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Mechanical properties of plantain pseudostem and implications for susceptibility to lodging

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Abstract: Plantain is an important staple food among Ghanaians but large quantities of the plants are lost due to lodging effect of windstorm. Peoples' livelihood and food security are at risk and there is the need to reduce the losses. The mechanical properties of the pseudostem of three varieties *Apantu pa, Apem pa* and *Apem hemaa* were examined. Samples of the plantain pseudostem were obtained by cutting down matured fruit bearing plants, 20 cm from the ground and at the petiole. Young's modulus, Yield stress and Ultimate stress were determined using three - point bending test method which followed the ISO (178) testing standard. The test results showed that the Young's modulus, Yield stress and Ultimate stress of the rainy season samples were significantly higher than that of the dry season samples. Therefore, the timing of the lodging as determined by the season (dry or wet) has an influence on the mechanical strength of plantain pseudostem.

Keywords: Plantain pseudostem, stem lodging, root lodging, mechanical strength.

Introduction

Plantain is one of Ghana's staple foods, and its cultivation has become a feature of great socio-economic importance from the point of view of food security and job creation. Ghana is the largest producer of plantain in West Africa and the second in Africa after Uganda and Rwanda (FAO, 2010). Plantain production in Ghana is under

smallholder farm units. More than 90% of the cultivated area in belongs to smallholder farming system (Dzomeku *et al.*, 2007)

In the 2008/2009 farming season, the production was 3,338,000 metric tons over a cropped area of 311,800 hectares, whiles in 2009/2010, production increased to 3,587,000 metric tons over a cropped area of 329,000 hectares (CILSS, 2010). The three main varieties of plantain on the Ghanaian market, namely, *Apantu*, *Apem* and *Apem hemaa*. *Apantu pa* and *Apem pa*, which are landraces (local) varieties, are more prone to fungal disease and pests attack.

Examples of the hybrid plantains are the *Apem hemaa* and are more disease tolerant and produce more fruits (yields) as compared to the landraces. *Apem pa* contributed 10.9% out of 12.1% for the French plantain whiles *Apem hemaa* hybrid plantain contributed 9.7% out of the 12.9% for the hybrid plantain (Dankyi *et al.*, 2007), thus showing the importance of the varieties tested in the Ghanaian smallholder plantain farming system.

Pests attack and wind effects are among the production risks faced by the farmer. Wind damage effect is due to stem lodging or root lodging and can bring about thousands of plant losses every year, countrywide. During the dry season the plants lose a lot of moisture due to the cool/hot dry low humidity weather conditions. Strong winds also cause plant losses due to lodging during the rainy season, though environmental conditions are humid and the amount of moisture loss from the plant is considerably low.

A lot of research has been done to improve plantain production in Ghana, but not much has been done to determine the mechanical strength of the pseudostem as a way of explaining the large scale lodging losses due to windstorm. Any remedial system to reduce the physical damage by wind would first have to explain the changes in the mechanical properties of the plant in the dry and rainy seasons. The three main varieties tested were *Apantu pa*, *Apem pa* and *Apem hemaa* as they form greater percentage of the cultivated varieties. The objectives of the study were to determine the mechanical properties (Young's modulus, Yield stress and Ultimate stress) of the plantain pseudostem of the selected varieties.

Materials and Methods

Plantain pseudostems were randomly selected at three farm sites in Kumasi. The plants were 10-12 months old, the roots and the plants were both healthy. The pseudostem samples of each plantain plant were taken from the petiole and at twenty (20) cm above ground surface. A total of nine (9) samples were selected for rainy season (called rainy season samples) and dry season (dry season samples) for testing. The experiment was carried out in the Civil Engineering Laboratory of the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. The geometrical

dimensions of the samples were recorded. The method used in this study was the three (3) point bending test, also known as the Flexural bending test. The test conforms to the International Standards Organisation (ISO 178). Each sample was placed between two supports and loading is applied at the middle span to produce a deflection as shown in Figure 1. At the mid span, the pseudostem was loaded increasingly at an interval of 5 seconds and the corresponding deflection was recorded. The test ended when the pseudostem sample failed by breaking. The mechanical properties that were measured were Young's Modulus, yield stress and ultimate stress.

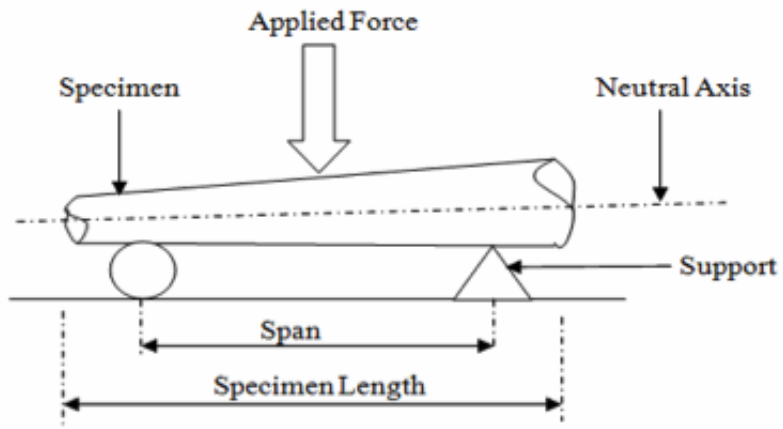

Figure 1 - Sketch of the experimental setup

Results and Discussion

Rainy season samples

Table 1 shows the Young's Modulus, Yield stress and Ultimate stress of all the rainy season plantain pseudostem samples.

Young's modulus values for *Apantu pa* samples were within the range of 11.71 - 22.75 GPa and a mean of 20.32 GPa. The Young's modulus of *Apem pa* samples was in the range of 4.49 - 9.00 GPa, and the mean was 6.18 GPa. For *Apem hemaa* samples the Young's Modulus was in the range of 7.85 - 12.84 GPa with a mean of 10.35 GPa. The Yield stress values for *Apantu pa* samples were in the range of 0.97 - 1.04 MPa having a range of 0.69 - 0.89 MPa with mean of 0.81 MPa. The ultimate stress for *Apantu pa* samples were 1.88 - 2.17 MPa, 0.94 - 0.97 MPa for *Apem pa*, and 1.21 - 1.57 MPa for *Apem hemaa* with a mean of 1.10 MPa; *Apem pa* was in the range of 0.55 - 0.58 MPa with a mean of 0.56 MPa and the *Apem hemaa.*

Table 1- Mechanical properties of rain season plantain pseudostem.

Plantain variety	Samples	Mid span diameter (m)	Young's modulus, E (GPa)	Yield stress, Σy (MPa)	Ultimate stress, Σu (MPa)
Apantu pa	1	0.138	11.71	0.97	1.93
	2	0.132	26.49	1.30	2.17
	3	0.131	22.75	1.04	1.88
	Average	0.134	20.32	1.10	1.99
Apem pa	1	0.166	5.03	0.58	0.94
	2	0.160	9.01	0.55	0.97
	3	0.162	4.49	0.55	0.95
	Average	0.163	6.18	0.56	0.95
Apem hemaa	1	0.165	10.37	0.69	1.21
	2	0.145	7.85	0.89	1.57
	3	0.153	12.84	0.85	1.48
	Average	0.154	10.35	0.81	1.42

Dry Season samples

Table 2 shows the Young's Modulus, Yield stress and Ultimate stress of the plantain varieties pseudostem samples in the dry season.

Young's modulus for *Apantu pa* was in the range of 0.78 GPa – 1.75 GPa with a mean of 1.20 GPa. *Apem pa* was in the range of 0.93 GPa – 1.41 GPa with a mean of 1.19 GPa and *Apem hemaa* having a range of 0.75 GPa – 1.34 GPa with a mean of 0.98 GPa.

The yield stress values for *Apantu pa*, *Apem pa* and *Apem hemaa* were in the ranges of 0.24 MPa – 0.26 MPa, 0.22 MPa – 0.32 MPa and 0.31 MPa – 0.39 MPa respectively. The mean yield stresses recorded are 0.26 MPa, 0.26 MPa and 0.35 MPa for *Apantu pa*, *Apem pa* and *Apem hemaa* respectively.

The ultimate stress for *Apantu pa* ranges from 0.48 MPa – 0.53 MPa, *Apem pa* 0.37 MPa – 0.64 MPa and 0.45 MPa – 0.49 MPa for *Apem hemaa*.

Variations in mechanical properties

Figures 2, 3 and 4 are the graphs of the Young's modulus, Yield stress and Ultimate stresses of *Apantu pa*, *Apem pa* and *Apem hemaa* for both rainy and dry seasons respectively. Table 3 shows the least significant difference (LSD) of the *Apantu pa*,

Table 2 - Mechanical properties of dry season plantain pseudostem samples.

Plantain variety	Samples	Mid span diameter (m)	Young's modulus, E (GPa)	Yield stress, Σy (MPa)	Ultimate stress, Σu (MPa)
Apantu pa	1	0.145	1.75	0.24	0.48
	2	0.153	1.06	0.27	0.53
	3	0.139	0.78	0.26	0.53
	Average	0.146	1.20	0.25	0.51
Apem pa	1	0.140	1.41	0.32	0.64
	2	0.190	0.93	0.25	0.37
	3	0.152	1.22	0.22	0.56
	Average	0.161	1.19	0.26	0.52
Apem hemaa	1	0.155	1.34	0.34	0.49
	2	0.171	0.75	0.39	0.47
	3	0.162	0.85	0.31	0.45
	Average	0.163	0.98	0.35	0.47

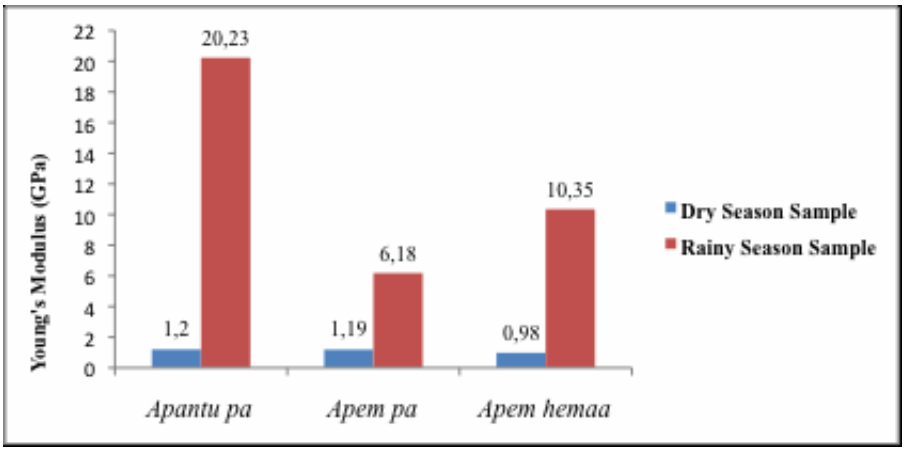

Figure 2 - Young's Modulus of rainy and dry season samples.

Apem pa and *Apem hemaa* of the mechanical properties for rainy and dry season samples at $p<0.05$. For all the varieties tested, there is a significant difference in the Young's Modulus, Yield Stress and Ultimate stress between the rainy season and dry season samples. The rainy season samples show higher values of Young's modulus, Yield stress and Ultimate stress than the dry season samples.

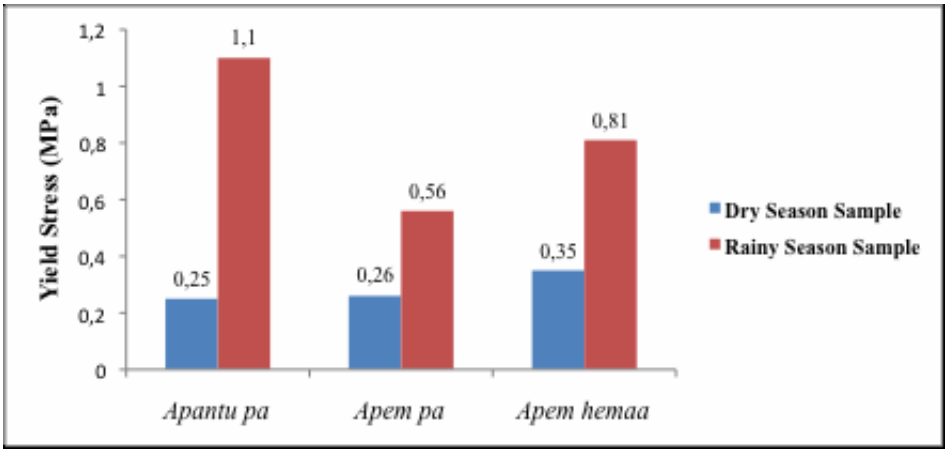

Figure 3 - Yield Stresses of rainy and dry season samples.

Percentage change in mechanical properties

There was a general reduction in the values of the mechanical properties obtained for the rainy season and dry season.

Apantu pa

The Young's modulus for the *Apantu pa* samples was 20.32 GPa in the rainy season but is reduced to 1.19 GPa in the dry season, a percentage reduction of 94.10 %. The Yield stress of the *Apantu pa* samples reduced by 76.80 % and the Ultimate stress also reduced by 74.30 %.

Apem pa

80.70 %, 53.3% and 45.20% reductions for the Young's modulus, Yield stress Ultimate stress respectively for the *Apem pa*.

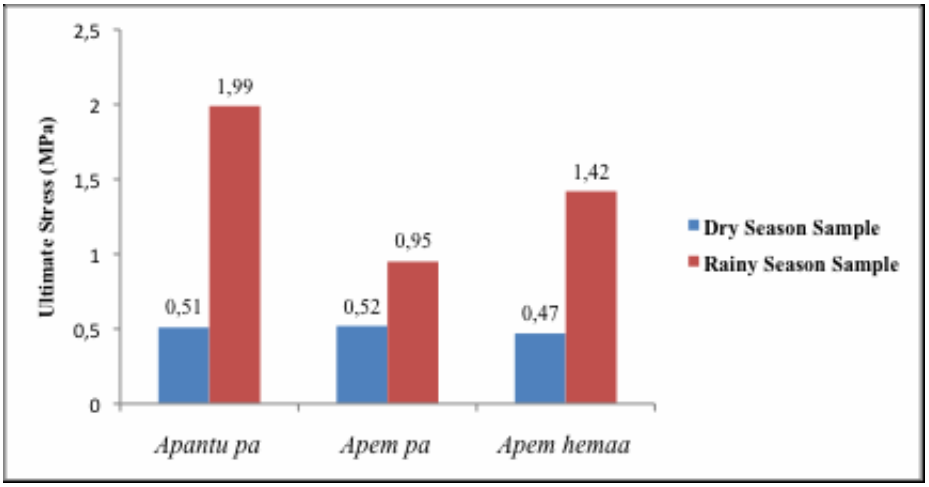

Figure 4 - Ultimate stresses of rainy and dry season samples.

Table 3 - Least significant differences (LSD) among samples.

Mechanical Property	Apantu pa	Apem pa	Apem hemaa
Young's Modulus	7.410	2.387	2.418
Yield Stress	0.1677	0.052	0.109
Ultimate stress	0.157	0.018	0.018

Apem hemaa

90.48 %, 57.3 % and 66.98 % are the reductions for the Young's modulus, Yield stress and Ultimate stress respectively for the *Apem hemaa*.

Conclusions

For the pseudostems of the three varieties tested (*Apantu pa Apem pa* and *Apem hemaa*), the Young's modulus, Yield stress and Ultimate stress were higher in the rainy season than they were in the dry season. There was significant difference in the mechanical properties of the rainy season and dry season samples. From the test results, *Apantu pa* pseudostem samples showed the highest value for all the three

mechanical properties studied during the rainy season. The variety of plantain pseudostem that had the lowest mechanical properties values in the rainy season was the *Apem pa*. Some questions could be raised for further research. Does the moisture content of the samples influence the mechanical strength? Would increased moisture content due to increased cell tugor influence the mechanical strength of the plant? Would irrigation of plantains lead to the maintenance of suitable moisture content that would lead to increase in mechanical strength and reduced lodging? Would the mechanical strength be related to the resistance of the plantain pseudostem to lodging?

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