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Experimental Research on the Tensile and Shear Properties of Fluted pumpkin vine for Machine Design

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ABSTRACT: This study determined the effect of pre-harvest treatment on some tensile and shear properties of fluted pumpkin vine. The fluted pumpkin plants were treated with farmyard manure, calcium chloride, and a combination of farmyard manure and calcium chloride. Vines were cut from the fluted pumpkin plants 60 days after planting, for laboratory analysis. The vine width and thickness were measured with a digital caliper; while the vine tensile and shear properties were determined using the Universal Testing Machine, according to ASTM International recommended procedures. The tests were conducted on the three vine regions (head, middle and tail). Results obtained revealed that pre-harvest treatment had a significant ($p \leq 0.05$) effect on the tensile and shear properties of the fluted pumpkin vine. Irrespective of the vine region, the highest tensile strength (mean ~ 42.07 Mpa), was recorded in vine treated with calcium chloride; while the lowest tensile strength (mean ~ 19.37 Mpa), was recorded b the vine treated with farmyard manure. Likewise, the calcium chloride treated vine had the highest Young's modulus (mean ~ 179.6 MPa); while the farmyard manure treated vine had the lowest Young's modulus (mean ~ 74.98 MPa). It was observed that the vine treated with farmyard manure recorded the highest tensile strain (mean ~ 25. 72%); while the vine treated with calcium chloride recorded the lowest tensile strain (mean ~16.54%). Regarding the shear properties of the fluted pumpkin vine, the study showed that calcium chloride treated vine displayed the highest shear force and shear resistance (122.77 N and 21.22 N/mm^2 respectively). In addition, the lowest shear force and shear resistance (74.11 N and 9.8 N/mm^2 respectively), were observed in the pumpkin vine treated with farmyard manure. These will be useful during the design and application of fluted pumpkin harvesting machines, to achieve maximum efficiencies.

Keywords: Calcium chloride, fluted pumpkin, shear resistance, tensile strength, vine

INTRODUCTION

Fluted pumpkin (*Telfaria occidentalis*), which belongs to the cucurbitaceae family, is native to West Africa. It is one of the most important vegetable grown in Nigeria (Kayode and Kayode, 2011), and widely cultivated across Africa. There are scores of fluted pumpkin varieties, which are distinguished by pod and seed colour, vine thickness, leaf size and area, growing vigour, days to flowering and succulence, nutrient content of the leaves and seeds, etc. (IPGRI, 1999; Kayode and Kayode, 2011). Fluted pumpkin seeds and leaves have a lot of nutritional and medicinal values. According to Aletor *et al*. (2002), fluted pumpkin leaves juice is an excellent blood builder and purifier. In addition, Kayode and Kayode (2011) reported that fluted pumpkin leaves contain high concentration of essential minerals, vitamins and antioxidants. Odewole *et al*., (2015a) stated that fluted pumpkin seeds contain oil, which is rich in vitamin E, vitamin A, zinc, and can also be used to manage prostrate and bladder problems in human beings. Stevenson *et al*. (2007) further stated that fluted pumpkin oil has strong antioxidant properties, and it is used for the treatment of hypertension, colorectal cancer, diabetes, and arthritis. These numerous advantages of fluted pumpkin have led to an increase in its cultivation and production in the region. Fluted pumpkin leaves are usually harvested manually in Nigeria, through hand cutting, by using scissor or knife. According to Nalawade *et al*. (2017), using scissor to harvest fruits and vegetables is an inexpensive harvesting method, but care and time are required in operating the scissor; moreover, its continuous usage can resulted to fatigue and pains in the figures. Therefore, the design and development of harvesting and handling machines for fluted pumpkin leaves have become inevitable.

Several researchers have designed and developed crops' harvesting, handling and processing machines, through the application of their engineering properties. Tian *et al*. (2017) designed and tested corn harvester, using the shear resistance and shear energy of the corn stalk. Likewise, Nalawade *et al*. (2017) used some physical characteristics of okra plant, such as; okra pod length and diameter, okra stem length and diameter, angle between the pod stalk and the stem to design and construct an okra-cutter-holder. This tool allowed the farmer to harvest the okra pods without touching the pod; thereby, minimizing injuries to the farmers and the pods. A mechanical harvester was designed for tef by Gebre *et al*. (2016), using the shear properties of the plant. Furthermore, Ghahraei *et al* (2008) designed and contrast a special harvester for sweet sorghum, using the maximum cutting force and energy of the sorghum stalk, at various moisture contents. Then in 2012, Baneh and his fellow researchers design and fabricate a portable reaper of a rice harvester. The cutting head system worked perfectly for four rice varieties (*Fajr, Khazar Binam* and *Hashemi*) commonly grown in Iran (Baneh *et al*., 2012). Odewole *et al*. (2015b) developed a fluted pumpkin seed dehulling machine that works on the principle of centrifugal force and impact forces, using the seed's physical characteristics and mechanical properties. The machine recorded a dehulling efficiency and throughput capacity of 87.26% and 2.82 g/s respectively.

Mechanical properties of plants materials are very important, during the design, construction, programming and application of their harvesting, handling and processing machines/systems. This will enable the machine/system to achieve its maximum efficiency, without compromising the quality of the harvested or processed product (Resende *et al*., 2007). According to Toscano et al. (2014), the mechanical strength of plants' leaves, stems and vines, are influenced by water content, humidity, crop variety and soil fertility. Likewise, White and Broadley (2003) stated that calcium plays an essential role in during plant's tissue growth and development, mechanical strength properties, resistance to external stresses, etc. Pre-harvest calcium application is beneficial to plants as it increases the tissues firmness and reduces post-harvest bacterial infections in peach (*Prunus persica* L.) fruits (Elmer *et al*., 2007; Singh *et al*., 2007). Samarakoon *et al.* (2017) reported that foliar application of calcium chloride increased the mechanical properties (fracture force and energy) of *geranium* and *poinsettia* plants leaves. Likewise, Samarakoon *et al.* (2019) observed the fracture force of poinsettia plant leaves per-harvest treated with chelated calcium (Ca-EDTA), increased by 26% when compared with the control. Igathinathane *et al*. (2010) observed that the force required to cut corn stalk was higher in the nodes (646.91 N), than in the internode that recorded a shearing force of 395.90 N. Zareiforoush *et al*. (2010) studied the effect of loading speed and plant part (node and internode) on some mechanical properties of rice straw. They observed that loading speed only influenced the flexural strength of the straw; while the internode part of the straw significantly affected the shear strength, shearing energy and young modulus. Plant materials undergo tension, flexural, shear, and friction forces during harvesting, handling and processing unit operations; and these forces are dependent on the plant variety, stalk/stem/vine diameter, stalk/vine region, maturity of the crop, and the cellular structure (Tunde-Akintunde and Akintunde, 2004). Although, several works have being done on the mechanical properties of fluted pumpkin, there is recorded literature on the effect of pre-harvest treatment on tensile and shear properties of fluted pumpkin vine, which can be application in the design and development of its harvesting machine. Therefore, the objective of this study was to evaluate the effect of pre-harvest foliar $CaCl_2$ treatment and farmyard manure on the tensile and shear properties of fluted pumpkin vine. The results obtained will be useful in the design, programming and optimization of fluted pumpkin harvesting machines and systems.

MATERIALS AND METHODS

Materials

Fluted pumpkin

Ugu-ala, a local fluted pumpkin variety commonly cultivated in Nigeria, was used for this study. According to Akoroda (1990) and Kayode and Kayode (2011), ugu-ala has succulent large leaves, small black seeds, thick stem, but slow growth.

Farmyard manure

The farmyard manure was formulated from the mixture of goat dung, cattle dung and poultry waste. The three constituents were mixed at the ratio of 3:5:2 (by weight), and composted for the period of three months.

Experimental design

To investigate the effects of pre-harvest treatment on the tensile and shear properties of fluted pumpkin vine, four treatments including control (no pre-harvest treatment), farmyard manure, calcium chloride, and farmyard manure + calcium chloride were evaluated. The farmyard manure was incorporated into the soil at the rate of 5000 kg/ha, three weeks before the planting of the fluted pumpkin seeds. The calcium chloride ($CaCl_2$), was applied in a foliar form, using a knapsack sprayer at the rate of 400 g/ha. While the farmyard manure was applied once during the research period; the $CaCl_2$ was applied once weekly, until the vines were cut for laboratory tests at the age of 60 days after sowing. Each treatment was replicated three times. The treated were coded as follows:

Treatment 1 (T1) = Control
Treatment 2 (T2) = Farmyard manure
Treatment 3 (T3) = Calcium chloride
Treatment 4 (T4) = Farmyard manure and calcium chloride

Methods

Sample preparation

The fluted pumpkin vines were prepared by stripping them of their leaves. Each vine was cut into three parts, based on the vine's region. They were the root, middle and tail regions. The width (major diameter) and thickness (minor diameter) of each sample was measured using a digital vernier caliper, having accuracy of 0.01 mm. The sectional area of each sample was observed to have an irregular polygon shape, which can be approximated to be a rectangular shape. The gross area of the pumpkin vine was calculated using equation 1.

$$\text{Area} = T \times W \qquad (1)$$

Where W = width
T = thickness or length

Tensile test

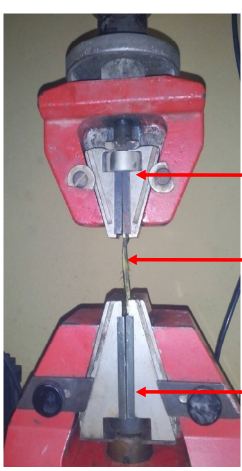

Figure 1: Fluted pumpkin vine undergoing tensile test.

The Universal Testing Machine (Testometric model), was used to determine the tensile properties of the fluted pumpkin vine. Individual sample was placed in between the two jaws of the machine (Figure 1). To prevent the vine from slipping from the machine jaw, a rubber pad was placed between the vine and the jaw, before it was clamped. During the testing the vine was subjected to tension, at a slow speed of 3mm/min, until the vine snapped. At the end of each test, the ensile strength and tensile energy of the vine was calculated electronically b the machine. The tensile test was conducted on four samples from each treatment plot.

Shear test

A modified WarnereBratzler device, attached to the Universal Testing Machine (Testometric model), was used to determine the shear properties of the pumpkin fruit vine. A modified sharp edge 1 mm thick 30^0 V-notch stainless steel knife was used for the shear test. According to Belew *et al*. (2003) and Igathinathane *et al*. (2010), it is essential to modify the blunt edge blade into a sharp edge, when testing tougher biomass food products; because, the blunt edge was meant for testing softer food products. During the test, the sample was placed in the support block that served as the platform holding the sample, and the blade moved freely through the support block's groove, until the vine was cut into two parts. At the loading continues, the machine generates a force-deformation curve, which corresponds to the shearing characteristics of the fluted pumpkin vine. The shear test was conducted on four samples from each treatment plot.

The shear stress of the pumpkin vine was calculated by using equation 2.

$$S_s = \frac{S_f}{A} \qquad (1)$$

Where:
S_s = shear stress
S_f = shear force
A = cut sectional area of the vine

Statistical analysis

The results obtained were statistically analyzed using SPSS 20.0. Then Duncan's Multiple Range Test (DMRT) was used to separate and compare the mean at 95% confidence level.

RESULTS AND DISCUSSION

Pumpkin vine area

The ANOVA results presented in (Table 1) revealed that

Table 1: Fluted pumpkin vine area

Treatment	Vine region		
	Head (mm^2)	Middle (mm^2)	Tail (mm^2)
T1	$5.33^a\pm0.29$	$5.70^a\pm0.17$	$4.83^a\pm0.19$
T2	$7.64^d\pm0.14$	$8.26^d\pm0.16$	$6.56^d\pm0.33$
T3	$5.75^b\pm0.38$	$6.20^b\pm0.11$	$5.35^b\pm0.22$
T4	$6.97^c\pm0.02$	$7.20^c\pm0.18$	$6.02^c\pm0.13$
Mean	6.42±0.97	6.84±1.01	5.69±0.70
Duncan (p ≤0.05)	*	*	*

Mean± standard deviation; n=10; * = significant at (p ≤0.05); columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05), according to DMRT.

Table 2: ANOVA results of the effect of vine region and treatment on the tensile strength of fluted pumpkin vine

Source of variation	df	sig
Region	2	1.19E-22*
Treatment	3	1.88E-26*
Region x Treatment	6	1.31E-09*

* = significant at (p ≤0.05).

treatment option and vine region had significant effect on the sectional area of the vine. It was observed in the separated means (Table 1), that the middle region had the highest area (mean ~ 6.84 mm^2); while the tail region had the lowest area (5.69 mm^2). Regarding the treatment applied to the pumpkin plant, the study showed that irrespective of the vine region, T1 vine recorded the lowest area (5.28 m^2) and the T2 vine had the highest area of 7.48 m^2. The highest vine area recorded by the pumpkin treated with farmyard manure could be attributed to the essential nutrients, supplied to the plant by the manure. According to Eboibi *et al.* (2018), organic manure helps to increase the growth and development of plants, by increasing their body mass and size. Furthermore, Cardoso *et al*. (2008) reported that organic manure had a high positive influence on plant stem diameter, when compared with inorganic manure. These results will aid the development and application of cutter for fluted pumpkin vines.

Tensile properties

Tensile strength

The study showed that treatment option and vine region had significant (p ≤0.05) effect on the tensile strength of the fluted pumpkin vine (Table 2). In addition, the interaction of the vine region and treatment option still exhibited significant (p ≤0.05) effect on the tensile strength of the pumpkin vine. The mean results plotted in (Figure 2) revealed that, regardless of the pre-harvest treatment applied, the head region of the vine had the highest tensile strength (mean~ 41.08 Mpa), while the tail region recorded the lowest tensile strength (mean ~25.95 Mpa). This signified that the ability of the vine to withstand tension, decreased linearly from the head region of the vine to the tail region. The regression equation shown in Equation 2, further affirmed that there is a strong relationship ($R^2\geq0.9$) between the vine region and the tensile strength of the fluted pumpkin vine. This could be attributed to the variation in the cellular structures within the vine length. Similar results were obtained by Xu *et al*. (2016) for cucumber cane; when tensile strength of 7.35 Mpa, 6.30 Mpa and 4.68 Mpa was recorded, when the cane was tested at the head, middle and tail respectively. In addition, Li *et al*. (2012) reported that the fracture force of herbaceous peony (*Paeonia Lactiflora* Pall.) stem was 118.0%, at the head, 112.5% at the middle and 106.4% at the tail.

The study further revealed the effect of pre-harvest treatment on the tensile strength of the pumpkin vine. As presented in (Figure 2), the pumpkin treated with farmyard manure recorded the lowest tensile strength (mean ~ 19.37 Mpa), lower than the control pumpkin vine that recorded a mean tensile strength of 37.67 Mpa. Furthermore, the results portrayed that the vine pre-harvest treated with $CaCl_2$ had the highest tensile strength (mean ~ 42.07 Mpa), in all the treatment options applied. In related development, it was observed that the vine pre-harvest treated with the combination of the farmyard manure and the $CaCl_2$, had a tensile strength lower (47.21 Mpa) than the control pumpkin vine. The lower tensile strength recorded by T4 pumpkin vine, despite their higher tensile force, is attributed to their higher surface area (Table 1). As shown in (Table 1), T4 pumpkin vine had significant higher surface area than the T1 pumpkin vine. Area is a major factor that determines the strength values of an agricultural product (Ince *et al*., 2009). This study results signified the ability of $CaCl_2$ in

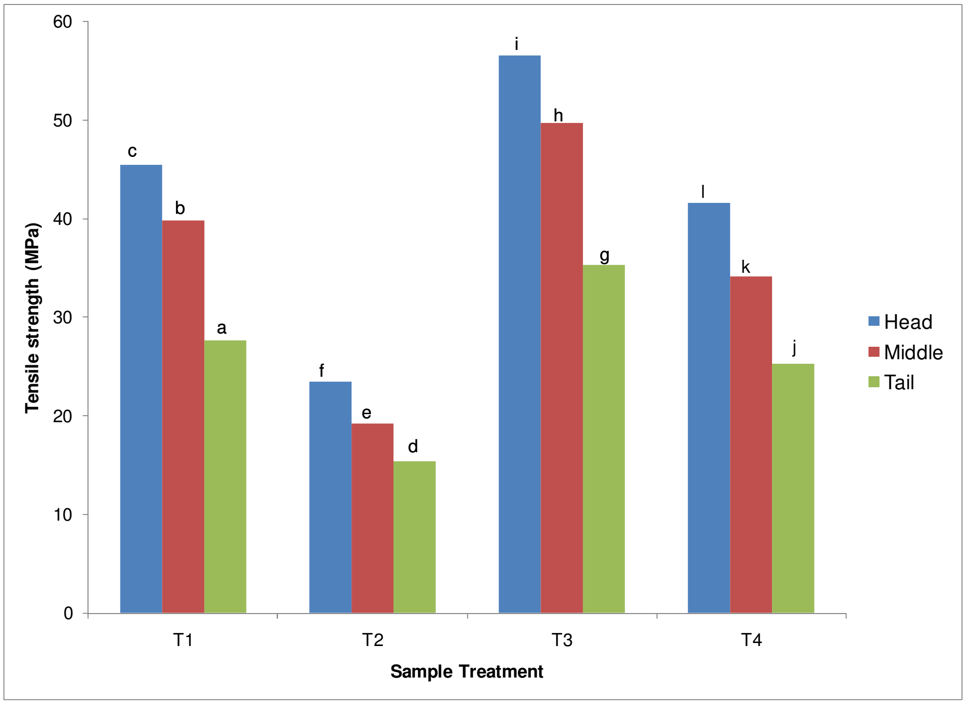

Figure 2: Tensile strength of fluted pumpkin vine. Columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05), according to DMRT.

increasing the firmness and toughness of agricultural products, fluted pumpkin vine inclusive. According to Li *et al.* (2012), calcium chloride has the ability of improving the structural rigidity to plant cells.

$$y = 13.42\,x + 8.525, \qquad R^2 = 0.902 \qquad (3)$$

Where:
y = tensile strength
x = fluted pumpkin vine region
R^2 = coefficient of determination

Tensile strain

The study results presented in (Table 3) showed that the pumpkin vine regions had significant (p ≤0.05 effect on the tensile strain of the vine. For all cases, the tensile strain of the pumpkin vine decreased linearly, from the head region to the tail region. At the head region, a mean tensile strain of 24.16% was recorded, this decreased to a mean value of 16.66% at the tail region. This portrayed that the ability of the vine to absolve tensile force decreased linearly from head region to the tail region. The regression analysis given in Equation 3, further affirmed that there is a strong relationship (R^2 ≥0.9) between the vine region and the tensile strain of the vine. Similar trends were reported by Xu *et al.* (2016), for cucumber cane. As regards to the pre-harvest treatment applied, the results (Table 2) depicted that treatment had significant (p ≤0.05) effect on the tensile strain of the pumpkin vine; although, the T1 and T4 vines did not exhibited an significant difference in tensile strain. Out of all the treatment options, T3 vine had the lowest tensile strain (mean ~16.54%); while the T2 vine had the highest tensile strain (mean ~ 25. 72%). This shows that the T2 vine was relatively weaker, when compared with than the T1, T3, and T4 vines.

$$y = 0.037\,x + 0.132, \; R^2 = 0.969 \qquad (4)$$

Young's modulus

Results obtained from the study and presented in (Table 4) showed treatment had significant (p ≤0.05) effect on the Young's modulus of the pumpkin vine. Regardless of the vine region, the study revealed that the T3 vine had the highest Young's modulus (mean ~ 179.6 MPa); while the T2 vine recorded the poorest Young modulus (mean ~ 74.98 MPa). Furthermore, it was observed that the T4 vine Young's modulus was insignificantly lower than the T1 Young modulus. This is credited to the large body size of the T4 vine, when compared with the T1 vine. The relatively highest Young's modulus recorded by the T3 vine, may be ascribed the calcium content of the treatment. According to Zhong *et al.* (2002), calcium positively influenced the cellular structure and the number

Table 3: Tensile strain of fluted pumpkin vine

Treatment	Vine region		
	Head (%)	Middle (%)	Tail (%)
T1	23.93^{b}±0.76	22.07^{b}±1.72	16.57^{b}±1.38
T2	29.43^{c}±2.14	26.07^{c}±1.14	21.67^{c}±0.68
T3	20.53^{a}±0.74	17.17^{a}±1.78	11.93^{a}±1.54
T4	22.73^{b}±0.78	20.67^{b}±1.88	16.47^{b}±1.74
Mean	24.16±3.59	21.49±3.62	16.66±3.79
Duncan (p ≤0.05)	*	*	*

Mean± standard deviation; n=4; * = significant at (p ≤0.05); columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05), according to DMRT.

Table 4: Young's modulus of fluted pumpkin vine

Vine region	Treatment			
	T1	T2	T3	T4
Head (MPa)	190.20^{b}±7.53	80.13^{a}±6.06	275.66^{c}±11.86	183.38^{b}±0.50
Middle (Mpa)	180.68^{b}±8.87	73.89^{a}±1.95	291.73^{c}±32.94	166.28^{b}±14.35
Tail (Mpa)	167.92^{b}±15.52	70.94^{a}±3.50	299.37^{c}±32.63	155.21^{b}±20.21
Mean	**170. 61**	**74.98**	**179.6**	**168.29**
Duncan (p **≤0.05)**	*	*	*	*

Mean± standard deviation; n=4; * = significant at (p ≤0.05); rows with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05), according to DMRT.

Table 5: ANOVA results of the effect of vine region and treatment on the shear properties of fluted pumpkin vine

Source of variation	Dependent variable	df	sig
Region	Shear force	2	4.08E-16*
	Shear resistance	2	2.22E-15*
Treatment	Shear force	3	7.97E-16*
	Shear resistance	3	6.21E-22*
Region x Treatment	Shear force	6	0.199828^{ns}
	Shear resistance	6	2.94E-03*

* = significant at (p ≤0.05); ns = non-significant (p ≤0.05).

of vascular bundles, which are important factors that determined the mechanical strength of plants stems.

Considering the effect of vine region on its Young's modulus, the results showed that the Young modulus declined from the head to the tail (Table 4). The mean Young's moduli were 182.34 MPa, 178.15 MPa and 173.36 MPa respectively for the head, middle and tail regions. This variations in the Young's modulus across the vine, is caused by non-homogeneous and non-isotropic properties of bio-materials. These results are in agreement with the ones previously reported by Xu *et al.* (2016) for cucumber cane, when Young's moduli of 280.58 MPa, 198.81 MPa and 137.22 MPa, were observed in the cucumber cane head, middle and tail respectively. The differences between this study results and other researchers' results could be attributed to the different plant used, farming method adopted and climatic conditions.

Shear properties

The results revealed that vine region had significant effect on the shear properties of the pumpkin vine (Table 5). But the interaction of the pumpkin section and treatment applied did not significantly (p ≤0.05) affected the shear force of the pumpkin vine. The separated means of the shear force and shear resistance of the pumpkin vine are presented in (Figures 3 and 4). As shown in (Figure 4), irrespective of the treatment applied, the tail region had the lowest shear force (mean~ 80.33 N) and shears resistance (14.56 m/mm^2); while the head region had the highest shear force (mean ~ 122.92 N) and shear resistance (19. 74 N/mm^2). This implies that the head region of the pumpkin vine required more force and energy to shear; when compared with the middle and tail regions. These results are in line with the ones previously reported by Tavakoli *et al* (2010) on rice (cv. Hashemi) straw. Tavakoli *et al* (2010) studied the shear properties of rice straw in three internodes position down from the ear, and observed that the shear strength of the straw decreased towards the third internode; while the shear energy increased significantly towards the third internode.

Considering the pre-harvest treatment option applied to

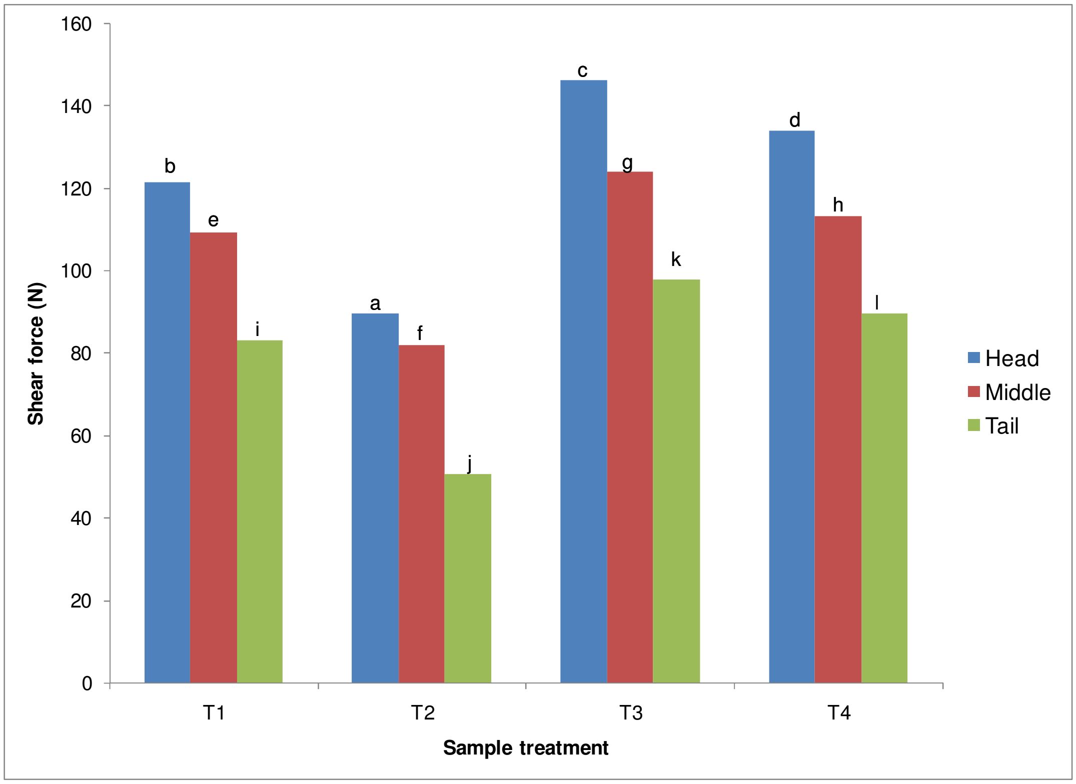

Figure 3: Shear force of fluted pumpkin vine. Columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05), according to DMRT.

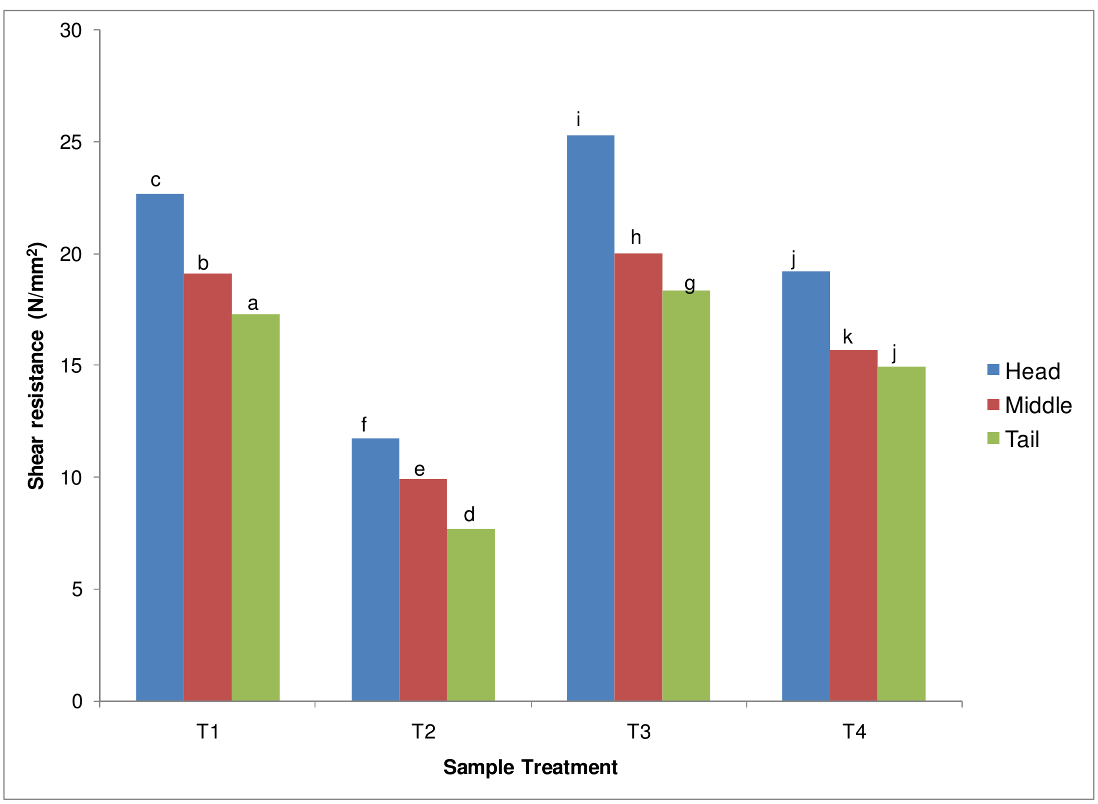

Figure 4: Shear resistance of fluted pumpkin vine. Columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05), according to DMRT.

the pumpkin plant, the study revealed that the fluted pumpkin pre-harvest treated with pure farmyard manure had the lowest shear properties; mean shear force of 74.11 N and mean shear resistance of 9.8 N/mm^2 (Figure 4). While the pumpkin treated with pure $CaCl_2$ had the highest shear properties; mean shear force of 122. 77 N, and mean shear resistance of 21.22 N/mm^2. It was further observed that the shear resistance of T4 pumpkin vine was significantly ($p \leq 0.05$) lower (mean ~ 16.62 N/mm^2), than the T1 shear resistance (19. 71 N/mm^2). The variation in the shear resistance is attributed to the higher sectional area of the T4 vine (mean ~ 6. 73 mm^2), when compared with the area (mean ~ 5.29 mm^2) of the T1 pumpkin vine. The study showed that, the force required to cut the untreated pumpkin vine (mean ~104.66 N) was significantly ($p \leq 0.05$) higher than the force used to cut the pumpkin vine planted with pure farmyard manure; but significantly ($p \leq 0.05$) lower than the force required to cut the pumpkin vine treated with the combination of farmyard manure and $CaCl_2$, that had a mean shear force of 112.33 N. These results have revealed the importance of pre-harvest treatment on the mechanical properties of pumpkin vine. The result obtained from the study will be helpful in the design, construction, programming and application of machines for pumpkin leaves harvesting and processing of this product.

Conclusion

In this study, the tensile and shear properties of fluted pumpkin vine pre-harvest treated with farmyard manure, calcium chloride and the combination of farmyard manure and calcium chloride were determined. The results depicted that pre-harvest treatment had significant effect on the tensile and shear properties of the fluted pumpkin vine. The tensile strength and Young's modulus of the pumpkin vine treated with farmyard manure were lower than the control, and the others treatments option applied. Whereas, the tensile strength and Young's modulus of the vine produced with calcium chloride were the higher than the control and the others treatments option applied. The study further revealed that the head region of the vine had the highest tensile properties, when compared with the results obtained from the middle and tail regions. Considering the shear properties of the vine, it was observed that regardless of the vine region, the vine treated with farmyard manure had the lowest shear force and shear resistance, among all the treatments option applied. It was observed that the shear force of the vine treated with combination of farmyard manure and calcium chloride was higher than the control; whereas, its shear resistance was lower than the control. The study revealed that calcium chloride treated pumpkin vine had the highest shear properties, irrespective of the vine region. Results obtained from this study will be useful in the design, development, programming and application of fluted pumpkin harvesting machines; thereby, reducing food and labour wastage.

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