis (1974) that the significant mechanical factors affecting the cut of corn stalks. Analysing the stalk cutting involves the correlation of the main mechanical properties of the stalk and the cutting blade. On the other hand, Esehaghbeygi et al. (2009) were measured the shear stress of canola stalk for four levels of moisture content (35%, 43%, 50% and 57%, wet basis), with different cutting heights, two kinds of varieties, three levels of fertiliser. The knife oblique angle of 30 degree was found to apply the slightest shearing pressure. Prasad and Gupta (1975) were measured the shearing force and ability for cutting corn stalks. They found that the maximum shearing force and the shearing ability in the direct shear test were seen to decline with the shearing velocity. İnce et al. (2005) reported that the bending stress was less with increasing moisture content. The estimation of the compressing bending got was about two times at low moisture content compared with a high moisture content. The mean compressing bending was ranged from 9.71 to 47.49 MPa. Batos et al. (2015) conducted a study on the wheat stalks. The cutting tests were done for two cutting velocities and two cutting angles. The moisture content of the samples ranged from 5.5% to 7.1%. The main cause for this difference was the greater friction at the larger cutting angle. In addition, it must be noted that the blade has to travel a longer distance in order to separate the sample at a cutting angle of 60° compared with 40°.The bending stresses were 1.09 N mm^{-2} for the first, 0.99 N mm^{-2} for the second and 1.07 N mm^{-2} for the third internode.

According to Miu (2016), the mechanical and physical properties of plant stalks affect their behaviour under the impact of the mechanical forces exerted through the harvester combine, in terms of plant curvature (towards cutting unit), cutting (shear stress), and pick up cob. To assist modeling, emulation, and optimising of combine operations, it is absolutely required to give consideration to credible experiential data. For some properties after harvesting of the cereal stalks. These presented plant stalk data depends on ripeness of plant, and environmental conditions during harvesting. This means that consideration should be given to the physical properties of the sweet corn plant and the related mechanical properties of the plant components, which is crucial in the process of modeling and engineering design of agricultural machines.

Knowledge of all the mechanical properties of biological materials is necessary for the layout of technological processes as mentioned by Szymanek et al. (2006).

In this study, the objectives were to create a database on the crop, particularly the physical and mechanical properties of sweet corn plant as such knowledge would be required to facilitate design engineers to create machines and equipment.

2 Material and methods

The data used in this research were collected during October to February 2016 - 2017 sweet corn cultivation at Sekinchan, Sungai Besar in Sabah Bernam district of Selangor, Malaysia located at 3°33'03.2"N 101°07'57.3"E. Sweet corn time of harvesting plant depends on its variety and time it is planted. Usually, the sweet corn plant takes 60 to 120 days from planting to harvest. For this study, sweet corn with age 60 and 68 days after planting were harvested to determinate the physical properties of sweet corn plant. Mechanical and physical properties conducted some tests of biomass material of sweet corn from the field and taking some samples to the laboratory.

2.1 Weight of corn cob

Forty samples of corn cobs and their components (corn cob, kernel, husk and silk) were harvested by hand selected randomly of corn cob where was selected mature corn cob and the exclusion of immature ones, weighed by using digital balance with accuracy of 0.01-999 g.

2.2 Porosity

Porosity is the factor indicates the frequency of pores in the bulk material and is shown in Equation 1 as a function of bulk and true densities. The porosity of sweet corn cobs was established using box known size. Then add corn cobs to the box randomly and determine the numbers and sizes of corn cobs, then the weight of each of them to find porosity by a percentage or kg m^{-3} (Mohsenin, 1986).

$$\varepsilon=(1-\rho b/\rho t)*100 \quad (1)$$

Where ε = Porosity (%), ρb = Bulk density (kg m^{-3}), ρt = True density (kg m^{-3}).

2.3 Length and diameter of corn cob

It is measured in length and diameter of corn cob by using a digital calliper.

2.4 Repose angle of corn cob

The repose angle (θ) was obtained by placing the sample into a vessel with known diameter base and altitude.

When the vessel was filled, it was tardily raised until it was free of the sample and the cone-shape created by the sample was then measured for its diameter (D) and height (H), and repose angle was computed with the Equation 2 (Mohsenin, 1986).Three replications were made for the angle of repose on each of the samples.

$$\theta = \tan^{-1}(2H / D) \qquad (2)$$

Where θ = Angle of repose (degree), H= Height of the cone (mm), D = Diameter of the cone (mm).

2.5 Angle of friction of corn cob

The angle of friction is the resistance level of the sample to flow on a given surface, which would be beneficial in designing the harvester tank. Samples of corn cobs were carefully put it on the surface made from malt steel. The surface was raised gently from one side until the corn cob began to slide down Three replications of the experiment were conducted.

2.6 Pulling force of biomass material (N)

Pulling force was measured using a 9500 series CPU digital force gauge which was designed for efficient measurement of tension in the field and different angles (0, 45 and 90 degree) for corn cobs, leaves, kernels and stalks as reported by (Gupta et al., 2008) with angles at 0, 10, 20 and 30 degrees pull angles. Samples were randomly selected, and 40 replications were made for each test. Figure 1 shows measurement pulling force of corn cobs.

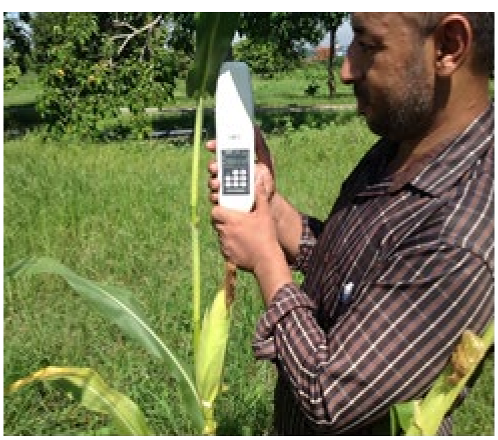


Figure 1 Measuring the pulling force of corn cobs

2.7 Shearing force of biomass material (N)

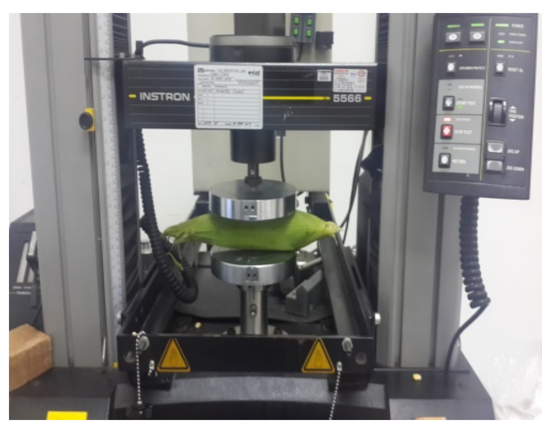
An Instron Universal Test Machine (IUTM) equipped with a 5 kN load cell and with an accuracy of ± 0.25% was employed for the measurement of the shearing force of corn cob and stalk and kernel in different angles (0 and 45 degree) (Batos et al., 2015; Esehaghbeygi, et al., 2009). Appropriate probe for each test was utilized with predetermined feed speed (50 mm min^{-1}) with 200 N load cell. Selection of samples was done at random and 40 replications were made for each test.

2.8 Compression force of corn cobs and kernel (N)

An Instron Universal Test Machine (IUTM) equipped with a 5kN load cell with an accuracy of ± 0.25% was employed for measuring the compression force of corn cob in different angles (0 and 90 degree) and kernel. Appropriate probe for this test was utilised with predetermined feed speed (50 mm min^{-1}) with 200 N load cell. Selection of samples was done at random and 40 replications were made for each test as reported by (Xu et al., 2014; Aviara et al., 2013) with three replications were made for each test. Figure 2 shows the measurement of compression force of corn cobs.

2.9 Penetration of corn cobs and kernel (N)

An Instron Universal Test Machine (IUTM) equipped with a 5 kN load cell with an accuracy of ± 0.25% was employed for measuring the penetration of corn cobs and kernel. Appropriate probe for this test was utilized with predetermined feed speed (50 mm min^{-1}) with 200 N load cell. Selection of samples was done at random and 40 replications were made for each test as reported by (Xu et al., 2014; Aviara et al., 2013) with three replications were made for each test. Figure 3 shows the measurement of penetration of corn cobs and kernel.



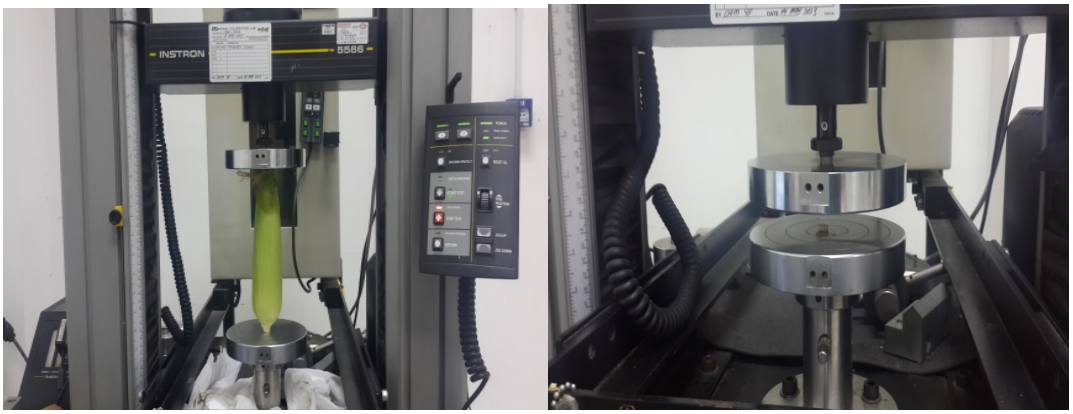


Figure 2 Measuring the compression force of corn cobs and kernel

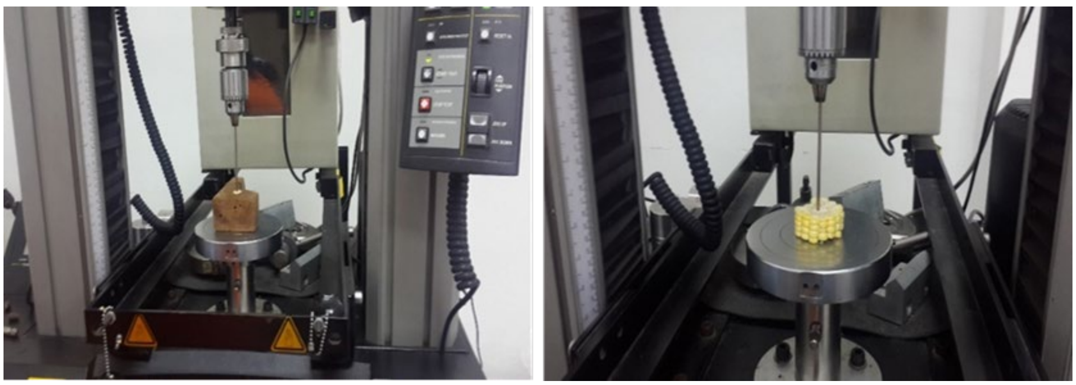


Figure 3 Measuring the penetration of corn cobs and kernel

3 Results and discussion

3.1 Physical and mechanical properties of sweet corn plant

3.1.1 Physical properties of corn cob

Determination of the physical properties of sweet corn is essential as these parameters are required in the design and operation of the harvesting machinery and post-harvest machinery for the harvested sweet corn cobs and other plant biomass. The physical properties of sweet corn plant reported in this study were from the samples taken from a sweet corn farm in Sekinchan, Selangor.

Table 1 presents the selected physical properties data of a sweet corn plant. The average height of the sweet corn plant was 211.7 cm, which is within the range stated by Szymanek (2011) which was 90 to 300 cm. Then, the maximum width of the plant ranges from 78 to 115 cm as shown in Table 1. Most of the plant only has 1 to 2 cobs per plant and the number of leaves is between 8 and 11 leaves per plant. However, Szymanek (2011) reported that the number of leaves was about 16 to 20 per plant. Table 1 appear the average diameter of stalk 20 cm from the ground is 2.21 cm, whereas the diameter of the stalk 25 cm from the tip is 0.97 cm.

Table 2 presents the selected physical properties data of sweet corn cobs. The average length of a sweet corn cob is 21.68 cm, which is within the range indicated by Szymanek (2011) which was 20.17 to 23.2 cm. While, the diameter of a corn cob ranges from 3.78 to 5.69 cm which is within the range indicated by Szymanek (2011). The number of kernels per row and number of kernel rows are 25 ± 2.60 and 15 ± 1.35 respectively, these results are similar to those reported by Szymanek (2011) which was the number of kernels per row is 28.05 (1.57) and number of kernel rows 14.72 (1.54) whereas, Szymanek (2011) observations indicated that the number of kernels per row was 26 (3.2) and number of kernel rows was 14 (2.4). Table 2 shows the average volume of corn (cm^3) is 431.8 ± 9.83 cm^3 whereas, porosity % is 46.74% ± 2.13%, repose of angle of corn cobs was 26.76 ± 1.142 degrees, however, angle of friction of corn cobs is 32.90 ± 0.82 degrees.

Table 1 Physical properties of sweet corn plant

Parameter	n	Min	Max	Av.	STD	95% CI
Maximum height of plant, cm	40	181.0	234.5	211.7	12.4	211.70 ± 3.62
Maximum width of plant, cm	40	78.0	115.0	96.0	7.4	96.00 ± 2.17
Number of corn cobs	40	1	2	1.13	0.344	1.13 ± 0.100
Number of leaves	40	8	11	10.22	0.765	10.22 ± 0.224
Diameter of plant stalk at 20 cm from ground level, cm	40	1.73	2.91	2.21	0.31	2.21 ± 0.09
Diameter of plant stalk at 25 cm from the top tip, cm	40	0.72	1.32	0.97	0.15	0.970 ± 0.043

Table 2 Physical properties of corn cobs

Parameter	n	Min	Max	Av.	STD	95% CI
Length of corn cob, cm	40	20.17	23.20	21.68	2.75	21.68 ± 0.853
Diameter of corn cob, cm	40	3.78	5.69	4.94	0.43	4.94 ± 0.134
Number of kernels per row	40	21	28	25	3.41	25 ± 2.60
Number of kernel rows	40	13	17	15	2.42	15 ± 1.35
Volume of corn, cm^3	40	405.03	454.54	431.8	15.05	431.8 ± 9.83
Porosity, %	40	42.81	52.78	46.74	3.26	46.74 ± 2.13
Repose angle of corn cobs	40	19.1	37	26.76	3.68	26.76 ± 1.142
Angle of friction of corn cobs	40	28	38	32.90	2.64	32.90 ± 0.82

3.2 Weight of plant

Table 3 presents the wet weight of a complete plant and the wet weight of each plant component, while Table 4 presents their corresponding dry weight. Dry weight is the weight of the plant excluding the moisture content. It is important to determine the dry weight of the leftover biomass after harvest in order to gauge its value for animal feed. Dry matter indicates of the amount of nutrient that is available to the animal in a particular feed. Knowledge of the moisture content of the plant is significant as the moisture content impacts the weight of the feed but offers no nutrient value. The 95% confidence interval also calculated for the wet and dry weights of each parameter. The percentage of the dry weight of each plant component is determined by dividing the dry weight of each plant component with the total weight of the plant. Table 4 shows that the stalk has the highest percentage of dry weight at 28.14% and silk has the lowest percentage of dry weight which is 2.60%. It is because stalk has the highest wet weight compared to other plant components.

Table 3 Wet weight of complete plant and weight of each component.

Parameter	n	Min	Max	Av	STD	95% CI, kg
Weight of total leaves, kg	40	0.062	0.089	0.077	0.006	0.077 ± 0.0018
Weight of stalk, kg	40	0.260	0.409	0.318	0.032	0.318 ± 0.0094
Weight of total corn cobs, kg	40	0.278	0.694	0.420	0.108	0.420 ± 0.0315
Weight of root, kg	40	0.056	0.079	0.068	0.006	0.068 ± 0.0017
Weight of silk, kg	5	0.004	0.008	0.006	0.002	0.06 ± 0.0013
Weight of husk, kg	40	0.061	0.127	0.084	0.016	0.084 ± 0.0044
Weight of kernel, kg	40	0.131	0.212	0.160	0.021	0.160 ± 0.0056
Weight of cob, kg	40	0.064	0.119	0.086	0.111	0.086 ± 0.0031
Weight of complete plant, kg	40	0.708	1.606	0.850	0.168	0.833 ± 0.049

Table 4 Dry weight of complete plant and weight of each component.

Weight, kg	n	Min	Max	Av.	STD	95% CI, kg	Percentage of dry weight, %
Total leaves, kg	40	0.027	0.039	0.034	0.0027	0.034 ± 0.0008	14.72
Stalk, kg	40	0.053	0.084	0.065	0.0066	0.065± 0.0019	28.14
Total corn cobs, kg	40	0.084	0.212	0.106	0.0332	0.106 ± 0.0097	45.89
Roots, kg	40	0.021	0.030	0.026	0.0022	0.026 ± 0.0006	11.26
Silks, kg	5	0.004	0.008	0.006	0.0018	0.006 ± 0.0016	2.60
Husks, kg	40	0.014	0.030	0.020	0.0038	0.020 ± 0.0010	8.66
Kernels, kg	40	0.026	0.043	0.032	0.0042	0.032 ± 0.0011	13.85
Cobs, kg	40	0.036	0.067	0.048	0.0063	0.048 ± 0.0017	20.78
Complete plant, kg	40	0.197	0.350	0.231	0.0374	0.231 ± 0.0109	100

Analysis of variance (ANOVA) test was used to compare the mean for each parameter. As shown in Table 5, the significant value between the wet and dry weight of the plant are all less than 0.05. From the analysis, it can be seen that dry weight has the greatest value of F-ratio among all the destructive parameters, which is 999.522. This F-ratio is a ratio of the variability between groups compared to the variability within the groups. This means producing a statistically significant result.

Post hoc Duncan test or multiple comparison tests was used to establish the significant differences between group means in an analysis of variance setting. Table 6 below shows the Duncan post hoc test for wet and dry weight parameter. For wet weight, leaves, stalks, roots, husks and stalks are in the same group. Corn ear has the highest mean which is 0.376, and silk has the lowest mean at 0.006. For dry weight, only leaves and kernels are in the same group, still, corn ear has the highest mean and silk has the lowest mean value.

Table 5 ANOVA result for wet weight and dry weight

ANOVA						
Parameter		Sum of Squares	df	Mean Square	F	Sig.
Wet weight	Between Groups	4.367	7	0.624	254.520	0.000
	Within Groups	0.765	312	0.002		
	Total	5.132	319			
Dry weight	Between Groups	0.238	7	0.034	999.522	0.000
	Within Groups	0.011	330	0.000		
	Total	0.250	337			

Table 6 Duncan test results for wet and dry weights of each plant component

Plant component	Wet weight, kg	Dry weight, kg
Leaves	0.077^{b}	0.033^{d}
Stalk	0.318^{b}	0.065^{f}
Corn cob	0.376^{e}	0.102^{g}
Root	0.068^{b}	0.026^{c}
Silk	0.006^{a}	0.005^{a}
Husk	0.096^{b}	0.020^{b}
Kernel	0.181^{c}	0.032^{d}
Cob	0.097^{b}	0.048^{e}

3.1.2 Mechanical properties

3.1.2.1 Pulling force of plant components of sweet corn

The pulling force of sweet corn is determined using 9500 series CPU (Central Processing Unit) digital force gauge.

Table 7 Pulling force of plant components of sweet corn

Plant component	Pulling degree	n	Av.	STD	95% CI (N)
Corn cob	0°	40	319.03	35.97	319.03 ± 11.15
	45°	40	116.21	8.15	116.21 ± 2.53
	90°	40	51.14	6.36	51.14 ± 1.97
Leaves	`	40	34.91	3.91	34.91 ± 1.21
	45°	40	26.68	1.25	26.68 ± 0.39
	90°	40	17.57	0.86	17.57 ± 0.27
Plant	0°	40	549.32	20.25	549.32 ± 6.27
	45°	40	400.19	9.85	400.19 ± 3.05
	90°	40	334.00	9.97	334.00 ± 3.09
Kernel	0°	40	12.45	0.62	12.45 ± 0.19

From Table 7, it was found that corn cob had the highest pulling force with 0◦ angle which was 319.03 ± 11.15 N however, the lowest value was with 90◦ angle 51.14 ± 1.97 N, and this characteristic is important to know the force needed to pick up and gather corn cob for the harvester design. The leaves had the highest pulling force with 0◦ angle which was 34.91 ± 1.21 N while, the lowest value with 90◦ angle was 17.57 ± 0.27 N. Furthermore, the plant has the highest pulling force with 0◦ angle which was 549.32 ± 6.27 N moreover; the lowest value with 90◦ angle was 334.00 ± 3.09 N. This indicates that increasing the pulling angle, will lead to decrease the pulling force that is required for take-off in the scope of this study. The kernel of sweet corn had pulling force with 0◦ angle, which was 12.45 ± 0.19 N. ANOVA test was used to compare the mean in each parameter. Table 8 presents the result of pulling force analysis of every plant component. All the significant values between the analyses were less than 0.05 and considered significant. From Table 8, it can be seen that pulling force of the plant has the greatest value of F-ratio among all the parameters, of which 2,407.671 is due to the very small mean square value within the groups.

Table 8 ANOVA test result of pulling force for analysis of corn cob, leaves and plant

ANOVA						
Analysis		Sum of Squares	df	Mean Square	F	Sig
Corn cobs	Between Groups	1,561,899.766	2	780,949.883	1,672.503	0.000
	Within Groups	54,631.367	117	466.935		
	Total	1,616,531.133	119			
Leaves	Between Groups	6,017.733	2	3,008.867	514.390	0.000
	Within Groups	684.378	117	5.849		
	Total	6,702.111	119			
Plants	Between Groups	973,141.303	2	486,570.652	2,407.671	0.000
	Within Groups	23,644.747	117	202.092		
	Total	996,786.050	119			

3.1.2.2 Shearing force of plant components of sweet corn

Table 9 presents the selected shearing force of plant components of sweet corns. The highest average maximum load of sweet corn cob was 503.76 ± 29.75 N with 0 degree of shearing force, while, the lowest shearing force of sweet corn cob was 0.10 ± 0.01 Mpa with 0 degree of shearing force. However, the lowest average maximum load of sweet corn cob was 448.27 ± 34.03 N with 45 degree of shearing force, while, the highest shearing force of sweet corn cob was 0.11 ± 0.02 Mpa with 45 degree of shearing force. Moreover, the highest average maximum load of sweet corn stalk was 205.45 ± 20.59 N with 0 degree of shearing force, while, the highest shearing force of sweet corn stalk was 0.75 ± 0.10 Mpa with 0 degree of shearing force. However, the lowest average maximum load of sweet corn stalk was 167.15 ± 25.10 N with 45 degree of shearing force, while, the lowest shearing force of sweet corn stalk was 0.50 ± 0.09 Mpa with 45 degree of shearing force. This is confirmed by Esehaghbeygi et al. (2009) who used different moisture content for shearing stress, the effects of oblique angle can be explained by the change of contact area between the knife and the stem while cutting has accrued and by the physical properties of stem tissues. Besides, the average maximum load of kernel was 12.00 ± 0.47 N with 0 degree of shearing force, while, the shearing force of kernel was 0.60 ± 0.07 Mpa with 0 degree of shearing force.

3.1.2.3 Compression force of plant components of sweet corn

Table 10 presents the selected compression force of plant components of sweet corns. The lowest average maximum load of sweet corn cob was 497.56 ± 63.14 N with vertical position of compression force, while, the lowest compression force of sweet corn cob was 49.76 ± 6.31 Mpa with the vertical position of compression force. However, the highest average maximum load of sweet corn cob was 2,801.26 ± 346.10 N with horizontal position of compression force, while, the highest compression force of sweet corn cob was 280.13 ± 34.61 Mpa with horizontal position of compression force. Furthermore, the average maximum load of kernel was 45.23 ± 4.32 N with horizontal position of compression force, while, the compression force of the kernel was 4.52 ± 0.43 Mpa with horizontal position of compression force.

3.1.2.4 Penetration force of plant components of sweet corn

Table 11 presents the selected penetration force of plant components of sweet corns. The average maximum load of sweet corn cob was 1.633 ± 0.144 N, while, the penetration force of sweet corn cob was 0.012 ± 0.001 Mpa. Likewise, the average maximum load of kernel was 11.891 ± 1.415 N, while, the penetration force of kernel was 0.089 ± 0.011 Mpa.

Table 9 Shearing force of plant components of sweet corn

Biomass material	Shearing force degrees	n	Maximum Load, N			Compressive stress, Mpa		
			Av.	STD	95% CI	Av.	STD	95% CI
Corn cob	0°	30	503.76	83.15	503.76 ± 29.75	0.10	0.04	0.10 ± 0.01
	45°	30	448.27	95.09	448.27 ± 34.03	0.11	0.06	0.11 ± 0.02
Stalk	0°	30	205.45	57.53	205.45 ± 20.59	0.75	0.27	0.75 ± 0.10
	45°	30	167.15	70.14	167.15 ± 25.10	0.50	0.25	0.50 ± 0.09
kernel	0°	30	12.00	1.33	12.00 ± 0.47	0.60	0.20	0.60 ± 0.07

Table 10 Compression force of plant components of sweet corn

Biomass material	Position	n	Maximum Load, N			Compressive stress, Mpa		
			Av.	STD	95% CI	Av.	STD	95% CI
Corn cob	Vertical	30	497.56	176.45	497.56 ± 63.14	49.76	17.64	49.76 ± 6.31
	Horizontal	30	2801.26	967.19	2801.26 ± 346.10	280.13	96.72	280.13 ± 34.61
kernel	Horizontal	30	45.23	12.07	45.23 ± 4.32	4.52	1.21	4.52 ± 0.43

Table 11 Penetration force of plant component of sweet corn

Biomass material	n	Maximum Load, N			Compressive stress, Mpa		
		Av.	STD	95% CI	Av.	STD	95% CI
Corn cob	30	1.633	0.401	1.633 ± 0.144	0.012	0.003	0.012 ± 0.001
kernel	30	11.891	3.953	11.891 ± 1.415	0.089	0.030	0.089 ± 0.011

3.1.2.5 Bending force of plant stalks of sweet corn

Table 12 presents the selected Bending force of plant stalks of sweet corn. The average maximum load of sweet corn stalk was 132.89 ± 20.63 N, while, the bending force of sweet corn stalk was 12.60 ± 2.07 Mpa. Likewise, the average modulus of the stalk was 418.06 ± 54.01 Mpa.

Table 12 Bending force of plant stalks of sweet corn

Biomass material	n	Maximum Load, N			Compressive stress, Mpa			Modulus, Mpa		
		Av.	STD	95% CI	Av.	STD	95% CI	Av.	STD	95% CI
Stalks	30	132.90	57.70	132.90 ± 20.6	12.60	5.78	12.60 ± 2.1	418.06	150.93	418.06 ± 54.01

4 Conclusions

Physical and mechanical properties of the plant are the most important in design agriculture machine to determine standards of design machine. Know weight and volume of corn cob, porosity, length and diameter of corn cob, repose angle of corn cob and angle of friction of corn cob they have a significant role in designing the tank corn cob of the harvester. While, know the weight of leaves, the diameter of a stalk, the diameter of the plant and height of plant it's an important indicator in design the tank biomass of the harvester. Whereas, the mechanical properties of the plant its considerable in design the cutting unit especially in design the cutting and chopping parts of the plant. Pulling force at three different angles (0º, 45º and 90º) where at 90º gave the lowest value of pulling force of corn cobs which was 51.14 ± 1.97 N, compression force at vertical 497.56 ± 63.14 N; at horizontal 2801.26 ± 346.10 N, shearing force at two different angles (0º and 45º) where at 45º gave the lowest value of shearing force of corn cobs which was 448.27 ± 34.03 N, and penetration 1.633 ± 0.144 N of sweet corn cobs.

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