# MECHANICAL PROPERTIES OF PLANTAIN PSEUDOSTEM

**By**

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## DECLARATION

I hereby declare that this work is my own work towards the Master of Science (Mechanical Engineering) and that, to the best of my knowledge, it contains no material previously published by another person nor materials which have been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

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**ABSTRACT**

Variations in some mechanical properties of plantain pseudostem for three main varieties in Ghana were examined in the rainy and dry seasons. *Apantu pa*, *Apem pa* and *Apem hemaa* were selected in farms in the Kumasi metropolis during the rainy and dry seasons. Samples of the plantain pseudostem were obtained by cutting down matured plants bearing fruits, 20 cm from the ground and at the petiole.

The strength properties namely; Young's modulus, yield stress and ultimate stress were determined using three - point bending test method which followed the International Standards Organisation (ISO) 178.

The test results showed that the Young's modulus, yield stress and ultimate stress were remarkable high in the rainy season and low in the dry season for all three varieties. *Apantu pa* samples proofed superior to the other two in the rainy season, having the highest value for Young's modulus of 26.49 GPa, yield stress of 1.3 MPa and ultimate stress of 2.17 MPa. In the dry season, the *Apem pa* samples proofed resilent than the other two, having the highest values of 1.41 GPa, 0.32 MPa and 0.64 MPa for Young's modulus, yield stress and ultimate stress respectively.

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## ABBREVIATION AND SYMBOLS

ASCE – American Society of Civil Engineers

A – Area

F – Axial concentrated load

M – Bending moment

CILSS – Comité Inter-Etate pour la Lutte Contre la Sécheresse au Sahel

CRI – Crop Research Institute

$C_1$ – Constant value

$C_2$ – Constant value

$\Delta y$ – Change in deflection

$\Delta F$ – Change in force

y – Deflection

x – Displacement

d – Diameter

c – Fiber distance

FHIA – Fundación Hondurena de Investigción Agricola

z – Height

I – Important factor

IITA – International Institute of Tropical Agriculture

ISO – International Organisation for Standards

IU – International Units

$L$ – Length

$y_{max}$ – Maximum deflection

$\sigma_m$ – Maximum allowable stress

$I$ – Second moment of area

$K_{zt}$ – Topographic factor

$F_u$ – Ultimate force

$\sigma_u$ – Ultimate stress

w, UDL – Universally distributed load

$q_z$ – Velocity pressure

$K_z$ - Velocity pressure exposure coefficient

$K_d$ – Wind directionality factor

$V$ – Wind speed

$F_y$ – Yield force

$\sigma_y$ – Yield stress

$E$ – Young's modulus

# CHAPTER 1: INTRODUCTION

## 1.1 MOTIVATION

According to the year 2000 census in Ghana, more than half of Ghana's workforce is directly engaged in agricultural activities. More than 90% of farm holdings are less than two (2) hectares (ha) in size and are subsistence farms yet they contribute 80% to Ghana's total agricultural output. Ghana's agricultural outputs include; cereals (maize, rice, sorghum, millet), roots and tubers (cassava, yam, cocoyam), plantain, cash crops (cocoa, oil palm, coconut, coffee, cotton) fruits and vegetables (pineapples, citrus, banana, cashew, tomato, pepper, okro, onion) [19].

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. More than 90% of the cultivated area in Ghana belongs to small holder farming system [19].

Plantain production has increased steadily over the years. In 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. The percentage increase was 7% [12].

According to the preliminary domestic food supply and demand position in 2009/2010, the gross domestic production of plantain was 3,587,000 metric tons, 3,048,950 metric tons was the total available domestic production for human consumption with a per capita consumption of 84.8 kg/annum. The national consumption was estimated to be 2,037,700 metric tons [12]. Figure 1-1 shows plantain ready for sale at a roadside market in Ghana.

This study is to help reduce the incidence of plantain lodging by determining the mechanical properties of the plantain pseudostem in Ghana.

Figure 1-1: Plantains at a roadside market in Ghana

## 1.2 PROBLEM STATEMENT

Plantain farming in Ghana is mainly at small and large scale levels. Small scale plantain farming is normally on a household level having the farm at the backyard. The large scale plantain farming is one that covers several hectares of land. A plantain farm can have from ten to several hundreds of plantain mats; a plantain mat carries three to four plantain plants.

There are three major varieties of plantain on the Ghanaian market, namely, *Apantu*, *Apem* and *Apemhemaa*. Both the *Apantu* and *Apem*, which are landraces (local) varieties, are more prone to fungal disease and pests. The hybrid plantains, example is the *Apemhemaa*, were introduced to supplement the landraces. They are more disease tolerant and produce more fruits (yields) as compared to the landraces.

However, it was observed that, for both the landraces and the hybrids, plantain plants were been toppled over or lodged by strong winds at certain times of the year. The lodging observed was of two types, root lodging and stem lodging. Plants with infected pseudostem and fruit carrying ones were seen to be lodged more often by steady winds. But most of the plantain plants were lodged over by strong winds. In the rainy season, strong winds accompany the rains, and the pressures of the winds are strong enough to cause lodging. In the case of the dry season, the wind pressures are considerably low, but plantain plant lodging was observed.

## 1.3 OBJECTIVE

The main objective of this thesis was to determine the effects of seasonal change on the mechanical properties of three main Ghanaian plantain variety pseudostem.

The specific objectives are:

- To determine the Young's modulus of selected plantain pseudostems for the rainy and dry seasons.
- To determine the yield stress of selected plantain pseudostems for the rainy and dry seasons.
- To determine the ultimate stress of selected plantain pseudostems for the rainy and dry seasons.
- To estimate the wind speeds to cause stem lodging in both the rainy and dry season.

## 1.4 SCOPE

Three main varieties of plantain in Ghana were covered in this work. They are *Apantu pa, Apem pa* and *Apemhemaa*. Tests were performed on plantain pseudostem samples obtained during the rainy season and dry season.

Chapter 2 reviews literature, the history, morphology, types, producing regions, farming season and constraints of plantain in Ghana. The constraints comprised of biological, climate and soil related.

The method, materials and procedure followed to perform the test are presented in Chapter 3. As part of the test, instruments such as vernier calipers, tape measure, three - point bending supports and meter rule were available at the laboratory. Pseudostem samples were collected from nearby farms in both the rainy and dry season. Mathematical equations used throughout the work are presented in this chapter. Limitations and assumptions made throughout the work are also presented in this chapter.

Chapter 4 presents the load – deflection curves for each sample under the two farming seasons. The curves informed the values of the Young's modulus, yield stress and ultimate stress. Discussion of the results and effects of the change in farming season on the Young's modulus, yield stress and ultimate stress of the pseudostem samples are also presented here. The mechanical properties of samples from the rainy and dry season were compared for the various cultivars.

Conclusion and recommendations of the thesis are also presented in Chapter 5.

## CHAPTER 2: LITERATURE REVIEW

### 2.1 HISTORY AND DESCRIPTION

Plantains and bananas plants are crop in the genus *Musa* and are giant perennial herbs which originated from Southeast Asia. Plantain and bananas are monocotyledonus plants, belonging to the section *Eumusa* within the genus *Musa* of the family *Musacease* in the other *Scitamineae*. Plantain and banana cultivars evolved by natural hybridization between the two species, *M. acuminate* (contributing genome A) and *M. balbisiana* (contributing genome B) [42].

All plantains and almost all important bananas are triploid. Triploid cultivars have genome combination of AAA, AAB, and ABB. Most plantain and banana hybrid cultivars are of tetraploid type ie, AAAA, AABB, and ABBB [45].

The world's production of plantain between 2000 and 2002 is 25,309,000 metric tons (Mt). Out of which Africa contributes 22,478,000 Mt of the world's production. The Americas contributes 1,835,000 Mt whiles Asia contributes about 996,000 Mt.

Africa leads the world's production by 89% followed by the Americas 7% and the least producing region is Asia with 4%.

Ghana is one of the leading producing countries of plantain in Africa. Other countries include Uganda, Rwanda, Nigeria and Cote d'Ivoire.

In the Americas, Colombia, Peru, Venezuela, Ecuador and Cuba are the leading producing countries producing plantains. Sri Lanka and Myanmar are the only leading plantain producers in Asia. Other areas that produce plantain include the Southern United States, Puerto Rico, Hawaii, Bolivia, Brazil, Cameroon, Egypt, Taiwan, Thailand, India, Indonesia, Malaysia, Philippines and Northern Australia [45].

Environmental conditions have profound influence on the production of plantain. There are three main conditions to enable good growth and they are temperature, moisture and soil condition.

Plantains grow best between 20°C and 30°C. The optimum for the dry matter accumulation is about 20°C and for the appearance of new leaves is 30°C. With temperatures above 38°C, the growth of the plantain plant stops [6] but under irrigation, this is prevented.

An average of 100 mm amount of rainfall per month would supply the required amount of moisture needed for the growth of plantain plant [45].

Plantains can be grown on a wide range of soils provided there is good drainage and adequate fertility. The best soils are usually deep, well drained, water retentive loams with high humus content. Soil pH of 5.5 – 6.5 is desirable [45].

Constraints in plantain production include diseases, pests, weeds, soil fertility, lodging, finance and marketing [40].

## 2.2 MORPHOLOGY OF PLANTAIN

A plantain plant consists of basically the roots, pseudo-stem, leaves and inflorescence. Figure 2-1 shows the parts of the plantain plant.

The roots system consists of primary, secondary and tertiary roots. Secondary roots are those that develop on primary roots, while tertiary roots develop on the secondary roots. The primary roots have the explorer roots and the feeder roots. The explorer roots are mainly for anchorage and are thicker than feeder roots. Feeder roots take up water and nutrients and usually grow from explorer roots [42].

Pseudo-stem is the cylindrical structure growing from the corm and carrying the foliage. The pseudo-stem is not wood because plantain crops are giant herbs, not trees. It consists of tight packing of overlapping leaf sheaths [42]. The pseudo-stem offers support for the leaves and inflorescence. The function of the pseudostem is purely connective and provides vascular connection between roots, leaves on one hand and the inflorescence on the other.

The inflorescence, also known as the bunch, is the collection of the plantain fingers (fruits) on a fruit stalk. There are types of inflorescence, and this depends on the type of variety.

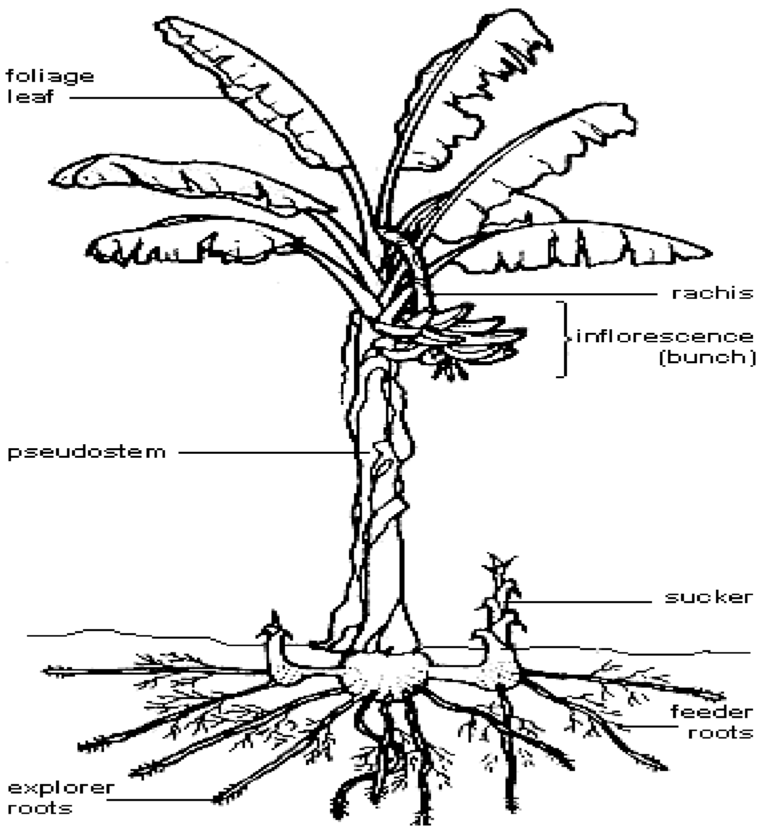



Figure 2-1: Morphology of plantain [42]

## 2.3 NUTRITIONAL VALUES OF PLANTAIN

Plantain is relatively high in calories at 125 per cup. One cup cooked plantain yields a trace of fat, 2.3 g dietary fiber, 465 mg potassium, 26 mcg folate, 10.9 mg vitamin C, 909 IU vitamin A, 32 mg magnesium and 3H carbohydrate. They are known to be a great source of calcium, vitamins A, $B_1$, $B_2$, $B_3$, $B_6$, C and minerals such as potassium and phosphorus [25].

Plantains are useful in managing patients with high blood pressure and heart diseases because they are low in sodium, very little fat and no cholesterol. They are also ideal for patients with gout or arthritis because they are free from substances that give rise to uric acid [25].

## 2.4 GROUPS OF PLANTAIN

There are four (4) main groups of plantains. They are mostly differentiated by; completeness of inflorescence at maturity, presence of neutral flowers and male bud at maturity, number of hands, and number and weight of fingers [42].

The four main groups are; French plantain, French horn plantain, False horn plantain and True horn plantain.

The French plantain has a complete inflorescence at maturity. This variety can achieve a height of about 2.5 m and circumference of 600 mm. It produces between 30-38 leaves before fruiting and takes 12 months to produce a mature bunch. The bunch carries as many as 6-12 hands and 60-170 small fingers [42].

The False Horn plantain variety has smaller number of hands as compared to the French plantain but larger fingers. The False Horn bunch can carry as many as 5-12 hands and 25-80 fingers. There are neutral flowers and no male bud at maturity. The inflorescence is incomplete.

The French horn plantain also has an incomplete inflorescence, no male bud but many neutral flowers at maturity. French horn plantain usually has 7-8 number of hands and fingers of 30-85.

The True Horn plantain variety usually has 1-5 hands. The fingers are few in number, 1-50. The True Horn plantains are longer and stouter than the False Horn plantains [42]. Figure 2-2 shows the various type of inflorescence of the different groups of plantain.

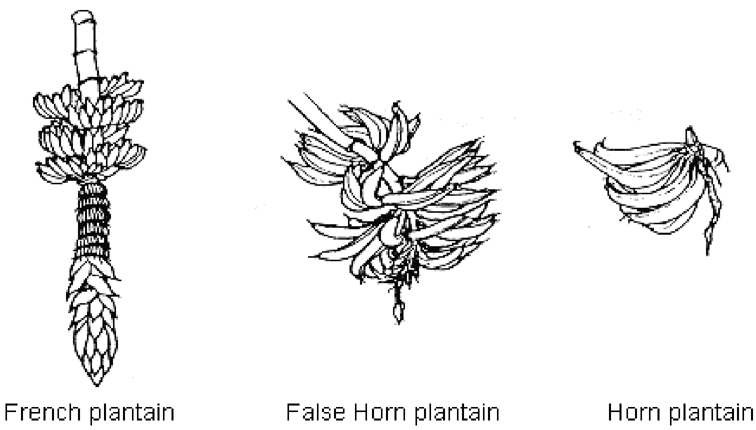



Figure 2-2: Types of inflorescence of the different groups of plantain [42]

## 2.5 TYPES OF PLANTAIN CULTIVARS IN GHANA

Out of the four main groups of plantain, three (3) are present in Ghana; they are the False horn plantain, True horn and French plantain [30].

There are also hybrids of plantains in Ghana. The hybrids were developed to be resistant to the major diseases affecting the three main groups. Some of the hybrids are FHIA-21, FHIA-01, FHIA-03 and FHIA-25 [16].

The False horn plantain, True horn plantain and French plantain are considered as local landraces and they have various varieties in the country. Locally *Apantu* and *Apem* are the names given to the False horn plantain and the French plantain respectively [30]. Table 2-1 shows the various varieties of plantain in Ghana.

In 2005, majority of farmers planted the local races. The local races had an adoption rate of 87.1% and the hybrid plantain had 12.9%. The False horn plantain had 73%, French plantain had 12.1% and the True horn plantain had 2.0 %. *Apantu pa* and *Asamienu* were the only varieties planted for the False horn and True horn plantain respectively. *Apem pa* contributed 10.9% out of 12.1% for the French plantain whiles *Apemhemaa* hybrid plantain contributed 9.7% out of the 12.9% for the hybrid plantain [16].

Table 2-1: Varieties of Plantain in Ghana [30]

| Group | Local variety | Translation / Description |
|---|---|---|
| False horn plantain | *Apantu pa / Brode pa* | True Apantu |
| | *Apantu Kwakuo* | Plantain eaten by monkeys |
| | *Anwanwii* | From Anwanwii, Cote d' Ivoire |
| | *Adoso* | Many fingers |
| | *Abomienu / Adurommienu* | Bears two bunches |
| | *Abomiensa / Adurommiensa* | Bears three bunches |
| | *Brode sebo* | Tiger skinned plantain |
| | *Brode yuo* | Pink pseudostem |
| | *Brode Kwakwaa* | Plantain named after "Kwakwaa" |
| | *Kwakuo ntorowa* | Monkey's garden egg |
| | *Nyiretia Apantu* | Short finger Apantu |
| | *Osoboaso Apantu* | Resembles |
| | *Sakro* | One hand |
| True horn plantain | *Asamienu* | Two hands |
| | *Asamiensa* | Three hands |
| French plantain | *Apem pa* | True / Ordinary French plantain |
| | *Adoso* | Huge with loose hands |
| | *Apemtia* | Dwarf Apem |
| | *Afua kuma* | Named after a woman born on Friday |
| | *Apem fitaa* | White Apem |
| | *Brode hene* | Chief of plantain |
| | *Nyiretia Apem* | Short fingers |
| | *Osabum/ Ogyebim* | Many hands |
| | *Osoboaso Apem* | Over produced Apem |
| | *Oniaba* | Without seed |
| | *Owudwo* | Produces ten |
| | *Soaduasa* | Produces thirty fingers |

## 2.6 PLANTAIN PRODUCING REGIONS IN GHANA

Ghana is situated in the centre of the countries along the Gulf of Guinea in West Africa. The country has an area of 238,530 square kilometers and lies between latitudes 4°44' and 11°11' N and longitudes 01°12' and 03°11' W. Ghana is bordered on the east, west and north by the Republic of Togo, Cote d'Ivoire and Burkina Faso respectively. On the south, Ghana is bordered by the Atlantic Ocean. The sea coast is 550 km long [27].

Administratively, Ghana is divided into ten regions as follows (capital towns in brackets): Ashanti (Kumasi), Brong Ahafo (Suyani), Central (Cape coast), Eastern (Koforidua), Greater Accra (Accra), Northern (Tamale), Upper East (Bolgatanga), Upper West (Wa), Volta (Ho) and Western (Sekondi-Takoradi) [27].

There are three agro-ecological zones; Coastal, Forest and Savannah zone in Ghana. These agro-ecological zones cut across the ten administrative regional boundaries. As shown in Table 2-2, the three agro-ecological zones can be further divided into sub-zones. The sub-zones differ in terms of average annual rainfall, type of vegetation, agriculture and livelihoods [8].

In Ghana, the Forest zone is the leading producing zone for plantain production. The forest zone stretches across the Brong Ahafo, Ashanti, Eastern, Western and some part of the Volta region. Figure 2-3 shows Ghana's agro-ecological zones and administrative regions

Table 2-2: Characteristics of agro-ecological zones in Ghana [8]

| Agro-ecological zone | Sub-zone | Annual rainfall range (mm) | Main food crops |
|---|---|---|---|
| Coastal | Coastal Savannah | 600 – 1,200 | Roots, maize |
| Forest | Rain Forest | 800 – 2,800 | Roots, plantain |
| | Deciduous Forest | 1,200 – 1,600 | Roots, plantain |
| | Transitional | 1,100 – 1,400 | Maize, roots, plantain |
| Northern Savannah | Guinea Savannah | 800 – 1,200 | Sorghum, maize |
| | Sudan Savannah | 800 - 1,100 | Millet, sorghum, cowpea |


Figure 2-3: Ghana’s agro-ecological zones and administrative regions [8]

## 2.7 FARMING SEASONS

Generally, there are two main farming seasons in Ghana; they are the rainy season and the dry season. The rainy season begins in April and ends in October whiles the dry season begins in November and ends in late March [40].

Rainfall determines largely the type of agricultural enterprised carried out in the various agro-ecological zones. The rain forest, deciduous forest, transitional and coastal zones experience bimodal rainfall pattern which gives rise to major and minor farming seasons. Unimodal rainfall distribution in the Guinea savannah and Sudan savannah of the northern zone gives rise to a single farming season.

The bimodal regions in Ghana include Western, Eastern, Ashanti, Brong Ahafo and parts of Volta and Central region. The major farming season is between the months of March and July whiles the minor farming season is between September and November [8].

The single farming season in the northern zone is between May and September [8].

## 2.8 PLANTAIN FARMING CONSTRAINTS

Yields losses in plantain production can be classified as soil related, biological and climate [25].

### 2.8.1 BIOLOGICAL CONSTRAINTS

Plantains are susceptible to a wide range of diseases and pests. Some pest and diseases are highly aggressive, very contagious and spread easily. They are persistent and practically difficult to eradicate once established.

Some of the diseases affecting plantain production in Ghana include Witting, Black Sigakota, pseudostem rot, nematodes and heart rot [30].

Witting occurs when fungi clogs the plant's vascular system hence reducing the plant's ability to transpire and grow. Black Sigakota (*Mycosphaerella fijensis*) is a leaf spot disease caused by a fungus. Pseudostem rot is another fungal disease. It affects the pseudostem and may cause it to fall prematurely. The rot lowers the fibre quality through discolouration. Nematodes are parasitic to the plantain plants and are detrimental to the plant's health. Heart rot is a fungal disease that causes the decay of the plantain plant.

Pests that lower the yields in plantain production can be grouped into two, major and minor pests. The major pests include grasshoppers, banana weevils, black ants, termites, mealy bugs and rhinoceros beetle. The minor pests include birds, rodents and monkeys [30].

### 2.8.2 CLIMATE CONSTRAINTS

Wind is the single climate constraint that affects the plantain production. Winds of 15 m/s and above can topple plants especially when they carry plantain bunch [5]. Height has a dramatic affect on wind tolerance. Steady winds cause significant leaf shredding, leaf drying and the distortion of the crown. In case of extreme winds, complete or partial toppling of the entire plant occurs. Wind causes more damage if the underground corm is weakened by insects or diseases [38]. Leaf tearing due to wind reduces bunch weight by 50% [5].

### 2.8.3 SOIL RELATED CONSTRAINTS

Soil fertility is one major factor that influences the yields in plantain production. Majority of farmers perform intercropping of plantain over a long period and do not practice any soil fertility maintenance on the farms. This gradually reduces the fertility of the soil. Some ways to maintain the soil fertility is the use of fertilizer or green manure [16].

## 2.9 PLANTAIN PSEUDOSTEM LODGING

Pseudostem lodging is the term used to describe the toppling of the plantain's pseudostem. Pseudostem lodging is one of the pre-harvest production losses in Ghana. It lowers yields dramatically. There are two main types of lodging; Root lodging and Stem lodging [40].

Root lodging occurs when the plantain plant is toppled over at the roots while Stem lodging occurs when the plantain plant is snapped at the pseudostem and toppled over. Figure 2-4 shows root lodging and Figure 2-5 shows stem lodging.

Figure 2-4: Root lodging of a backyard plantain plant

Figure 2-5: Stem lodging of a backyard plantain plant

A strong wind is the main factor of stem lodging and loose soil is the main factor for root lodging. Other factors include insects, nematodes, weight of bunch and height of plantain plant. Insects such as banana weevils bore through the pseudostem hence reducing the fibre quality. Nematodes such as burrowing nematodes burrow through the soil around the roots of the plants and therefore make the base of the plant weak against strong winds. Also, most pseudostem that are tall and have small girth size are mostly prone to wind damage. Occasionally, the weight of the bunch makes the pseudostem bend towards the bunch and with steady winds; the pseudostem will lodge [40].

## 2-10: WIND LOADS

Wind is caused by difference is pressure [49]. When there is a difference in pressure, air is accelerated from a higher to a lower pressure. The basic wind speed is defined by the

American Society of Civil Engineers (ASCE) as the three second gust speed at 10m above ground in a specified exposure category [2].

The basic wind speeds that causes stem lodging of plantain pseudostem are usually high and are in the company of rainstorms and hurricane. 40-72 km/h (11-20 m/s) is the range of basic wind speed expected to cause lodging, especially pseudostem carrying fruits [38].

Design wind pressure, according to the American Society of Civil Engineers (ASCE), is the equivalent static pressures to be used in the determination of wind loads [2]. There are three allowed procedure use to determine the design wind loads and these are (1) Simplified procedure (2) Analytical procedure and (3) Wind tunnel [2].

The Analytical procedure is the typical procedure used to determined design wind pressure on structures [39]. In this procedure, wind velocity pressure, gust factor and pressure coefficient are factors considered in determining design wind pressure. The wind velocity pressure is the pressure of the moving wind on the surface whiles the pressure coefficient accounts for varying pressure across the structure [39]. The gust factor accounts for the dynamic interaction between the flowing wind and the structure. The gust factor for a stiff structure is given as 0.85 [39].

The wind pressure is determined from the direction of the wind, terrain at which the structure is sited, height of the structure and the geometry of the structure surface. These determinants are velocity pressure coefficient ($K_z$), topographic factor ($K_{zt}$), wind directionality factor ($K_d$), basic wind speed (v) and important factor (I). Wind directionality factor accounts for the wind direction and structure geometry. Velocity pressure coefficient takes into accounts the wind pressures on the types of structure surfaces. Important factor also accounts for the degree of hazard to human life and damage to property. Topographic factor accounts for the various type of exposure of structures at various terrain types [39].

Exposure categories are based on the ground surface roughness, which is determined from the natural topography, vegetation and construction facilities. Ground surface roughness are in three groups; Surface roughness B, refers to urban and suburban areas, wooded areas or other terrain with numerous closely spaced obstruction having the size of a single family dwellings or larger; Surface roughness C, refers to open terrain with scattered obstructions having heights less than 9.1m and; Surface roughness D, refers to flat, unobstructed areas and water surfaces outside hurricane prone regions [2]. Table 2-3 shows the velocity pressure exposure coefficient for different exposure categories at different heights.

Table 2-4 shows the wind directionality factor of different types of geometry of structure and Table 2-5 shows the force coefficient of the wind pressure with respect to the cross section, type of surface (smooth or rough) and the ratio of the height to the diameter (h/D).

Table 2-3: Velocity pressure exposure coefficients [2]

| **Height above ground level** | **Exposure** | | | |
|---|---|---|---|---|
| | **B** | | **C** | **D** |
| **(m)** | **Case 1** | **Case 2** | **Case 1 & 2** | **Case 1 & 2** |
| (0 – 4.6) | 0.70 | 0.57 | 0.85 | 1.03 |
| (6.1) | 0.70 | 0.62 | 0.90 | 1.08 |
| (7.6) | 0.70 | 0.66 | 0.94 | 1.12 |
| (9.1) | 0.70 | 0.70 | 0.98 | 1.16 |

Table 2-4: Wind directionality factor [2]

| **Structure type** | **Directionality Factor** |
|---|---|
| Chimneys, Tanks, and Similar Structures | |
| • Square | 0.90 |
| • Hexagonal | 0.95 |
| • Round | 0.95 |

Table 2-5: Force coefficient [2]

| **Cross-Section** | **Types of Surface** | **h/D** | | |
|---|---|---|---|---|
| | | 1 | 7 | 25 |
| Round | Moderately smooth | 0.5 | 0.6 | 0.7 |
| | Rough | 0.7 | 0.8 | 0.9 |
| | Very rough | 0.8 | 1.0 | 0.2 |

# CHAPTER 3: MATERIALS AND METHODS

## 3.1 INTRODUCTION

To obtain the mechanical strength of selected plantain cultivars, the study was carried out in three main steps. The first is to obtain the agronomic parameters that are the diameter at the tip, diameter at the base and the length of the selected plantain cultivars. The second is to plot the various loads against the deflections corresponding to the various loads obtain the load-deflection curve of each sample. The third is to determine the Young's modulus from the curves, the yield strength, ultimate stress and then compare the various curves and Young's modulus. The study was performed in the rainy season and dry season. Nine tests for both the rainy and dry season. Prior to the commencement of the tests, the plantain cultivar samples were moved from the various farms to the Civil Engineering laboratory (KNUST).

## 3.2 MATERIALS

The study was carried out in the Civil Engineering laboratory of the Kwame Nkrumah University of Science and Technology (K.N.U.S.T), Kumasi. Materials used are plantain pseudostems, three point bending supports, vernier calipers, tape measure, weighting scale, weights, pointer and a metre rule. Plantain pseudostems were randomly selected at the farms and they were all healthy, 10-12 months old and had healthy roots. Plantain pseudostem samples were obtained from the Crop Research Institute (C.R.I) farm of the Council for Scientific and Industrial Research (C.S.I.R), Kumasi, backyard farms of Kwame Nkrumah University of Science and Technology (K.N.U.S.T), Kumasi and backyard farm at Boadi in Kumasi. The samples obtained in the Rainy season were observed to be heavier than those from the dry season. The pseudostem of each plantain plant was taken from the petiole and twenty (20) cm above ground. Table 3-1 shows the varieties, quantities and locations of the pseudostem samples.

Table 3-1: Groups, varieties, quantities and locations of samples used

| GROUP | Variety | Quantity | Location |
|---|---|---|---|
| False horn plantain | *Apantu pa* | 2 | K.N.U.S.T |
| French plantain | *Apem pa* | 2 | K.N.U.S.T |
| False horn plantain | *Apantu pa* | 2 | C.R.I |
| French plantain | *Apem pa* | 2 | C.R.I |
| Hybrid | *Apemhemaa* | 2 | C.R.I |
| False horn plantain | *Apantu pa* | 2 | Boadi |
| French plantain | *Apem pa* | 2 | Boadi |
| Hybrid | *Apemhemaa* | 4 | Boadi |

Figure 3-1: Pseudostem samples at the Civil Engineering laboratory, KNUST

## 3.3 METHOD

The method used in this study is the three (3) point bending test, also known as the Flexural bending test. The test conforms to ISO 178, in which case, the test is stopped when sample fails.

The three (3) point bending test is when the sample is placed between two supports at the ends of the sample, and loading is applied at the middle span to produce a deflection. There are three main parameters of the three (3) point bending test; they are the support span, loading and the maximum deflection. From this test, the Young Modulus and ultimate stress can be found for the sample or specimen.

Figure 3-2 shows the sketch of the experimental setup

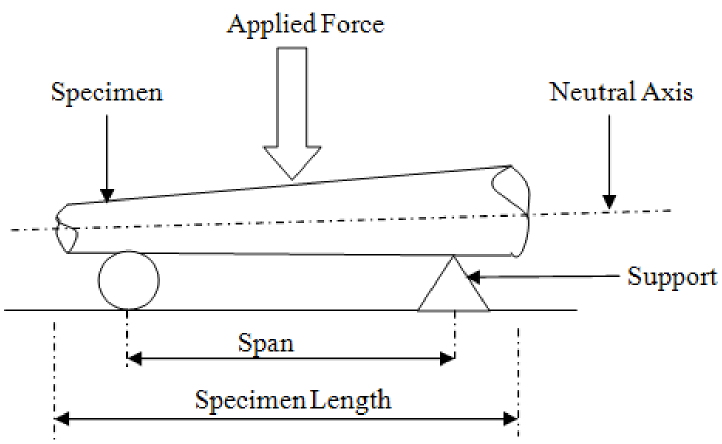



Figure 3-2: Sketch of the experimental setup

## 3.4 PROCEDURE

The lengths and diameters of the pseudostem samples were recorded, for both the rainy and dry seasons' samples. The diameters obtained were from the tip, mid and bottom sections of the pseudostem samples. Specimen length and span were also recored and tabulated. Table 5-2 and Table 5-3 show the dimensions of the pseudostem samples obtained.

The pseudostem was placed carefully on the two supports as shown in Figure 3-3. A pointer and a meter rule were set up to record the deflection along the neutral axis. 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. Figure 3-4 shows a sample that failed under loading.

Figure 3-3: Setup of the three point bending test of the pseudostem sample

Figure 3-4: A failed pseudostem sample under loading for the three point test

Table 3-2: Rainy season plantain pseudostem samples dimensions

| **Plantain cultivars** | **Apantu pa** | | | **Apem pa** | | | **Apem-hemaa** | | |
|---|---|---|---|---|---|---|---|---|---|
| Test samples | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Length of samples (m) | 2.84 | 2.90 | 2.67 | 1.91 | 1.85 | 1.87 | 2.32 | 2.11 | 2.27 |
| Length of span (m) | 2.24 | 2.20 | 2.07 | 1.31 | 1.25 | 1.27 | 1.72 | 1.51 | 1.67 |
| Circumference at the tip (m) | 0.18 | 0.17 | 0.15 | 0.41 | 0.384 | 0.39 | 0.351 | 0.299 | 0.327 |
| Circumference at the middle (m) | 0.22 | 0.20 | 0.20 | 0.50 | 0.477 | 0.482 | 0.473 | 0.448 | 0.45 |
| Circumference at the base (m) | 0.69 | 0.66 | 0.67 | 0.63 | 0.624 | 0.625 | 0.682 | 0.615 | 0.636 |

Table 3-3: Dry season plantain pseudostem samples dimensions

| **Plantain cultivars** | **Apantu pa** | | | **Apem pa** | | | **Apem hemaa** | | |
|---|---|---|---|---|---|---|---|---|---|
| Test samples | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Length of samples (m) | 2.20 | 2.67 | 2.17 | 2.528 | 2.46 | 2.33 | 2.20 | 2.32 | 2.27 |
| Length of span (m) | 1.60 | 2.07 | 1.57 | 1.928 | 1.86 | 1.73 | 1.60 | 1.72 | 1.67 |
| Circumference at the tip (m) | 0.34 | 0.34 | 0.323 | 0.346 | 0.451 | 0.352 | 0.348 | 0.390 | 0.361 |
| Circumference at the middle (m) | 0.40 | 0.435 | 0.39 | 0.464 | 0.518 | 0.480 | 0.430 | 0.496 | 0.47 |
| Circumference at the base (m) | 0.57 | 0.621 | 0.55 | 0.531 | 0.745 | 0.60 | 0.626 | 0.682 | 0.657 |

## 3.5 EQUATIONS

### 3.5.1 Mechanical properties

For simply supported beams, subjected to a point load at the mid span, as shown in Figure 3-5 below, the maximum deflection and bending moment occurs at the mid span.

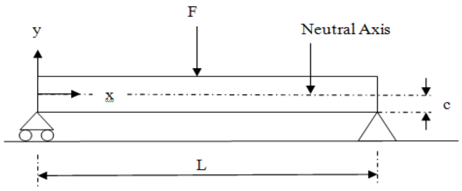



Figure 3-5: Simply supported beam with concentrated load

Applying the Euler-Bernoulli beam analysis equation

Integrating once more,

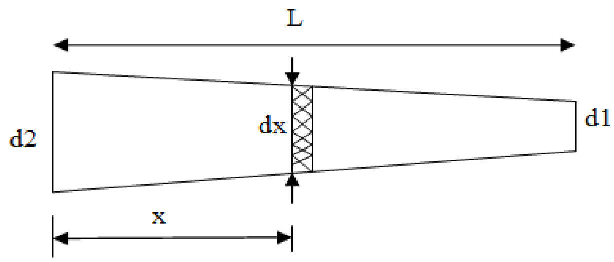



Figure 3-6: Sketch of the dimension of samples

From Figure 3-6, *dx* is the elemental diameter at the perpendicular distance *x* from *d2*.

Solving for *dx*;

From the Euler-Bernoulli bending equation;

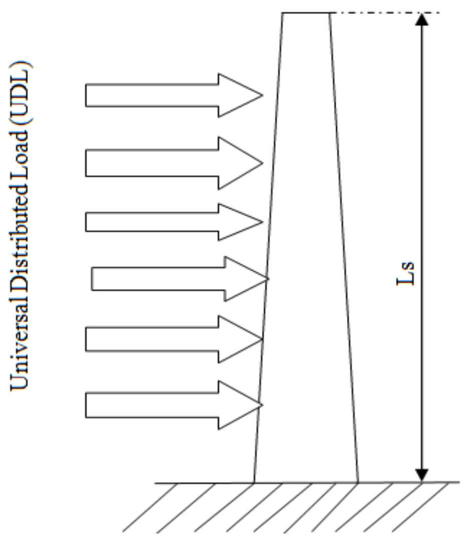
$q_z$ = Wind velocity pressure

$G$ = Gust factor

$C_f$ = Pressure coefficient

The wind velocity, $q_z$ is expressed in meters per second (m/s) as;

Upon substitution, the wind pressure becomes;



# CHAPTER 4: RESULTS AND DISCUSSIONS

## 4.1 RAINY SEASON

### 4.1.1 LOAD-DEFLECTION PLOT

After the three point test, the mid span deflections with the corresponding loads were tabulated and use to obtain a plot of load against deflection. The results obtained from the *Apantu pa* samples are shown in Table A-1, Table A-2 and Table A-3 whiles the plots are showed in Figure 4-1, Figure 4-2 and Figure 4-3. The *Apem pa* samples results are also tabulated in Table A-4, Table A-5 and Table A-6 and the respective plots are in Figure 4-4, Figure 4-5 and Figure 4-6. Table 4-7, Table 4-8 and Table 4-9 shows the results of the *Apemhemaa* and Figure A-7, Figure A-8 and Figure A-9 shows the respective plots.

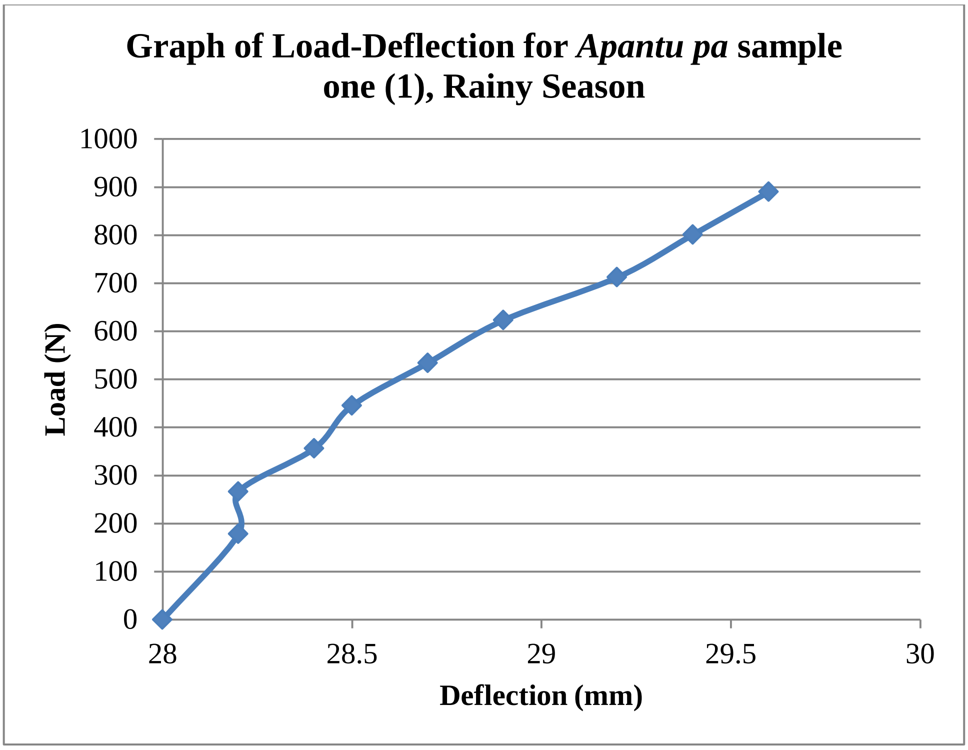



Figure 4-1: Graph of load-deflection for *Apantu pa* sample one (1), Rainy season

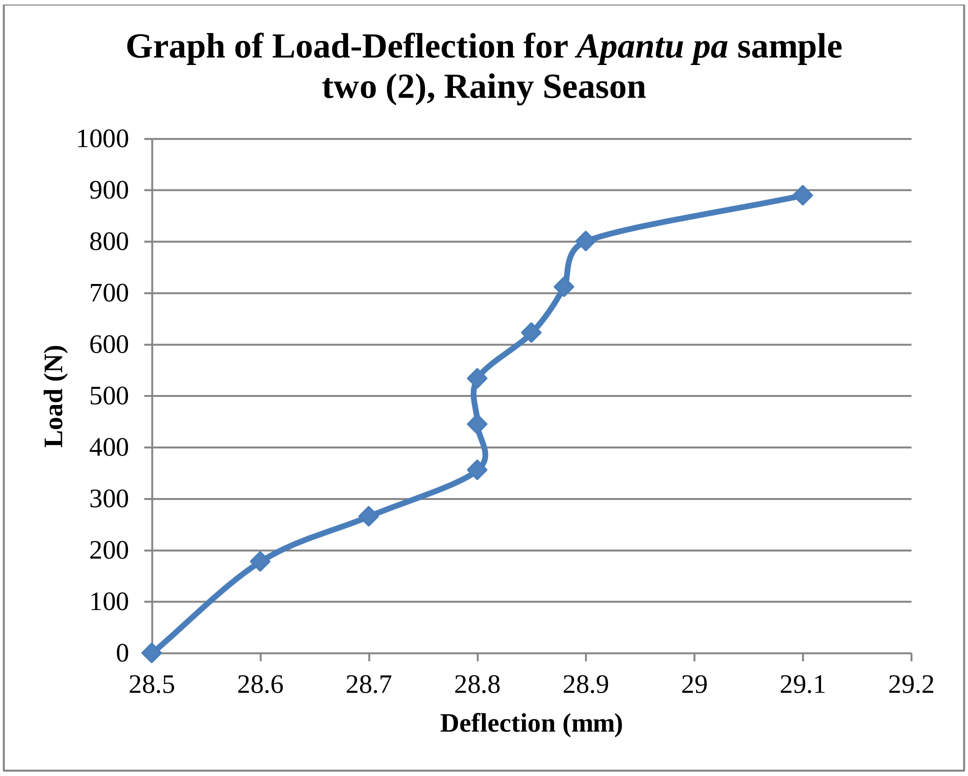



Figure 4-2: Graph of load-deflection for *Apantu pa* sample two (2), Rainy season

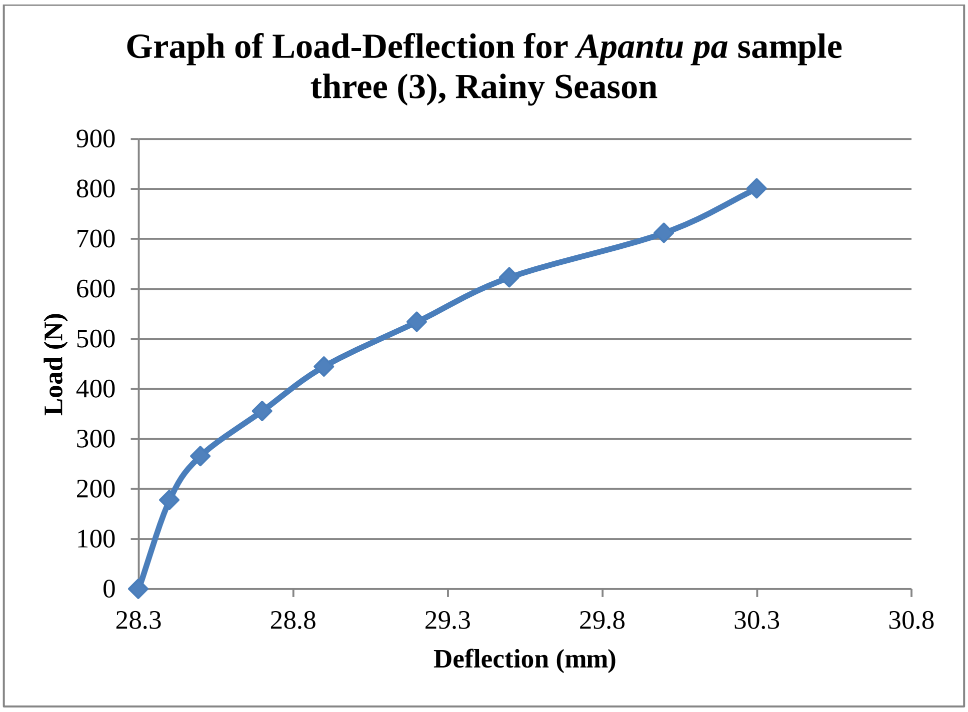



Figure 4-3: Graph of load-deflection for *Apantu pa* sample three (3), Rainy season

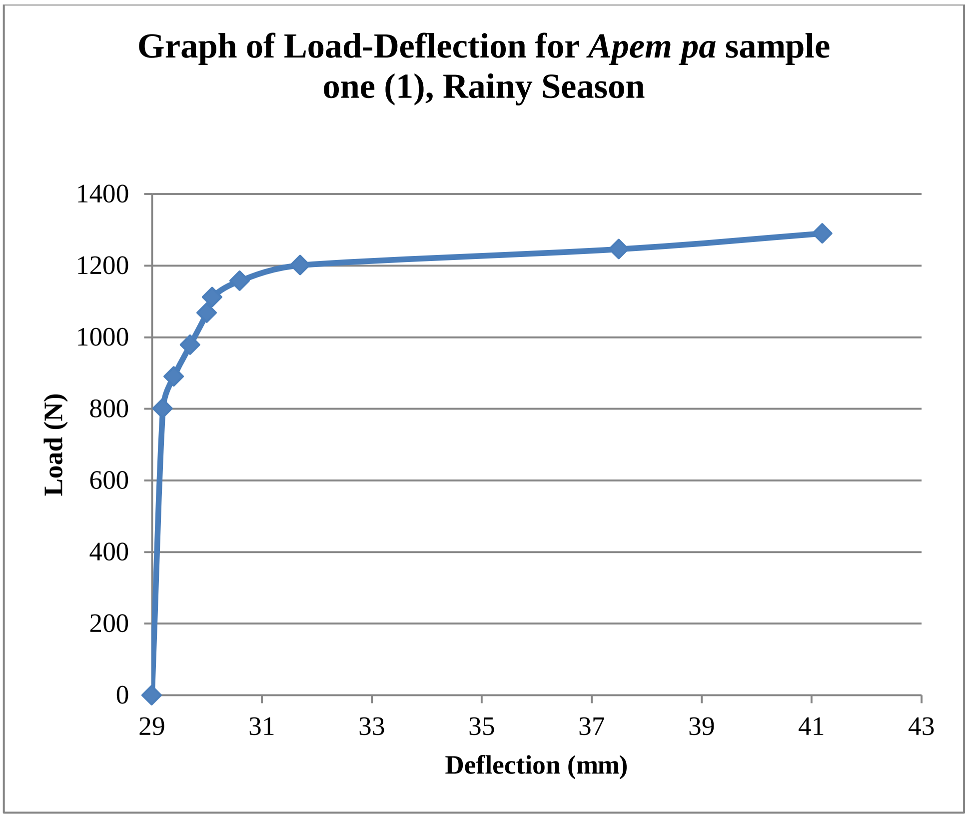



Figure 4-4: Graph of load-deflection for *Apem pa* sample one (1), Rainy season

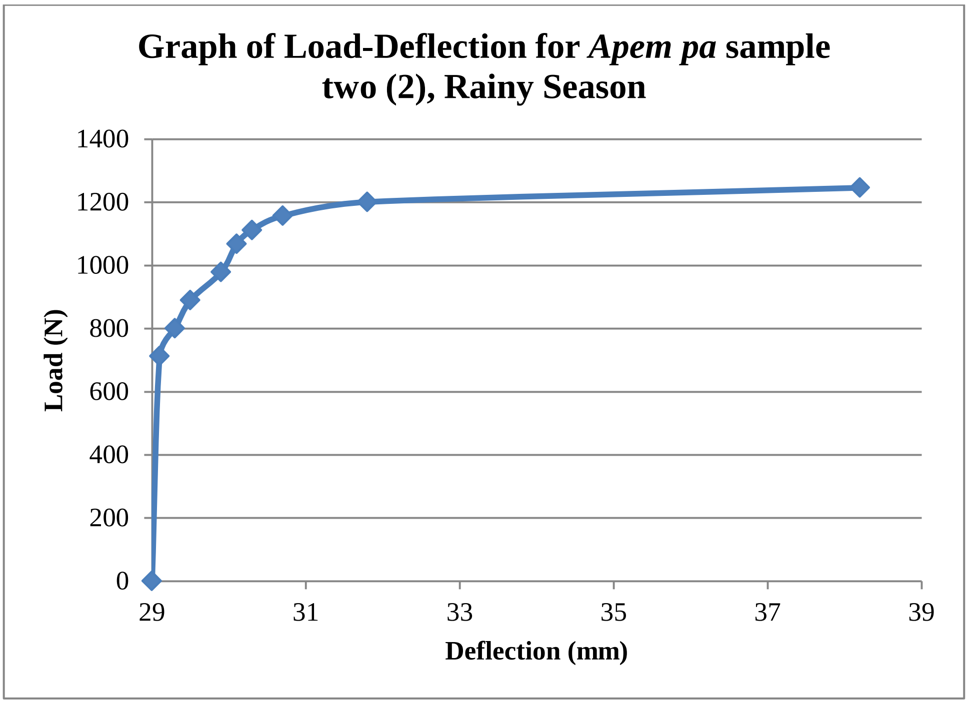



Figure 4-5: Graph of load-deflection for *Apem pa* sample two (2), Rainy season

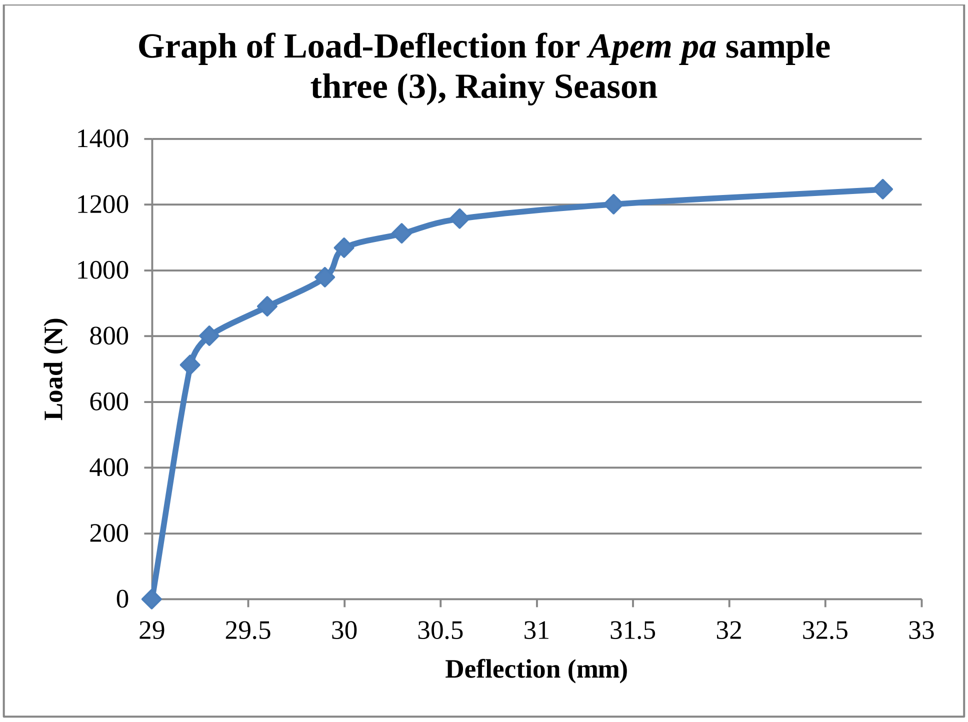



Figure 4-6: Graph of load-deflection for *Apem pa* sample three (3), Rainy season

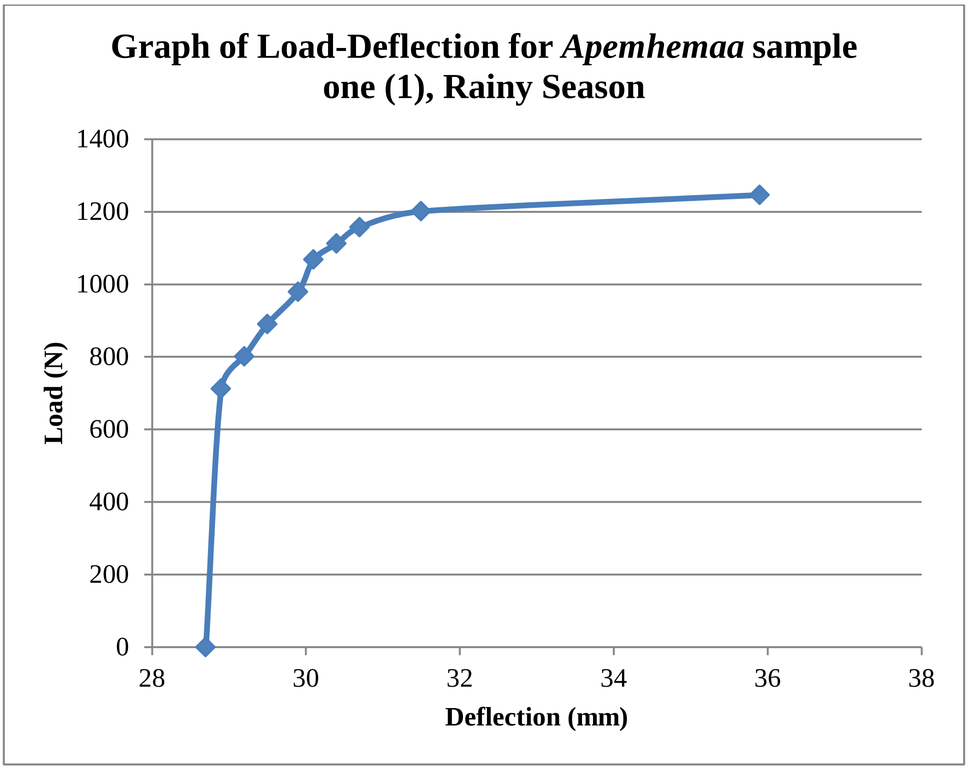



Figure 4-7: Graph of load-deflection for *Apemhemaa* sample one (1), Rainy season

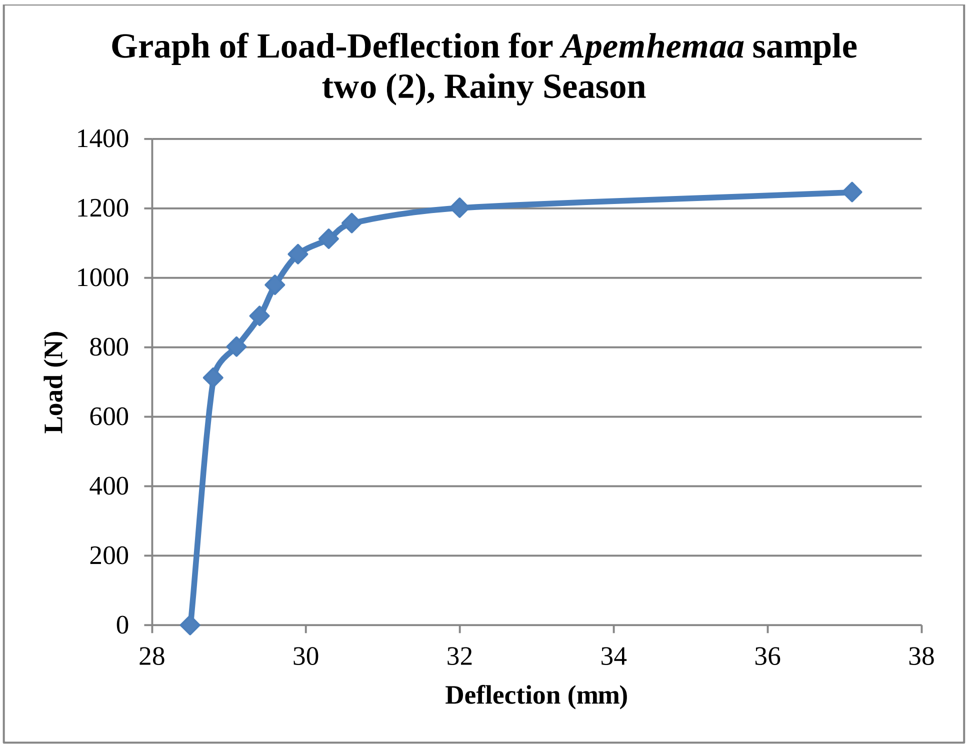



Figure 4-8: Graph of load-deflection for *Apemhemaa* sample two (2), Rainy season

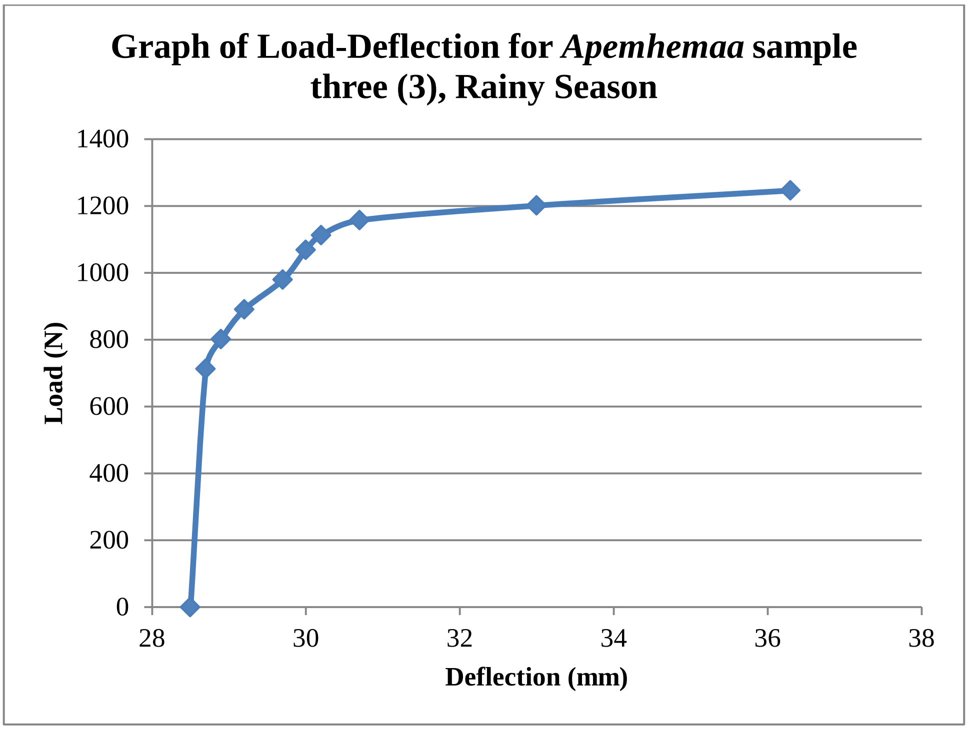



Figure 4-9: Graph of load-deflection for *Apemhemaa* sample three (3), Rainy season

The main mode of failure of the entire plantain pseudostem samples is by breaking. This happens when the bending moment created by loading is more than the moment of resistance of the pseudostem.

The samples obtained during the rainy season deflected proportionally up to the 267N load mark. The *Apantu pa* samples had yield loads as 445 N, 534 N and 267 N respectively as shown in Figures 4-1, 4-2 and 4-3. *Apem pa* samples showed a higher yield load as compared to the *Apantu pa* samples. Figure 4-4, 4-5 and 4-6 of *Apem pa* samples shows yield loads of 801N, 712 N and 712 N respectively. Comparatively, *Apemhemaa* samples had equivalent yield loads as the Apem pa samples. Figures 4-7, 4-8 and 4-9 of the *Apemhemaa* samples obtained yield loads of 712 N.

The ultimate loads of the various samples obtained during the rainy season varied slightly among them. *Apantu pa* samples failed at loads of 890 N, 890 N and 801 N, whiles the *Apem pa* samples failed at loads of 1,290 N, 1,246 N and 1,246 N respectively. A general ultimate load of 1,246 N was recorded for all the *Apemhemaa* samples.

### 4.1.2 MECHANICAL PROPERTIES

The mechanical properties to be determined are the Young's modulus, yield stress and ultimate stress, which were calculated from the derived equations in Chapter 3 and follow the calculation procedure for *Apantu pa* sample one in the rainy season in Appendix C.

Table 4-1 shows the Young's Modulus, Yield stress and Ultimate stress of all the plantain varieties pseudostem samples in the rainy season. Table 4-2 shows the average calculated values of the mechanical properties for the *Apantu pa*, *Apem pa* and *Apemhemaa* samples.

#### 4.1.2.1 Young's Modulus

In the rainy season, the Young's modulus after the bending test was within the range of 11.71 GPa – 22.75 GPa for the *Apantu pa* samples and the mean is 20.32 GPa. The *Apem pa* samples was in the range of 4.49 GPa – 9.00 GPa, and a mean of 6.18 GPa, whiles the *Apemhemaa* samples was in the range of 7.85 GPa – 12.84 GPa with a mean of 10.35 GPa. Figure 4-10 shows the mean Young's modulus of *Apantu pa*, *Apem pa* and *Apemhemaa* plantain pseudostem samples in the rainy season.

#### 4.1.2.2 Yield Stress

The yield stress results in the rainy season depict that the yield stress of the *Apantu pa* was in the range of 0.97 MPa – 1.04 MPa with mean of 1.10 MPa, *Apem pa* was in the range of 0.55 MPa – 0.58 MPa with mean of 0.56 MPa and the *Apemhemaa* recorded a range of 0.69 MPa – 0.89 MPa with mean of 0.81 MPa. Figure 4-11 shows the mean Yield stress of *Apantu pa, Apem pa* and *Apemhemaa* plantain pseudostem samples in the rainy season.

#### 4.1.2.3 Ultimate Stress

The ultimate stress of the plantain pseudostem, is the stress beyound which the samples would fail, is within 0.94 MPa – 2.17 MPa for the samples in the rainy season. The ranges obtained in the rainy season are 1.88 MPa – 2.17 MPa for *Apantu pa*, 0.94 MPa – 0.97 MPa for *Apem pa*, and 1.21 MPa – 1.57 MPa for *Apemhemaa*. Figure 4-12 shows the mean ultimate stress values of 1.99 MPa for *Apantu pa*, 0.95 MPa for *Apem pa*, and 1.42 MPa for *Apemhemaa* for the rainy season.

Table 4-1: Rainy season Mechanical properties of Plantain pseudostem samples

| Plantain variety | Samples | Mid span diameter (m) | Young's modulus, E (GPa) | Yield stress, $\sigma_y$ (MPa) | Ultimate stress, $\sigma_u$ (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 |
| *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 |
| *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 |

Table 4-2: Average Rainy season Mechanical properties of Plantain pseudostem samples

| Plantain variety | Mid span diameter (m) | Young's modulus, E (GPa) | Yield stress, $\sigma_y$ ( MPa) | Ultimate stress, $\sigma_u$ (MPa) |
|---|---|---|---|---|
| *Apantu pa* | 0.134 | 20.32 | 1.10 | 1.99 |
| *Apem pa* | 0.163 | 6.18 | 0.56 | 0.95 |
| *Apem hemaa* | 0.154 | 10.35 | 0.81 | 1.42 |

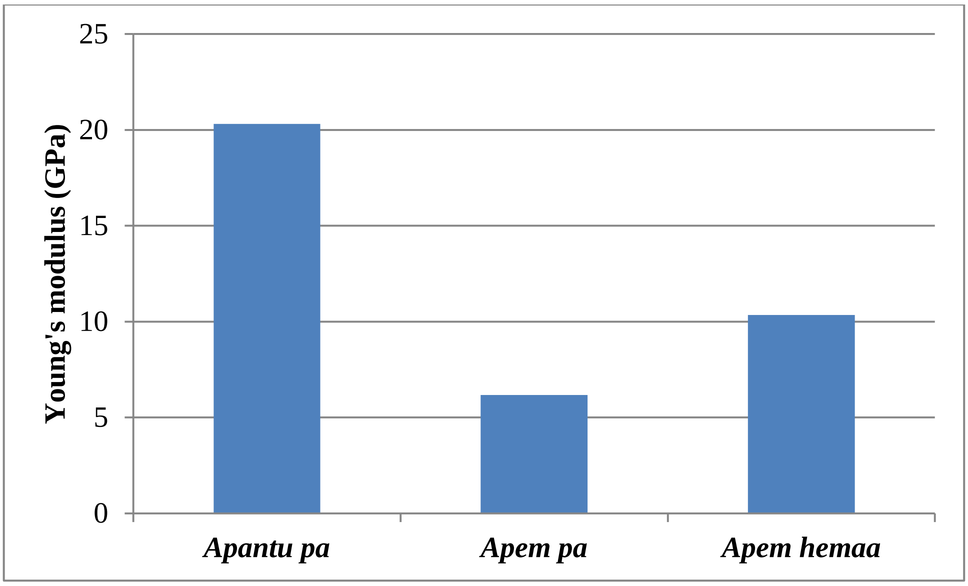



Figure 4-10: Young’s modulus of plantain pseudostem samples, Rainy season

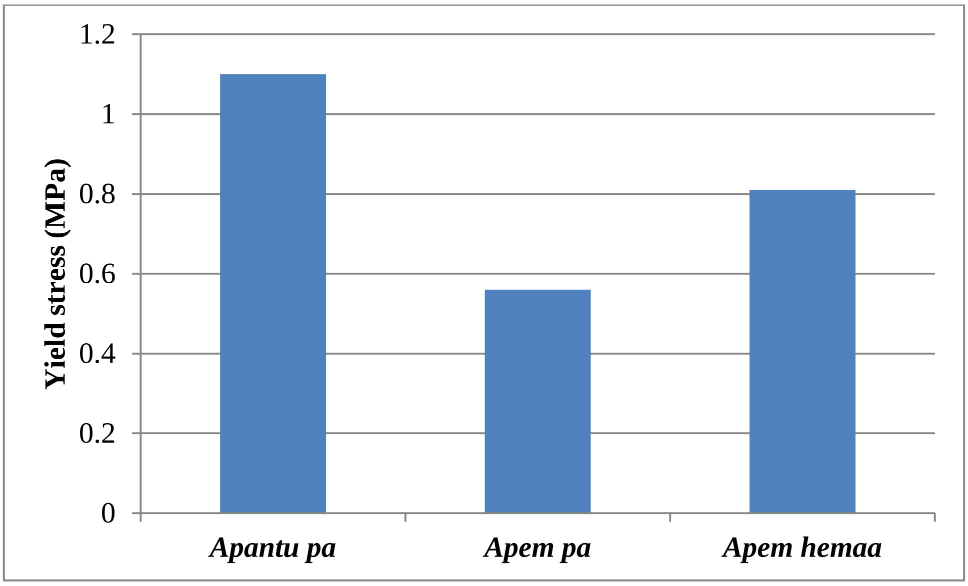



Figure 4-11: Yield stress of plantain pseudostem samples, Rainy season

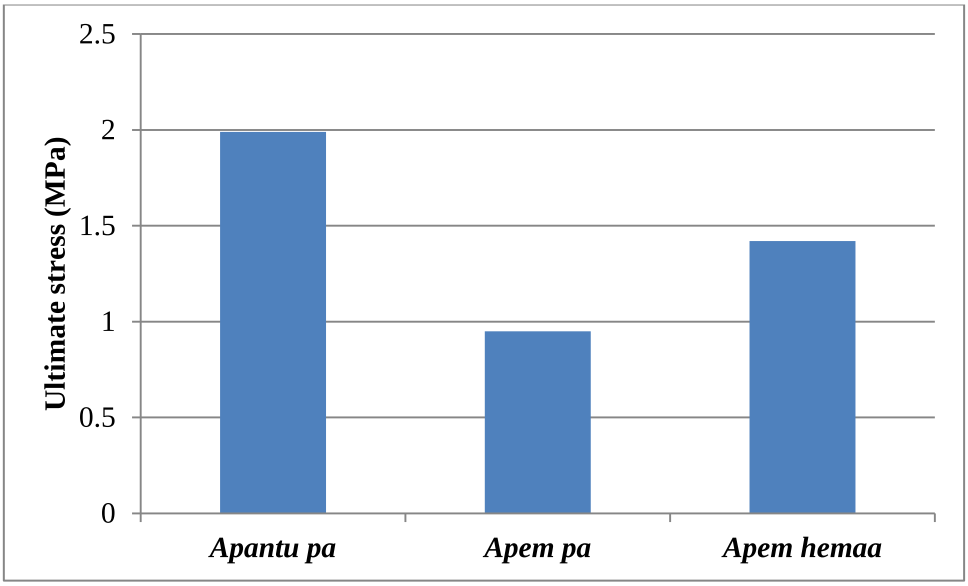



Figure 4-12: Ultimate stress of plantain pseudostem samples, Rainy season

## 4.2 DRY SEASON

### 4.2.1 LOAD-DEFLECTION PLOT

After the three point test, the mid span deflections with the corresponding loads were tabulated and use to obtain a plot of load against deflection. The results obtained from the *Apantu pa* samples are shown in Table B-1, Table B-2 and Table B-3 whiles the plots are showed in Figure 4-13, Figure 4-14 and Figure 4-15. The *Apem pa* samples results are also tabulated in Table B-4, Table B-5 and Table B-6 and the respective plots are in Figure 4-16, Figure 4-17 and Figure 4-18. Table B-7, Table B-8 and Table B-9 shows the results of the *Apemhemaa* and Figure 4-19, Figure 4-20 and Figure 4-21 shows the respective plots.

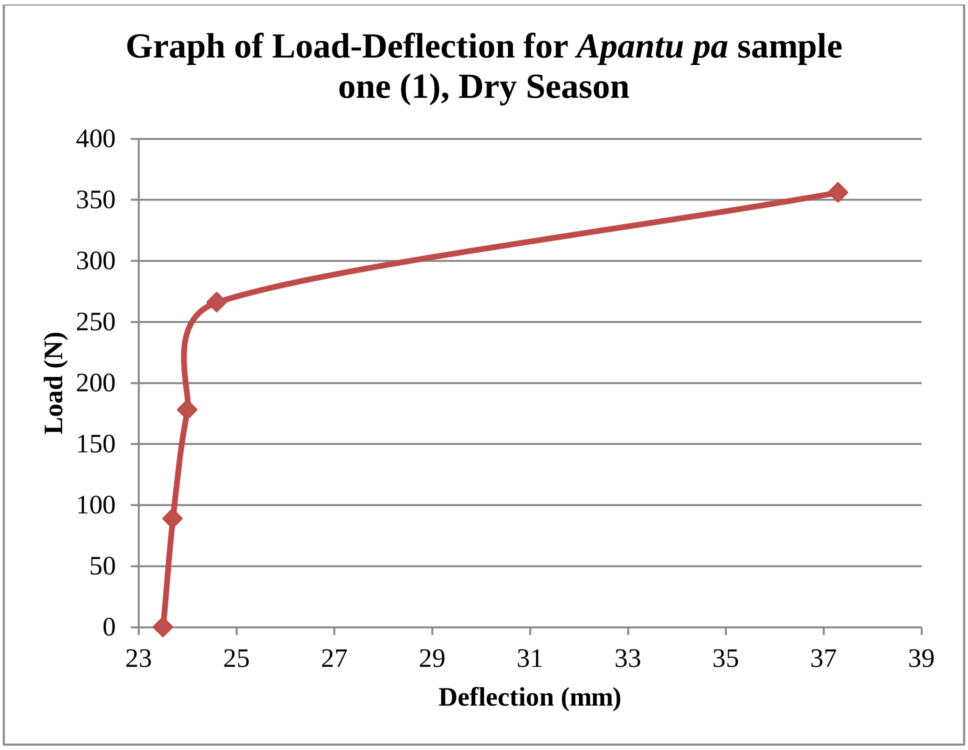



Figure 4-13: Graph of load-deflection for *Apantu pa* sample one (1), Dry season

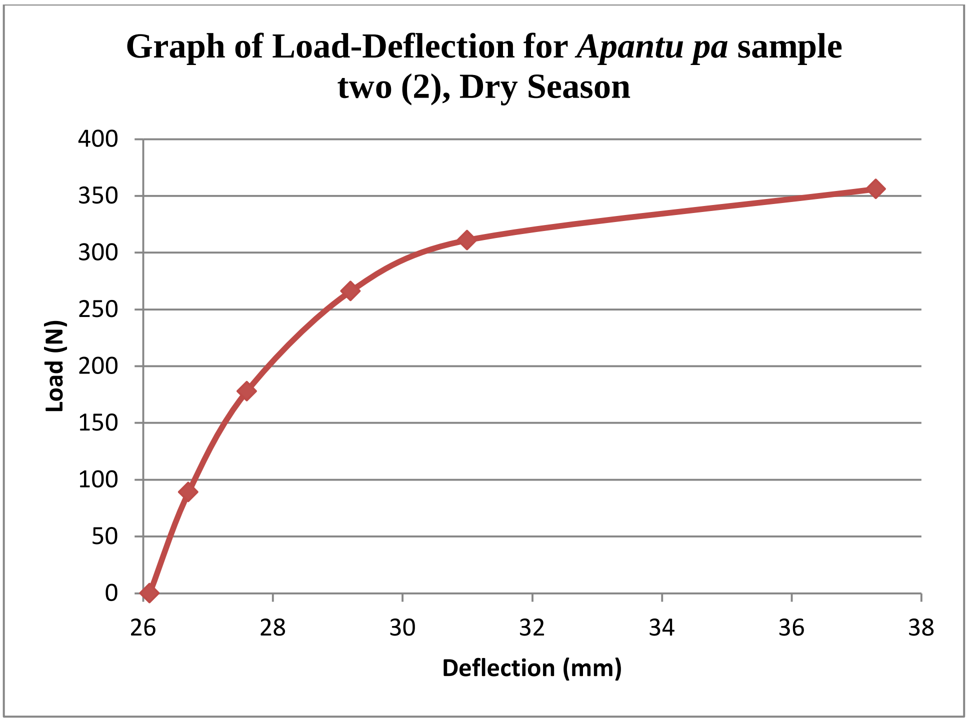



Figure 4-14: Graph of load-deflection for *Apantu pa* sample two (2), Dry season

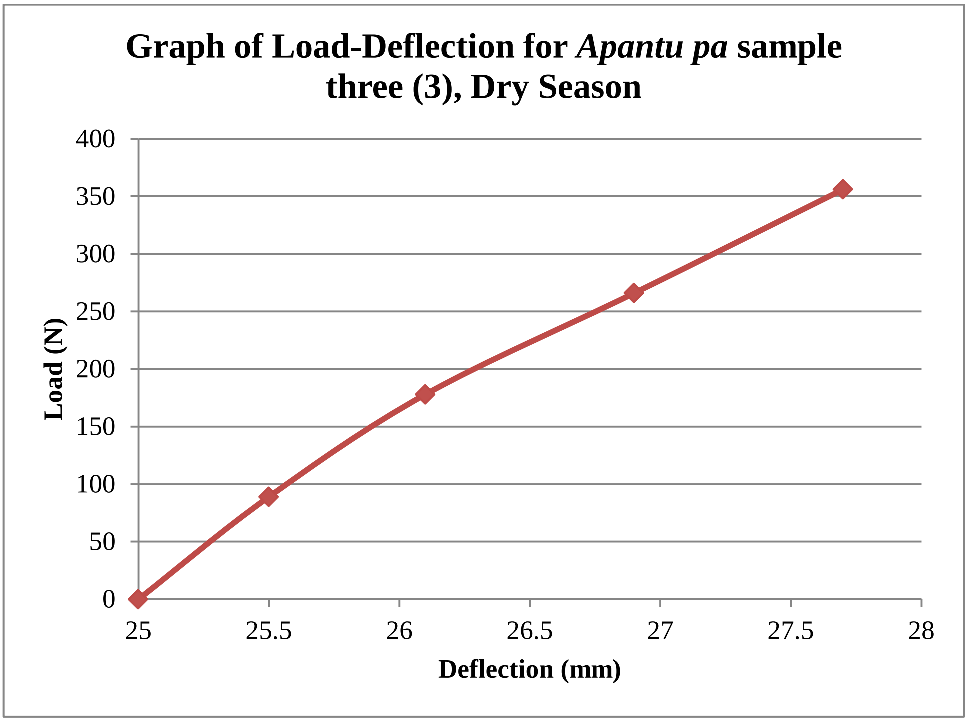



Figure 4-15: Graph of load-deflection for *Apantu pa* sample three (3), Dry season

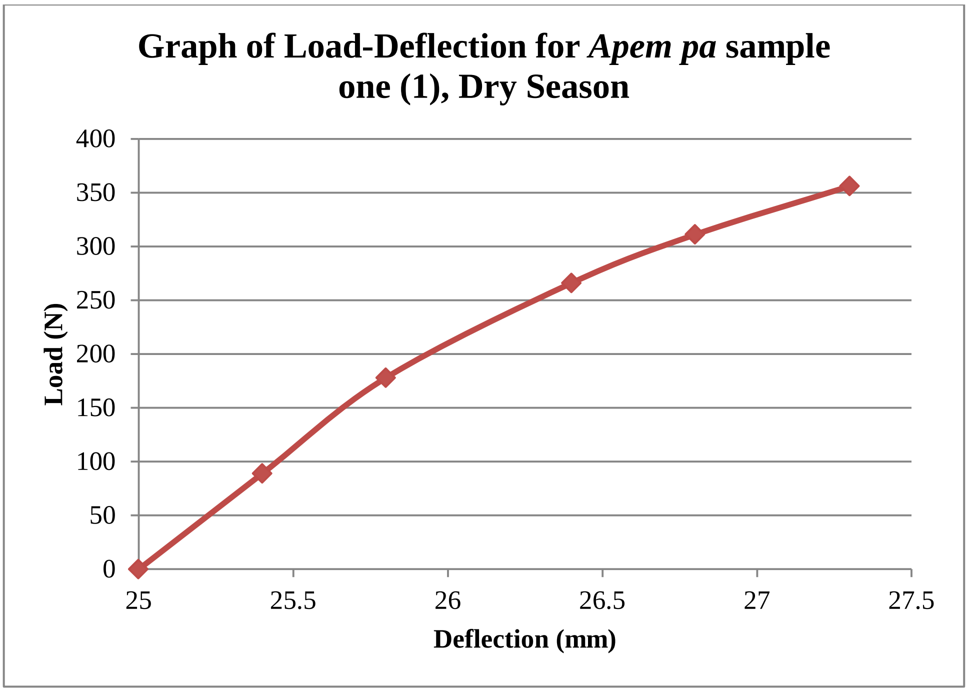



Figure 4-16: Graph of load-deflection for *Apem pa* sample one (1), Dry season

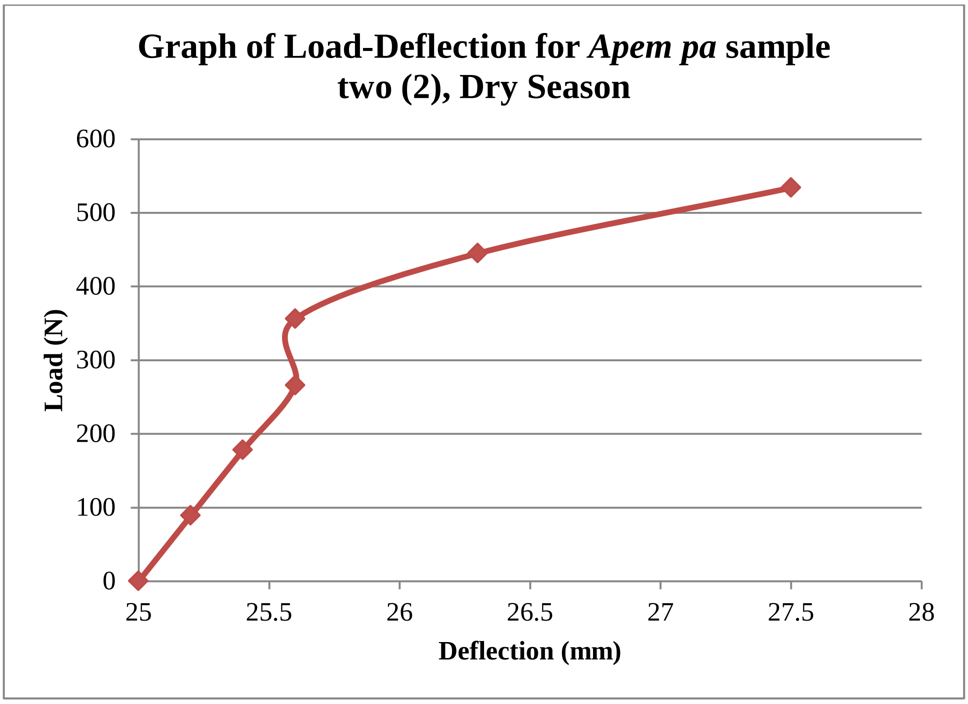



Figure 4-17: Graph of load-deflection for *Apem pa* sample two (2), Dry season

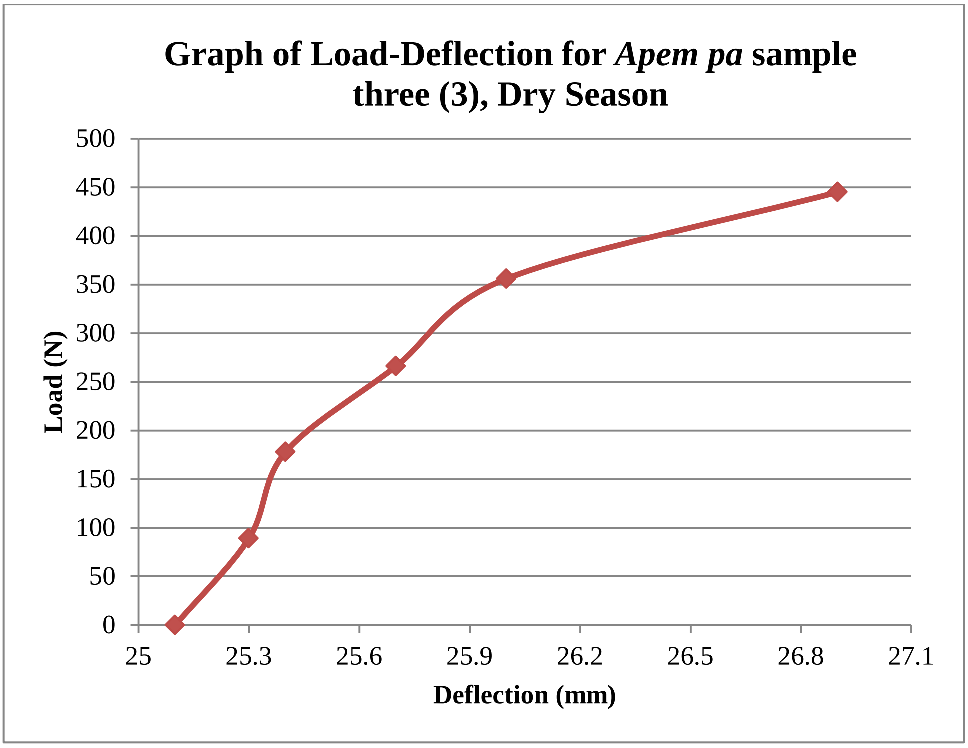



Figure 4-18: Graph of load-deflection for *Apem pa* sample three (3), Dry season

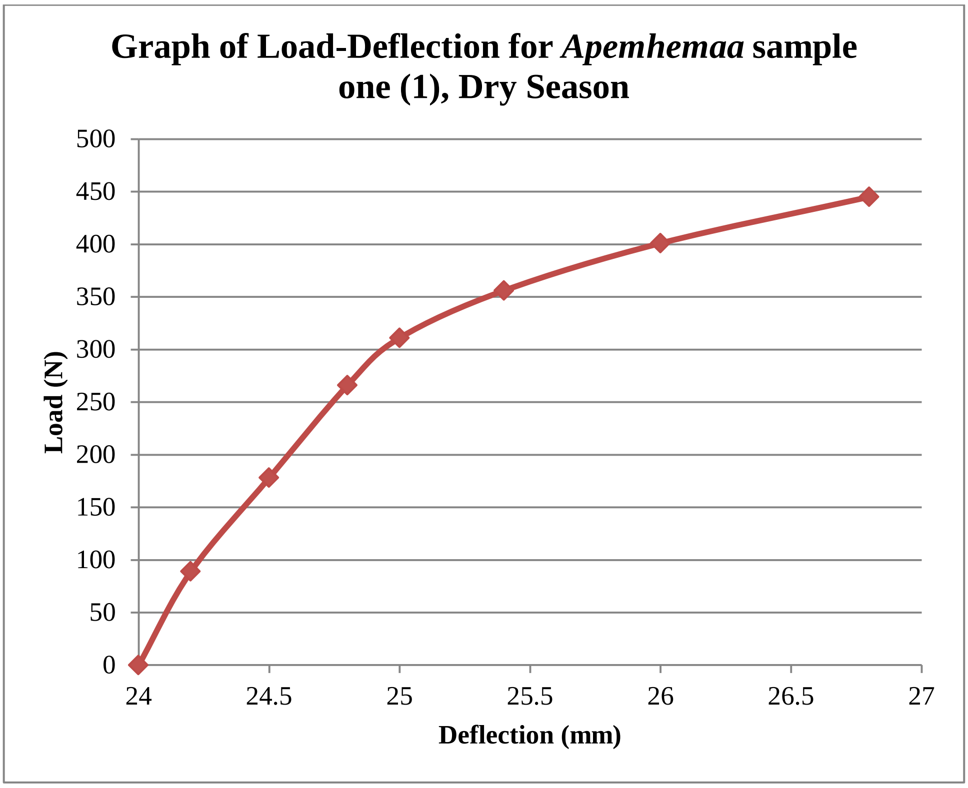



Figure 4-19: Graph of load-deflection for *Apemhemaa* sample one (1), Dry season

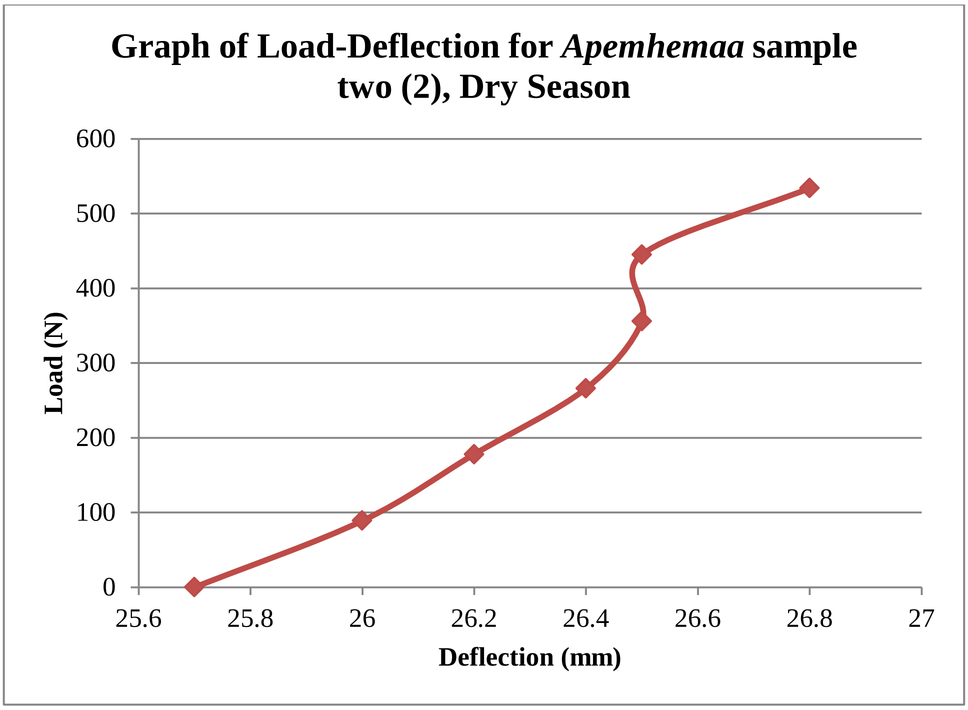



Figure 4-20: Graph of load-deflection for *Apemhemaa* sample two (2), Dry season

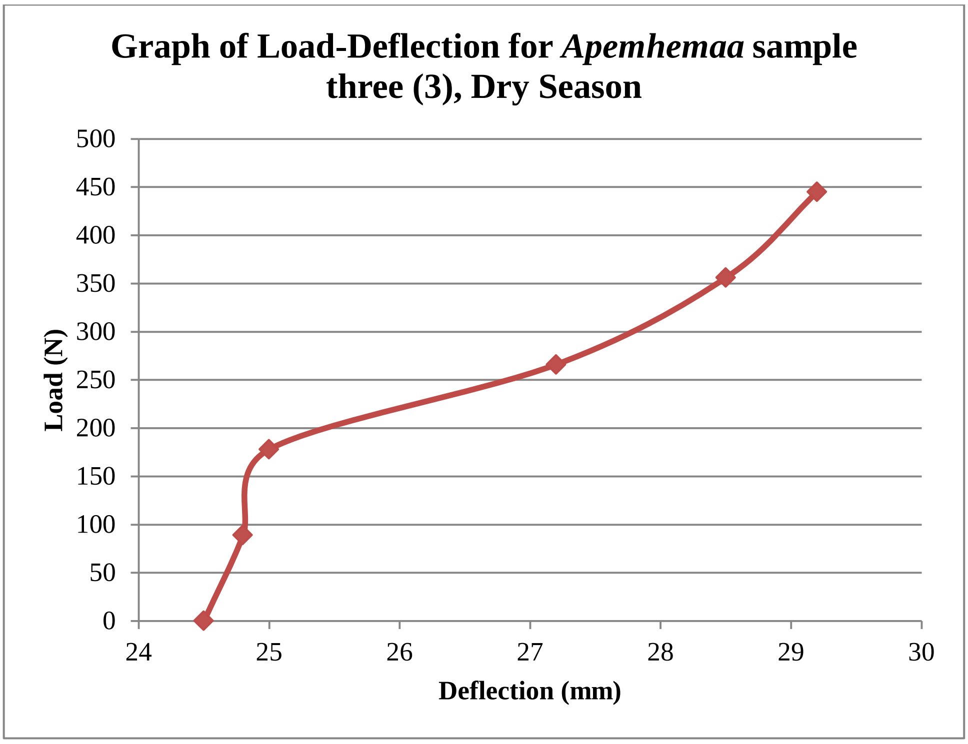



Figure 4-21: Graph of load-deflection for *Apemhemaa* sample three (3), Dry season

In the dry season, the yield and ultimate loads reduced significantly for all the samples as compared to that of the rainy season. All three samples of the *Apantu pa* variety had yield loads of 178 N and an ultimate load of 356 N as shown in figures 4-13, 4-14 and 4-15. *Apem pa* samples obtained yield loads of 178 N, 365 N and 178 N respectively and ultimate loads of 356 N, 534 N and 445 N respectively. The hybrid samples of *Apemhemaa* also had yield loads of 311.5 N, 445 N and 178 N with corresponding ultimate loads of 445 N, 534 N and 445 N respectively.

### 4.2.2 MECHANICAL PROPERTIES

The Young's modulus, yield stress and ultimate stress were also calculated from the derived equations in chapter 3 and follow the calculation procedure for *Apantu pa* sample one in the rainy season in Appendix C. Table 4-3 and Table 4-4 shows the calculated values and average values of the mechanical properties for the *Apantu pa*, *Apem pa* and *Apemhemaa* samples in the dry season respectively.

#### 4.2.2.1 Young's Modulus

In the dry season, the range of the Young's modulus decreased significantly for all samples. *Apantu pa* recorded a 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 *Apemhemaa* recorded a range of 0.75 GPa – 1.34 GPa with a mean of 0.98 GPa. Figure 4-22 shows the mean Young's modulus of *Apantu pa*, *Apem pa* and *Apemhemaa* plantain pseudostem samples in the dry season.

#### 4.2.2.2 Yield Stress

There was a reduction in the yield stress of the plantain pseudostem samples for the dry season as compared to the rainy season. For the dry season, *Apantu pa*, *Apem pa* and

*Apemhemaa* had yield stress 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 *Apemhemaa* respectively. Figure 4-23 shows the mean Yield stress of *Apantu pa*, *Apem pa* and *Apemhemaa* plantain pseudostem samples in the dry season.

#### 4.2.2.3 Ultimate Stress

The dry season obtained ultimate stress ranges of 0.48 MPa – 0.53 MPa for *Apantu pa*, 0.37 MPa – 0.64 MPa for *Apem pa* and 0.45 MPa – 0.49 MPa for *Apemhemaa*. The mean ultimate stresses are 0.51 MPa, 0.52 MPa and 0.47 MPa for *Apantu pa*, *Apem pa* and *Apemhemaa* respectively as shown in Figure 4-24.

Table 4-3: Dry season Mechanical properties of Plantain pseudostem samples

| Plantain variety | Samples | Mid span diameter (m) | Young's modulus, E (GPa) | Yield stress, $\sigma_y$ (MPa) | Ultimate stress, $\sigma_u$ (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 |
| *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 |
| *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 |

Table 4-4: Average Dry season Mechanical properties of Plantain pseudostem samples

| Plantain variety | Mid span diameter (m) | Young's modulus, E (GPa) | Yield stress, $\sigma_y$ ( MPa) | Ultimate stress, $\sigma_u$ (MPa) |
|---|---|---|---|---|
| *Apantu pa* | 0.146 | 1.20 | 0.25 | 0.51 |
| *Apem pa* | 0.161 | 1.19 | 0.26 | 0.52 |
| *Apem hemaa* | 0.163 | 0.98 | 0.35 | 0.47 |

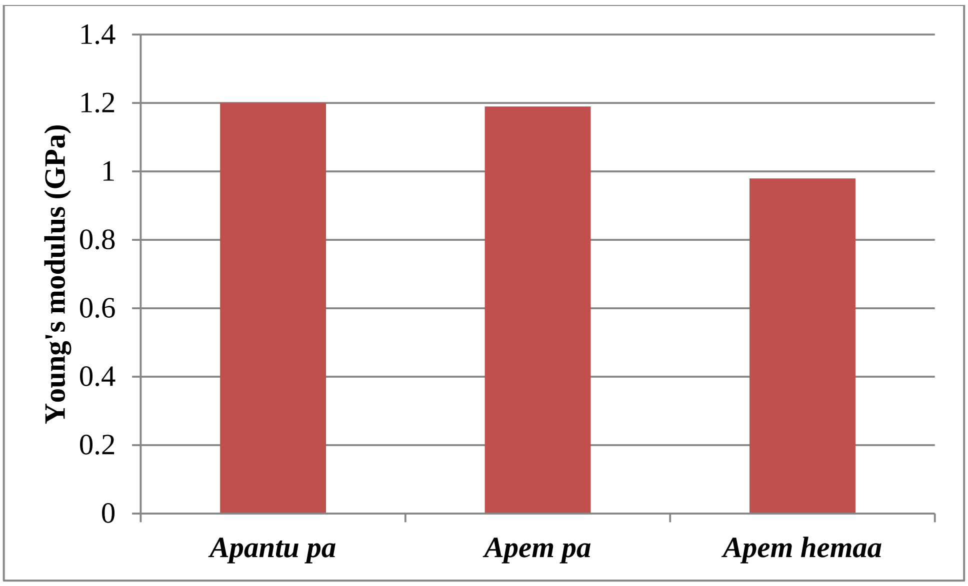



Figure 4-22: Young's modulus of plantain pseudostem samples, Dry season

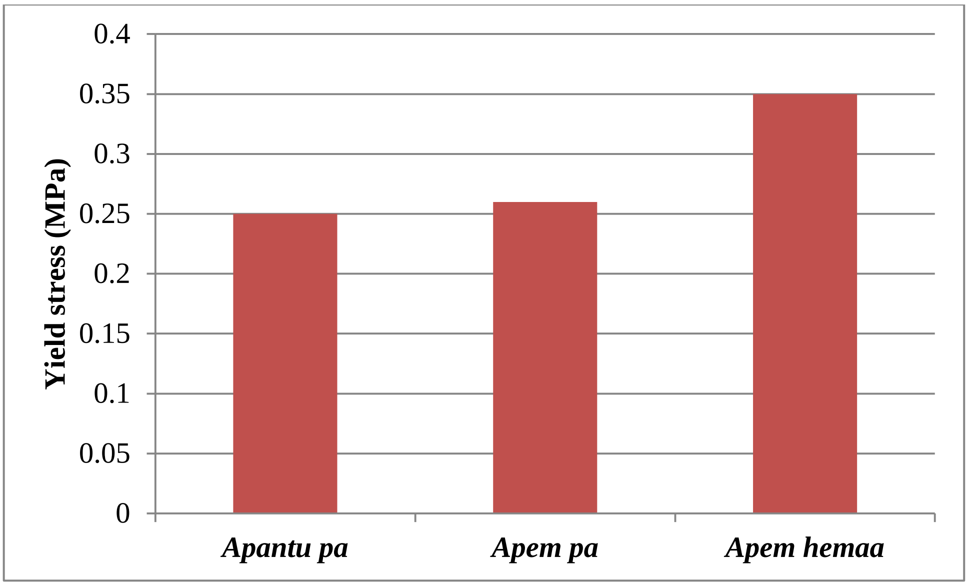



Figure 4-23: Yield stress of plantain pseudostem samples, Dry season

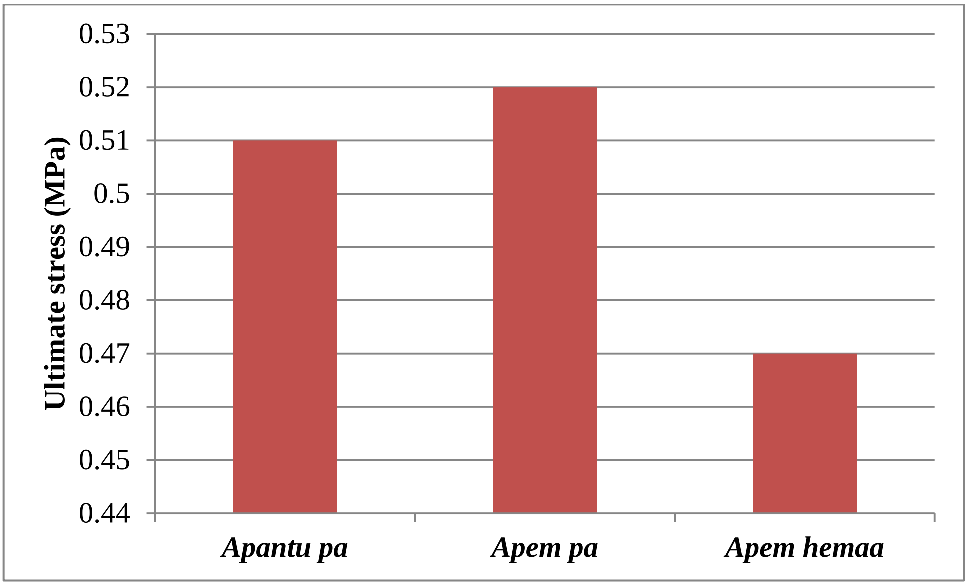



Figure 4-24: Ultimate stress of plantain pseudostem samples, Dry season

4.3 EFFECTS OF CHANGE IN SEASON ON RESULTS

There was a general reduction of the mechanical values obtained from the rainy season to the dry season. The Young's modulus for the *Apantu pa* samples is 20.32 GPa in the rainy season but is reduced to 1.19 GPa in the dry season. The reduction calculated for the *Apantu pa* samples is 94.10 %. Both the Yield and Ultimate stresses of the *Apantu pa* samples also reduced at 76.80 % and 74.30 % respectively.

*Apem pa* samples reduced less as compared to the *Apantu pa* and *Apemhemaa*. 80.70 % reduction for the Young's modulus, 53.3 % reduction for the Yield stress and 45.20 % reduction for the Ultimate stress.

90.48 %, 57.3 % and 66.98 % are the reduction rates for the Young's modulus, Yield stress and Ultimate stress respectively for the *Apemhemaa*. Figure 4-25, Figure 4-26 and Figure 4-27 compares the values mechanical properties of the rainy season to the dry season for the three plantain pseudostem variety.

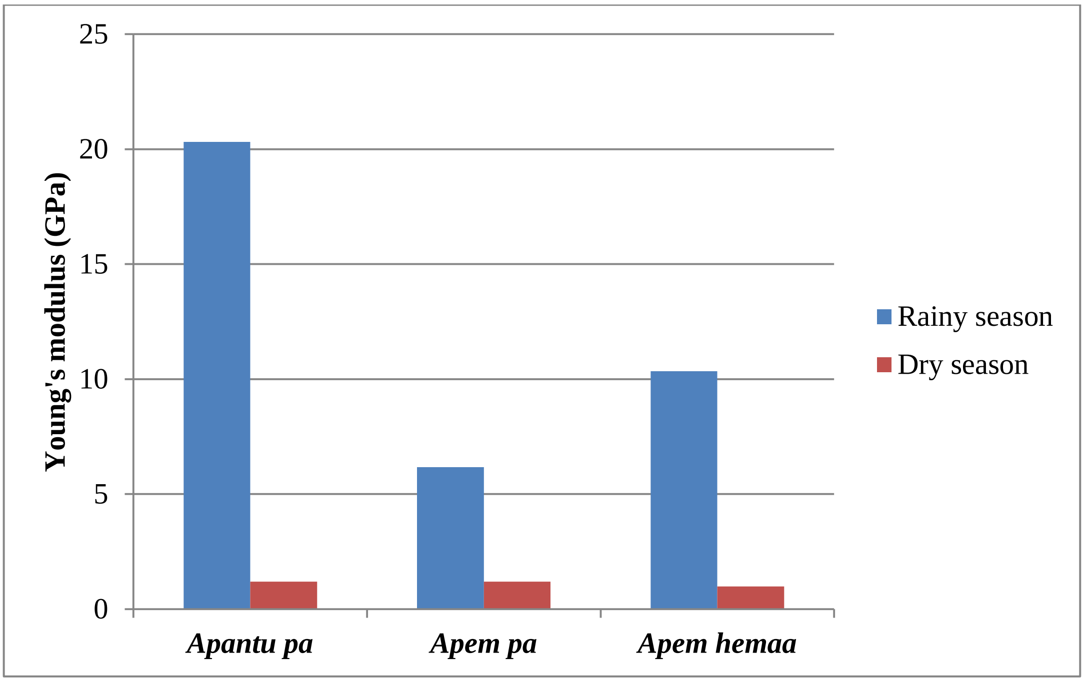



Figure 4-25: Rainy and Dry season Young's modulus of plantain pseudostem samples

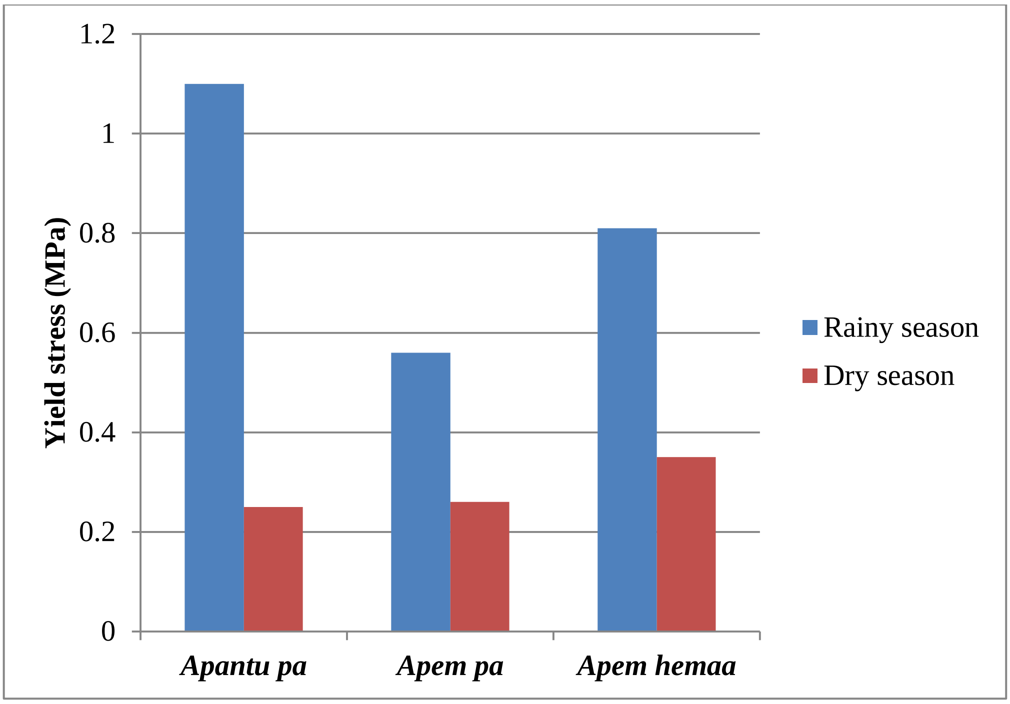



Figure 4-26: Rainy and Dry season Yield stress of plantain pseudostem samples

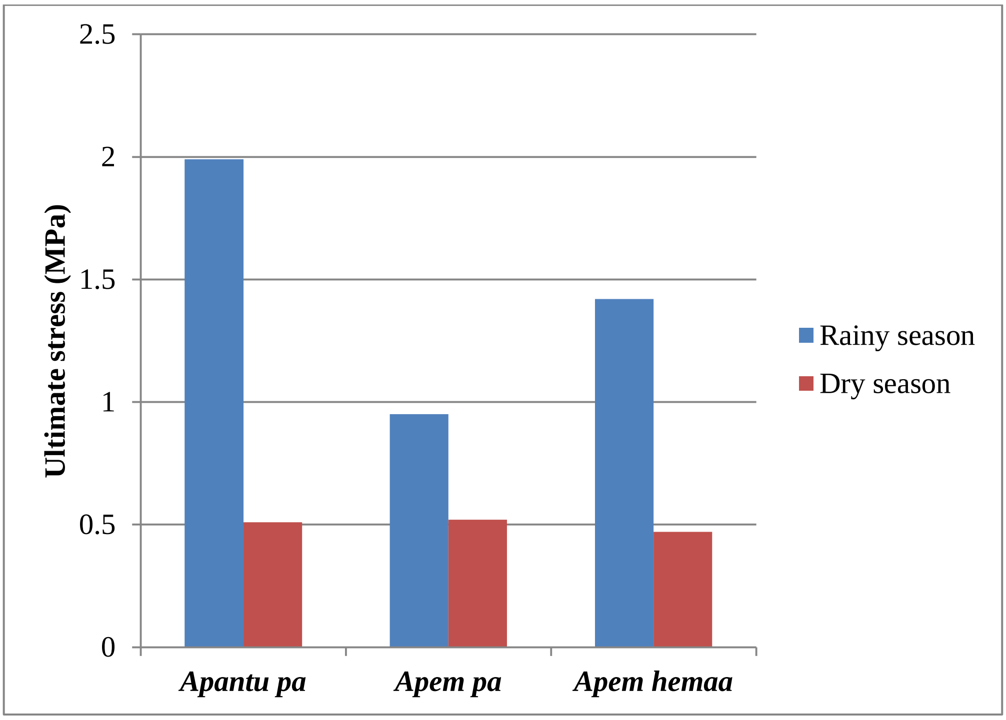



Figure 4-27: Rainy and Dry season Ultimate stress of plantain pseudostem samples

## 4.4 STATISTICAL ANALYSIS

Analysis of variance made between Young's Modulus, Yield stress and Ultimate stress, and the plantain varieties are shown in Appendix D.

From Table D-1, analysis of variance of Young's Modulus, there was no significant difference ($P>0.05$) between the plantain varieties in the same farming season, but there was a significant difference ($P<0.05$) between the rainy and dry season for the same plantain variety as shown in Table D-2.

For the Yield stress, Table D-3 shows no significant difference ($P>0.05$) between the plantain varieties in the same farming season, however there was a significant difference ($P<0.05$) between the rainy and dry season for the same plantain variety as shown in Table D-4.

The analysis of variance performed on the Ultimate stress is shown in Table D-5 and Table D-6. Table D-5 shows no significant difference ($P>0.05$) between the plantain varieties in the same farming season and Table D-6 shows a significant difference ($P<0.05$) between the rainy and dry season for the same plantain variety.

## 4.5 DESIGN WIND PRESSURE AND SPEED

The design wind pressure and basic wind speeds are estimated wind pressure and speeds at which stem lodging of plantain pseudostem will occur. Plantain pseudostems are able to withstand wind loads if the wind load pressure is less than the maximum allowable bending stress of the plantain pseudostem. When the wind load pressure is higher than the maximum allowable bending stress of the plantain pseudostem, stem lodging will occur.

Table 4-5 shows the values of the design wind pressure and basic wind speed for lodging to occur for all samples obtained in the rainy season whiles Table 4-7 shows that of the dry season. The average design wind pressure and design wind speed for the rainy and dry season are shown in Table 4-6 and Table 4-8 respectively.

Table 4-5: Design wind pressure and wind speed for Rainy season

| Rainy season | | | | | | |
|---|---|---|---|---|---|---|
| Plantain cultivars | Samples | Mid span dia (m) | Length , Ls (m) | Ultimate stress, $\sigma_u$ (MPa) | Wind pressure, P (N/m$^2$) | Design Wind speed,v (m/s) |
| *Apantu pa* | 1 | 0.138 | 2.84 | 1.93 | 123.54 | 22.23 |
| | 2 | 0.132 | 2.90 | 2.17 | 116.41 | 21.58 |
| | 3 | 0.131 | 2.67 | 1.88 | 116.29 | 21.57 |
| *Apem pa* | 1 | 0.166 | 1.91 | 0.94 | 231.73 | 30.45 |
| | 2 | 0.160 | 1.85 | 0.97 | 227.54 | 30.17 |
| | 3 | 0.162 | 1.87 | 0.95 | 226.20 | 30.01 |
| *Apem hemaa* | 1 | 0.165 | 2.32 | 1.21 | 199.07 | 28.22 |
| | 2 | 0.145 | 2.11 | 1.57 | 211.26 | 29.07 |
| | 3 | 0.153 | 2.27 | 1.48 | 201.89 | 28.42 |

Table 4-6: Average Rainy season wind pressure and design wind speed of samples

| Plantain cultivars | Design Wind pressure, P (N/m$^2$) | Design Wind speed,v (m/s) |
|---|---|---|
| *Apantu pa* | 118.75 | 21.79 |
| *Apem pa* | 228.49 | 30.23 |
| *Apem hemaa* | 204.07 | 28.57 |

Table 4-7: Design wind pressure and wind speed for Dry season

| Dry season | | | | | | |
|---|---|---|---|---|---|---|
| Plantain cultivars | Samples | Mid span diameter (m) | Length, Ls (m) | Ultimate stress, $\sigma_u$ (MPa) | Wind pressure, $q_z$ ($N/m^2$) | Design Wind speed,v (m/s) |
| *Apantu pa* | 1 | 0.145 | 2.20 | 0.48 | 58.81 | 15.34 |
| | 2 | 0.153 | 2.67 | 0.53 | 52.44 | 14.48 |
| | 3 | 0.139 | 2.17 | 0.53 | 59.37 | 15.41 |
| *Apem pa* | 1 | 0.140 | 2.53 | 0.64 | 53.67 | 14.65 |
| | 2 | 0.190 | 2.46 | 0.37 | 82.10 | 18.12 |
| | 3 | 0.152 | 2.33 | 0.56 | 70.91 | 16.84 |
| *Apem hemaa* | 1 | 0.155 | 2.20 | 0.49 | 73.52 | 17.15 |
| | 2 | 0.171 | 2.32 | 0.47 | 85.33 | 18.47 |
| | 3 | 0.162 | 2.27 | 0.45 | 72.11 | 16.98 |

Table 4-8: Average Dry season wind pressure and design wind speed of samples

| Plantain cultivars | Design Wind pressure, P ($N/m^2$) | Design Wind speed,v (m/s) |
|---|---|---|
| *Apantu pa* | 56.87 | 15.08 |
| *Apem pa* | 68.89 | 16.54 |
| *Apem hemaa* | 76.98 | 17.59 |

The design wind pressure and speed are the estimated wind pressure and speed that would cause pseudostem lodging. The plantain pseudostems will fail or break when their ultimate stress is exceeded; therefore, the design wind pressure and speed was obtained using the ultimate stress values of the selected plantain varieties.

In the rainy season, the wind speed expected to cause failure of the plantain pseudostem ranges between 21.57 m/s and 30.44 m/s. *Apantu pa* samples, as compared to the two varieties, would need a lesser average wind speed of 21.79 m/s whiles *Apem pa* samples would require a higher average wind speed of 30.23 m/s.

However, in the dry season, wind speeds of range 14.48 m/s – 18.47 m/s is expected to cause plantain pseudostem lodging. *Apemhemma* is expected to be more resilient to wind damage than the other two varieties with an average wind speed of 17.59 m/s.

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

The effects of the change in season on the mechanical properties covered in this work were very significant. For all three varieties covered, *Apantu pa Apem pa* and *Apemhemaa*, the pseudostem's Young's modulus, Yield stress and Ultimate stress were higher in the rainy season than they were in the dry season.

From the test results, *Apantu pa* pseudostem samples showed the highest value for all the three mechanical properties studied during the rainy season whiles in the dry season, it recorded the lowest yield stress.

Tests results obtained in the dry season showed that the *Apem pa* pseudostem samples have the highest ultimate stress values. *Apem pa* pseudostem samples also recorded the least values for the Young's modulus, Yield stress and Ultimate stress in the rainy season.

Of all the test results obtained in both the rainy season and dry season, *Apemhemaa* pseudostem samples showed average values in the mechanical properties studied as compared to the other two varieties.

The variety of plantain pseudostem that had the lowest mechanical properties values of the three varieties in the rainy season is the *Apem pa* whiles the variety with the highest mechanical properties values is the *Apantu pa*.

The analysis of variance performed on the three mechanical properties between the plantain varieties and the farming season showed that for all three mechanical property tested for, there was no significant difference between the plantain varieties in the same season. However, for Young's Modulus, Yield stress and Ultimate stress, there was significant difference between the rainy and dry season for the same plantain variety.

## 5.2 RECOMMENDATIONS

After the study, the following recommendations were made;

1. During the dry season, the moisture contents in the plantain pseudostem decreases significantly. Farmers should irrigates the plantain plants in the dry season to increase the moisture contents which would increase the mechanical strength of the plantain pseudostem.
2. Further studies should be conducted on this study. The following factors should be considered and measured;
   a. Density of plantain pseudostem samples
   b. Moisture contents of plantain pseudostem samples
   c. Internal structure of plantain pseudostem samples
   d. Center of gravity of plantain pseudostem samples
   e. Uniform dimensions of plantain pseudostem samples

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APPENDIX A: Load-Deflection Tables for the Rainy Season

Table A-1: Load-Deflection of *Apantu pa* pseudostem sample one (1), Rainy season

| *Apantu pa* sample one (1) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 28.0 |
| 178 | 28.2 |
| 266 | 28.2 |
| 356 | 28.4 |
| 445 | 28.5 |
| 534 | 28.7 |
| 623 | 28.9 |
| 712 | 29.2 |
| 801 | 29.4 |
| 890 | 29.6 |

Table A-2: Load-Deflection of *Apantu pa* pseudostem sample two (2), Rainy season

| *Apantu pa* sample two (2) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 28.5 |
| 178 | 28.6 |
| 266 | 28.7 |
| 356 | 28.8 |
| 445 | 28.8 |
| 534 | 28.8 |
| 623 | 28.85 |
| 712 | 28.88 |
| 801 | 28.9 |
| 890 | 29.1 |

Table A-3: Load-Deflection of *Apantu pa* pseudostem sample three (3), Rainy season

| *Apantu pa* sample three (3) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 28.3 |
| 178 | 28.4 |
| 266 | 28.5 |
| 356 | 28.7 |
| 445 | 28.9 |
| 534 | 29.2 |
| 623 | 29.5 |
| 712 | 30.0 |
| 801 | 30.3 |

Table A-4: Load-Deflection of *Apem pa* pseudostem sample one (1), Rainy season

| *Apem pa* sample one (1) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 29.0 |
| 801 | 29.2 |
| 890 | 29.4 |
| 979 | 29.7 |
| 1,068 | 30.0 |
| 1,112 | 30.1 |
| 1,157 | 30.6 |
| 1,201 | 31.7 |
| 1,246 | 37.5 |
| 1,290 | 41.2 |

Table A-5: Load-Deflection of *Apem pa* pseudostem sample two (2), Rainy season

| *Apem pa* sample (2) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 29.0 |
| 712 | 29.1 |
| 801 | 29.3 |
| 890 | 29.5 |
| 979 | 29.9 |
| 1,068 | 30.1 |
| 1,112 | 30.3 |
| 1,157 | 30.7 |
| 1,201 | 31.8 |
| 1,246 | 38.2 |

Table A-6: Load-Deflection of *Apem pa* pseudostem sample three (3), Rainy season

| *Apem pa* sample three (3) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 29.0 |
| 712 | 29.2 |
| 801 | 29.3 |
| 890 | 29.6 |
| 979 | 29.9 |
| 1,068 | 30.0 |
| 1,112 | 30.3 |
| 1,157 | 30.6 |
| 1,201 | 31.4 |
| 1,246 | 32.8 |

Table A-7: Load-Deflection of *Apemhemaa* pseudostem sample (1), Rainy season

| *Apemhemaa* sample one (1) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 28.7 |
| 712 | 28.9 |
| 801 | 29.2 |
| 890 | 29.5 |
| 979 | 29.9 |
| 1,068 | 30.1 |
| 1,112 | 30.4 |
| 1,157 | 30.7 |
| 1,201 | 31.5 |
| 1,246 | 35.9 |

Table A-8: Load-Deflection of *Apemhemaa* pseudostem sample two (2), Rainy season

| *Apemhemaa* sample two (2) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 28.5 |
| 712 | 28.8 |
| 801 | 29.1 |
| 890 | 29.4 |
| 979 | 29.6 |
| 1,068 | 29.9 |
| 1,112 | 30.3 |
| 1,157 | 30.6 |
| 1,201 | 32.0 |
| 1,246 | 37.1 |

Table A-9: Load-Deflection of *Apemhemaa* pseudostem sample three (3), Rainy season

| *Apemhemaa* sample three (3) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 28.5 |
| 712 | 28.7 |
| 801 | 28.9 |
| 890 | 29.2 |
| 979 | 29.7 |
| 1,068 | 30.0 |
| 1,112 | 30.2 |
| 1,157 | 30.7 |
| 1,201 | 33.0 |
| 1,246 | 36.3 |

APPENDIX B: Load-Deflection Tables for the Dry Season

Table B-1: Load-Deflection of *Apantu pa* pseudostem sample one (1), Dry season

| *Apantu pa* sample one (1) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 23.5 |
| 89 | 23.7 |
| 178 | 24.0 |
| 266 | 24.6 |
| 356 | 37.3 |

Table B-2: Load-Deflection of *Apantu pa* pseudostem sample two (2), Dry season

| *Apantu pa* sample two (2) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 26.1 |
| 89 | 26.7 |
| 178 | 27.6 |
| 266 | 29.2 |
| 311 | 31.0 |
| 356 | 37.3 |

Table B-3: Load-Deflection of *Apantu pa* pseudostem sample three (3), Dry season

| Apantu pa sample three (3) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 25.0 |
| 89 | 25.5 |
| 178 | 26.1 |
| 266 | 26.9 |
| 356 | 27.7 |

Table B-4: Load-Deflection of *Apem pa* pseudostem sample one (1), Dry season

| *Apem pa* sample one (1) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 25.0 |
| 89 | 25.4 |
| 178 | 25.8 |
| 266 | 26.4 |
| 311 | 26.8 |
| 356 | 27.3 |

Table B-5: Load-Deflection of *Apem pa* pseudostem sample two (2), Dry season

| *Apem pa* sample two (2) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 25.0 |
| 89 | 25.2 |
| 178 | 25.4 |
| 266 | 25.6 |
| 356 | 25.6 |
| 445 | 26.3 |
| 534 | 27.5 |

Table B-6: Load-Deflection of *Apem pa* pseudostem sample three (3), Dry season

| *Apem pa* sample three (3) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 25.1 |
| 89 | 25.3 |
| 178 | 25.4 |
| 266 | 25.7 |
| 356 | 26.0 |
| 445 | 26.9 |

Table B-7: Load-Deflection of *Apemhemaa* pseudostem sample one (1), Dry season

| *Apemhemaa* sample one (1) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 24.0 |
| 89 | 24.2 |
| 178 | 24.5 |
| 266 | 24.8 |
| 311 | 25.0 |
| 356 | 25.4 |
| 401 | 26.0 |
| 445 | 26.8 |

Table B-8: Load-Deflection of *Apemhemaa* pseudostem sample two (2), Dry season

| *Apemhemaa* sample two (2) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 25.7 |
| 89 | 26.0 |
| 178 | 26.2 |
| 266 | 26.4 |
| 356 | 26.5 |
| 445 | 26.5 |
| 534 | 26.8 |

Table B-9: Load-Deflection of *Apemhemaa* pseudostem sample three (3), Dry season

| *Apemhemaa* sample three (3) | |
|---|---|
| Force (N) | Deflection (mm) |
| 0 | 24.5 |
| 89 | 24.8 |
| 178 | 25.0 |
| 266 | 27.2 |
| 356 | 28.5 |
| 445 | 29.2 |

APPENDIX C: Calculation Procedure

Young's Modulus, Yield Stress and Ultimate Stress

The Young's Modulus, yield stress and ultimate stress of *Apantu pa* sample one, Rainy season, is calculated below.

Data:

Length of specimen, Ls = 2.84 m

Length of span, L = 2.24 m

Diameter at tip, d1 = 0.057 m

Diameter at base, d2 = 0.219 m

Yield force, $f_y$ = 445 N

Ultimate force, $f_u$ = 890 N

Calculation:

Using

Second moment of area, I;

Design Wind Pressure and Design Wind Speed

The Design Wind Pressure and Design Wind Speed expected to topple the *Apantu pa* sample one of the Rainy season sample;

APPENDIX D: Statistical Analysis

Analysis of Variance

**Table D-1:** Analysis of variance between the Plantain varieties for Young's Modulus

Anova: Single Factor

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Row 1 | 2 | 221.2867 | 110.6433 | 19334.96 |
| Row 2 | 2 | 76.90333 | 38.45167 | 1246.17 |
| Row 3 | 2 | 115.92 | 57.96 | 4584.35 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 5578.497 | 2 | 2789.248 | 0.332509 | 0.740573 | 9.552094 |
| Within Groups | 25165.48 | 3 | 8388.492 | | | |
| | | | | | | |
| Total | 30743.97 | 5 | | | | |

**Table D-2:** Analysis of variance between the Rainy and Dry seasons for the Young's Modulus

Anova: Single Factor

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Column 1 | 3 | 378.2167 | 126.0722 | 5603.551 |
| Column 2 | 3 | 35.89333 | 11.96444 | 2.996159 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 19530.88 | 1 | 19530.88 | 6.967167 | 0.057608 | 7.708647 |
| Within Groups | 11213.1 | 4 | 2803.274 | | | |
| | | | | | | |
| Total | 30743.97 | 5 | | | | |

**Table D-3:** Analysis of variance between the Plantain varieties for Yield Stress

Anova: Single Factor

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Row 1 | 2 | 43.93 | 21.965 | 370.3735 |
| Row 2 | 2 | 26.58667 | 13.29333 | 45.95209 |
| Row 3 | 2 | 35.88667 | 17.94333 | 132.9537 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 75.3294 | 2 | 37.6647 | 0.205713 | 0.824665 | 9.552094 |
| Within Groups | 549.2793 | 3 | 183.0931 | | | |
| | | | | | | |
| Total | 624.6087 | 5 | | | | |

**Table D-4:** Analysis of variance between the Rainy and Dry seasons for the Yield Stress

Anova: Single Factor

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Column 1 | 3 | 79.75667 | 26.58556 | 76.62514 |
| Column 2 | 3 | 26.64667 | 8.882222 | 0.623181 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 470.112 | 1 | 470.112 | 12.17145 | 0.025151 | 7.708647 |
| Within Groups | 154.4966 | 4 | 38.62416 | | | |
| | | | | | | |
| Total | 624.6087 | 5 | | | | |

**Table D-5:** Analysis of variance between the Plantain varieties for Ultimate Stress

Anova: Single Factor

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Row 1 | 2 | 80.75 | 40.375 | 1138.122 |
| Row 2 | 2 | 47.67333 | 23.83667 | 96.3272 |
| Row 3 | 2 | 60.74333 | 30.37167 | 467.874 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 277.5262 | 2 | 138.7631 | 0.244542 | 0.797287 | 9.552094 |
| Within Groups | 1702.323 | 3 | 567.4411 | | | |
| | | | | | | |
| Total | 1979.85 | 5 | | | | |

**Table D-6:** Analysis of variance between the Rainy and Dry seasons for the Ultimate Stress

Anova: Single Factor

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| Column 1 | 3 | 140.6733 | 46.89111 | 280.9058 |
| Column 2 | 3 | 48.49333 | 16.16444 | 0.922915 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 1416.192 | 1 | 1416.192 | 10.05002 | 0.033852 | 7.708647 |
| Within Groups | 563.6575 | 4 | 140.9144 | | | |
| | | | | | | |
| Total | 1979.85 | 5 | | | | |