SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF COWPEA AS RELATED TO MECHANICAL THRESHING OF THE ENTIRE PLANT SHOOT

BY

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Dedicated to

my wife, Afulenu

D E C L A R A T I O N

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

E. I. U. NWUBA

November, 1988

CERTIFICATION

This thesis entitled "Selected Physical and Mechanical Properties of Cowpea as Related to Mechanical Threshing of the Entire Plant Shoot" by Ephraim Ifeanyi Uba Nwuba meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

To eliminate pod-picking, it has become necessary to replace the conventional cowpea (Vigna unguiculata (L.) Unlp) pod thresher with whole shoot thresher.

This research work deals with selected physical and mechanical properties of cowpea stalk, pod and grain, as related to the mechanical threshing of the entire cowpea shoot. In the study it was found that the cowpea varieties differed significantly in their grain size which ranged from G.35 to 9.18mm in length; and the suitability of the varieties to whole shoot threshing decreased with the grain size. The mechanical properties of the cowpea stalk were found to increase with decrease in moisture content and increase in the rate of loading. The mean stalk elastic modulus and crushing/bending strength at 25mm/min rate of loading were 30.4 MPa and 5.10MPa respectively, in radial compression; and 4l70MPa and 38.6MPa respectively, in simple bending at about 8% moisture content, wet basis (MC,wb), the moisture level at which the stalk became more brittle. The minimum force of 7.25 to 29N required to crack the dry pod was very low when compared to grain and stalk. While the elastic modulus,of grain in uniaxial compression (mean 454MPa at 7.5% MC, wb) was independent of variety and grain size.

The IAR cowpea pod thresher was tested for whole shoot threshing and was redesigned. It was confirmed that the stalk moisture content of about 8% wb was very suitable for

Whole shoot threshing, although threshing at slightly higher moistures would be possible. The crushing and breaking energy requirements of single stalk of cowpea at 8% MC, wb, were 0-00393 and 0.109 J respectively, while the threshing energy requirement of the whole shoot thresher was estimated as 139 J at 450m/min cylinder speed.

Finally, an air flow rate of $16m^2$/min was found to be adequate for pneumatic cleaning of threshed whole shoot cowpea,

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LIST OF SYMBOLS AND ABBREVIATIONS

a	Semi-major axis of an elliptical area or half length of rectangular contact area, mm.
b	Semi-minor axis of an elliptical area, or half width of contact area, mm
C_e	Cleaning efficiency, %
Conf. Int.	Confidence internal (for mean)
d	Diameter, mm
d_1, d_2	Diameter of blower impeller at blade width w_1 and w_2, mm
d_o	Diameter of hollow pith in stalk, mm
D	Total deformation, mm
D_e	Elastic deformation, mm
D_p	Plastic deformation, mm
DIM	Dimensi n
E	Elastic modulus, MPa
E_1, E_2	E for first and second bodies in contact, MPa
E_t	Threshing Energy, J
F	Applied normal load or force, N
F_b, F_c,	Maximum bending and crushing force, N
f - d curve	Force-Deformation curve
G_d	Grain damage, %
I	Moment of inertia, kg-m^2
K.E.	Kinetic energy, J
l	Length, or arc length, mm
M	Bending momemt or maximum bending moment, N - mm
m	Mass, kg

M_{gr}	Mog in grain, %
MC, wb	Moisture content, wet basis, %
Mog	Material-other-than-grain
MPa	Megapascal (= $10^6 N/m^2$ = $1N/mm^2$)
N	Speed in revolutions per minute
ns	Not significant at 0.05 level
pop.	Population
P_l	Processing loss, %
Q_A	Actual required air flow rate through the blower, m^3/min.
Q_T	Theoretical air flow rate, m^3/min.
q	Normal pressure distribution, MPa
q_o	Maximum contact pressure, MPa
R	Principal radius of curvature, radius or distance of body from axis of rotation, mm
R_1, R_2	R for first and second bodies in contact or major radii of curvature of elliptical body, mm.
R_1', R_2'	Minor radii of curvature of elliptical body, mm
RL	Rate of loading, mm/min.
r	Distance of particle from axis of rotation, mm
rpm	Revolutions per minute
S.D.	Standard deviation
S.E.	Standard error
T_e	Threshing efficiency, %
t	Thickness of grain, mm
v	Velocity of air, m/min
v_1, v_2	Tangential components of absolute velocities of impeller, m/min.
w	Weight of grain, kg

W_c, W_b	Work done in crushing and breaking cowpea stalk, J
w	Width, mm
w_1, w_2	Width of impeller blade at diameter d_1, d_2, mm
x	Distance from centre of contact along x - axis when two bodies are pressed together, mm
x,y,z	Cartesian coordinates
y	Distance of the extreme fibre from the neutral axis in bending, mm
Z	Term defined as R/b
β	Per cent degree of elasticity
ε_c	Crushing strain
μ	Poisson's ratio
μ_1, μ_2	Poisson's ratio for first and second bodies in contact
ν	Maximum deflection in bending, mm
ν_e	Elastic component of deflection in bending, mm
σ_b	Bending strength of stalk, MPa
σ_c	Crushing strength of stalk, MPa
ϕ	Diameter (in dimensioning),mm
ω	Angular velocity, rad/s

Chapter 1

INTRODUCTION

1.1 Importance of the Problem

Cowpea (Vigna unguiculata (L.) Walp) is grown in large quantities in the tropical and subtropical regions of the world as a cheap and rich source of protein which is a limiting factor in the diet of many people in the developing world. Cowpea is very nutritive with about 24% protein and 60% carbohydrate content. It is used in many forms in diet; and is one of the most common stable food in Nigeria. Cowpea is mostly grown in West Africa and other parts of the world for its protein-rich edible seeds.

At present, a joint research is being carried out by the University of Nigeria, Nsukka and the University of Georgia, U.S.A., on the use of cowpea in novel foods. Considerable success has been reported in the use of cowpea in beef patties and several bakery products, and in novel foods by extrusion cooking (McWatters, 1985; Phillips et al, 1985).

While the cowpea grains are for human consumption, the haulms are used for feeding animals and for green manuring. The ash from burnt haulms is used as potash for cooking, and the young succulent leaves are eaten as vegetable.

Some varieties of cowpea like FARV 13 and Dinner are harvested when the pods are green and are used as green vegetable. Moreover, as a leguminous plant, cowpea is capable of enriching the soil with nitrogen through the symbiotic association with the nitrogen-fixing bacteria in its root nodules.

Cowpea has an excellent nutritive value as may be seen from Tables 1.1 to 1.3. The average protein content of the seeds is between 22 and 26%. It is a good source of phosphorus and thiamine and when green it is rich in ascorbic acid (Oyenuga, 1955; Bhatt, 1970; Steele, 1972; and Bressani, 1985).

Cowpea leaves contain 33 - 34% protein by dry weight. It has a good supply of iron, calcium, phosphorus, zinc and ascorbic acid (Imungi et al, 1973). Some varieties of cowpea are however deficient in two essential amino acids: methionine and tryptophane (F. A. O., 1958; Bhatt, 1970; and Steele, 1972). According to Bhatt (1970), 100 to 125g of cowpea seeds will adequately supply the recommended daily intake of essential amino acid for nitrogen balance in humans when cowpea is supplemented for methionine and tryptophane.

For these reasons, the production of cowpea in Nigeria is undergoing a sporadic increase in recent times. The production is however being hampered by the traditional method of harvesting and existing storage facilities.

Table 1.1: Chemical composition of cowpeas and the major food crops of the Savanna zones of Nigeria.

	Cowpea Seeds	Sorghum Flour	Fresh Yams	Fresh Cassava	Groundnuts
Calories/100g.	340	353	104	153	579
% Protein	22.0	10.0	2.0	0.7	27.0
% Fat	1.5	2.5	0.2	0.2	45.0
% Carbohydrate	60	73	24	37	17
Protein g/1000Kcals.	65.0	28.0	19.0	4.5	47.0
Vitamin 'A' (I.U./100g)	20	Trace	20	Trace	Trace
Thiamine (mg/100g)	0.90	0.40	0.10	0.07	0.90
Riboflavine (mg/100g)	0.15	0.10	0.03	0.03	0.15
Nicotinic acid (mg/100g)	2.0	3.0	0.4	0.7	17.0
Ascorbic acid (mg/100g)	Trace	0	10	30	Trace

Source: Steele, 1972.

Table 1.2: Relative composition (%) cowpeas and different types of meat

	Cowpea	Beef	Pork	Chicken
Ash	3.78	5.4	2.8	4.2
Protein	22.75	19.3	14.6	19.1
Fat	1.3	14.4	24.6	9.7
Water	8.70	60.1	58.1	66.5

Source: Ojomo, 1967.

Table 1.3: The nutritive value of cowpea protein

Essential amino acid	A. Reference Patterns				B. % of concentration in whole egg protein	
	Cowpeas					
	Cultivated	Wild	Whole Egg	FAO	Cultivated	Wild
Isoleucine	1.1	1.4	1.3	1.5	58	65
Leucine	2.0	2.4	1.8	1.7	82	86
Lysine	1.8	2.2	1.4	1.5	98	102
Phenylalanine	1.6	1.6	1.1	1.0	90	87
Tryosine	0.9	1.0	0.7	1.0	65	64
Cystine	0.2	0.1	0.5	0.7	37	21
Methionine	0.3	0.5	0.7	0.8	29	47
Threonine	1.0	1.0	1.0	1.0	71	62
Tryptophan	0.4	-	0.2	0.5	82	-
Valine	1.7	1.4	1.4	1.5	67	73

A. The ratio of essential amino-acids to threonine (the 'Reference Pattern') in cultivated and wild cowpeas compared with the FAO provisional pattern for optimum growth and the pattern in whole egg protein.

B. Essential amino-acids in cultivated and wild cowpeas as percentages of the concentrations in whole egg protein.

In A and B, the values for cultivated cowpea are means from 7 Nigerian cultivars.

Source: Steele, 1972.

Harvesting is still carried out by hand picking of pods. Goble et al (1968) observed that harvesting and threshing represented about 50% of the total cost of production of cowpea in the southern parts of the United States. The Institute for Agricultural Research, Samaru, Zaria (I.A.R) found that harvesting utilized about 56% of the total production labour requirement of cowpea among the local farmers in Nigeria (Hays et al, 1977).

Harvesting of cowpea by hand picking of pods (plate I) is a very strenuous task requiring about 440 man-hours/ha among the local farmers in northern Nigeria (Hays et al, 1977). The task requires bending which results in sharp pains at the low back. Mwuba and Kaul (1986) have shown that agricultural tasks requiring trunk flexion waste a lot of human energy in combating gravity. They recommended that alternative approaches should be designed to eliminate bending. Hand picking of cowpea pods is costly and time-consuming; and has become a very great bottleneck in cowpea production. Cutting of mature shoot is a less laborous alternative to pod picking. When the shoots are dry, they could be fed into a thresher to extract the grains and the chaff could be used for livestock feeding. This suggests that the present pod thresher could be replaced with a whole shoot thresher.

In recent times the attention of agricultural engineers has been directed to the importance of engineering properties of agricultural materials in machine and structural design and, in processing and control engineering.

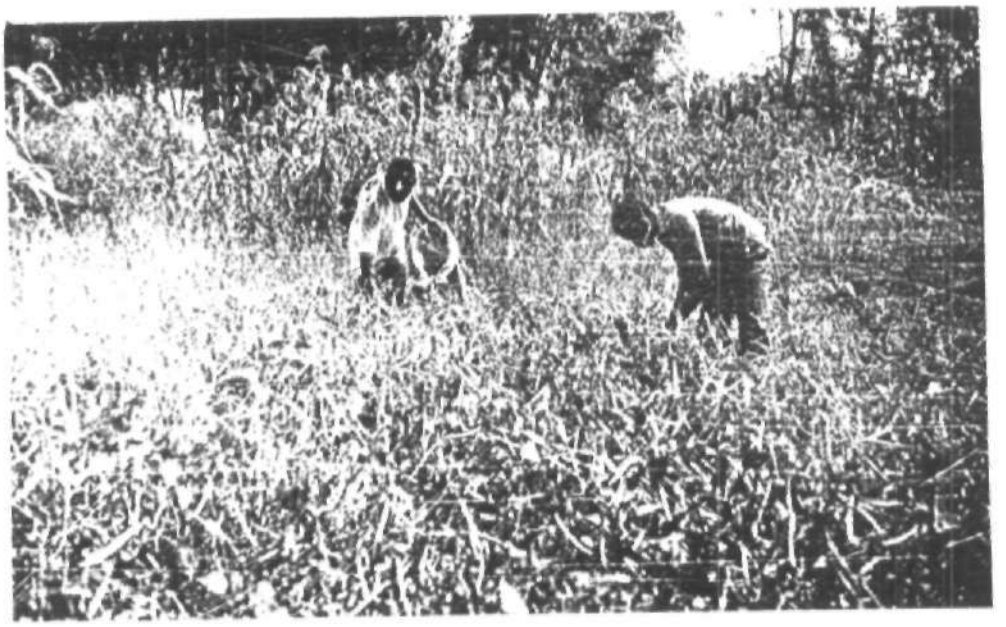


Plate I - Traditional harvesting of cowpea by hand picking of pods

The knowledge of the shape and size of agricultural products is important in the determination of stress distribution in materials under load, machine clearance for threshing, cleaning, sizing and grading of grains. The shape and size is also essential in light reflectance and colour evaluation, separation by pneumatic and electrostatic devices, and in heat transfer. Accurate measurement of the frontal area is essential for the determination of terminal velocity, drag coefficient and Reynolds number in fluidized systems.

The density and specific gravity of agricultural materials are needed for calculating their thermal diffusivity in heat transfer, for determining Reynolds number in pneumatic and hydraulic handling of materials, for separating products from impurities and in predicting physical structure and chemical composition. In addition, surface appearance and colour of materials help in timing the harvesting period and in selective harvesting (Mohsenin, 1970).

Many investigators have carried out studies on the mechanical properties of the agricultural materials in order to develop necessary data for engineering design, while others have studied the effect of mechanical damage on crop use. According to Anazodo (1982), the determination of the mechanical properties of agricultural products under static or dynamic loading is aimed at: (a) Objective textural measurement of the unprocessed and processed food material.

(b) The reduction of mechanical damage to agricultural

produce during harvesting, handling, processing and storage.

(c) The determination of design parameters for harvest and post-harvest systems.

In the present study only some physical and mechanical properties of cowpea that are related to the mechanical threshing of the entire crop shoot were investigated. The results were applied in the redesign of a cowpea pod thresher to make it suitable for the entire crop shoot.

1.2 Nature of the Problem

The determination of mechanical properties of biomaterials is not a simple task since they are apparently affected by temperature, moisture content and the rate of loading (Zoerb and Hall, 1960; Mohsenin, 1970; Saxena, 1972; Anazodo, 1980).

Biological materials do not behave in a purely elastic, plastic or viscous manner because of their structural nature. Rather they possess a combined solid-like and liquid-like behaviour. Their stress - strain relationship is not only dependent on the magnitude of the stress but also is a function of time. Materials with this type of behaviour are said to be viscoelastic. Studies have shown that agricultural products are viscoelastic (Zoerb and Hall, 1960; Mohsenin et al, 1963; Timbers, 1964; Morrow et al, 1966; Saxena, 1972; Anazodo, 1980). From the data available, it appears that the viscoelastic behaviour of biomaterial is non-linear (Zoerb et al, 1960;

Mohsenin, 1970). Since non-linear viscoelastic theory has not been well-defined in literature, linear viscoelastic technique was applied in this study to define the behaviour of cowpea stalk and kernel under the influence of external load.

The threshing problems posed by the massive cowpea stalks are enormous. The failure of the agricultural product in a thresher cylinder concave has been known to be mainly caused by compressive and bending stresses (Anazodo, 1980). The magnitude of these stresses are best indicators of the optimum threshing energy. But the extent of variety influence on these stresses should be known. The extraction of the undamaged grains from the massive stalks calls for size measurements of the grain in order to determine the necessary machine clearances and the sieve sizes. But the grain sizes are likely to vary in different varieties. It then will be necessary to optimize these machine clearances to accommodate the various variety difference.

Time for harvesting the cowpeas presents another problem. Grain moisture content has been found to be the major single crop factor that determines the harvest timing (Hunt, 1964; Waelli and Buchele, 1967; Prasad and Gupta, 1975; and Handy et al, 1977). But many varieties of cowpea exhibit progressive flowering. Fruiting does not occur at the same time but spreads over a period of time. This is, however, beyond the scope of this research. Nevertheless, the required characteristics of varieties adaptable to mechanization were put

forward, and the most suitable variety among those studied was found.

Moisture content obviously will be an important factor in threshing of the whole shoot. The studies attempted to find out the influence of moisture content on various properties, and the behavicur of the materials at different moisture content.

1.3 Objectives of the Study

The objectives of this research are specifically stated as follows:

1. To obtain data on some physical properties of cowpea.
2. To determine some mechanical properties of cowpea stalk, pod and kernel.
3. To study the influence of variety, moisture content and rate of loading on the physical and mechanical properties of cowpea.
4. To relate some physical and mechanical properties to a design proposal of a cowpea whole shoot thresher.

1.4 The Scope and Limitations of the Study

In this project, the physical properties of cowpea studied will be limited to the size and shape of cowpea grain, the thinckness of the pod hull, moisture content and the dimensions of the stalk which will be applied in the determination of mechanical properties.

The scope of mechanical properties are limited to the determination of stalk properties in radial compression and simple bending, measurement of the minimum cracking force of the pod, and the properties of grain under uniaxial loading.

Finally a pod thresher will be redesigned applying the measured properties.

A study of this type is prone to a lot of limitations. The biological nature of the experimental materials in this study limited the accuracy of the data obtained. Each specimen used for the test was a biological system which might grossly differ from identical products when mass-produced in a factory. Bio-materials are alive, and are undergoing vital activities. They are constantly changing in shape, size and content. The cell is therefore, sensitive to such external factors as humidity, temperature, oxygen, food supply, and energy consumption, which jointly influence its internal physiology. Also elasticity in biomaterials varies with the stage of maturity and physiological conditions.

High variability has therefore been found among replications of experiments with biomaterials (Mohsenin, 1970; Saxena, 1972; Anazodo, 1980). This is not so when compared to the engineering material produced under strict quality control processes.

Quasi-static analysis used in this study, is employed in majority of studies on mechanical properties of agricultural materials probably because of the ease of instrumentation and

simplicity of analysis. However for the application of the material properties determined in laboratory to the field conditions, the quasi-static analysis should be supplemented with dynamic investigations.

Chapter 2

REVIEW OF LITERATURE

2.1 Physical Properties of Agricultural Products - Shape and Size

Beside the separation of grains from chaff, the shape and size of grains are very useful parameters in the design of sizing and grading machines, storage devices, and in dealing with any problem of stress distribution in the grains under load (Mohsenin, 1970; Fashina, 1986). Ige (1977 and 1978) used the grain size of cowpea as parameter for determining the clearance distance between the teeth on the drum, and those on the concave of his cowpea pod thresher. He calculated the minimum clearance distance as 11.8mm. To make allowance for the chaff which might enter the space with the grain, he used 12.5mm clearance distance for the design.

Shape and size are necessary for satisfactory description of a physical object. One method of determining the shape of an object is to compare the tracings of different cross sections of the object with shapes listed in a charted standard (Mohsenin, 1970). The shape obtained is defined either as the number on the chart or by the use of descriptive terms, such as round, oblate, oblong, conic, ovate, blique, obovate, elliptical, truncated, unequal, ribbed, regular or irregular.

Another method for defining the shape of an object is by the use of mathematical formulae.

Curray (1951) used the following formulae to estimate the roundness, roundness ratio and sphericity of some objects:

$$\text{Roundness} = A_p/A_c = \Sigma r/NR \quad \text{---} \quad 2.1$$

$$\text{Roundness ratio} = r_1/R_1 \quad \text{---} \quad 2.2$$

$$\text{Sphericity} = d_c/d_c = d_i/d_c \quad \text{---} \quad 2.3$$

where A_p = largest projected area of the object in natural rest position

A_c = area of smallest circumscribing circle

Σr = sum of all radii of curvature

R = radius of the maximum inscribed circle

N = total number of corners summed in numerator

r_1 = the radius of curvature of the sharpest corner

R_1 = mean radius of the object

d_c = diameter of sphere of the same volume as the object

d_c = diameter of the smallest circumscribing sphere or the longest diameter of the object.

d_i = diameter of largest inscribed circle

Roundness is a measure of sharpness of the corners of a solid object. While the concept of sphericity rests on the isometric property of a sphere. The value of sphericity ranges between 0 and 1. An orange has a sphericity of about 0.95 (Waziri and Mittal, 1983).

The shape of an agricultural product can also be determined by comparing it to existing geometrical shapes. The shape of the product is then approximated to the closest existing geometrical shape. This is a very convenient method particularly

where mathematical formulae will be applied in the determination of some properties. Misra and Young (1981) used this method to determine the shape of soyabean grain which they approximated to an ellipse. Consequently they used the mathematical formulae relating to ellipse to determine the modulus of elasticity of soyabean in uniaxial compression. The shape of cowpea grain was determined in this project by comparing it to an existing geometrical shape.

Diverse measuring instruments are used to determine the size of various agricultural products. Large products can be measured with ordinary ruler. Venier calipers and micrometer screw gauge are used to measure the size of large fruits and grains. Ige (1977) and Fashina (1986) used micrometer screw gauge to measure the size of cowpea grain and Egusi (Colocynthis citrullus L.) seed, respectively. Waziri and Mittal (1983) used the same instrument to measure the size of groundnut kernels and pods. The micrometer screw gauge was used in this study to determine the size of cowpea grains and the thickness of the pod hulls (pericarp), while the venier calipers was used for measuring the dimensions of the cowpea stalk.

For tiny grains like millet and sorghum, and seeds of certain flowers and vegetables, the over-head projector or photographic enlarger can be used to determine the axial measurements taking into consideration the magnification factor of the instrument used. Waziri and Mittal (1983) used this method to determine the size of sorghum and millet.

The determination of the average diameter of an agricultural product requires ideally a great number of measurements in various directions. In practice, however, three measurements: major, intermediate and minor diameters, are sufficient (Mohsenin, 1970; Ige, 1977; Waziri and Mittal, 1983; and Fashina, 1986). These measurements are called length, width and thickness in cowpea grain.

2.2 Mechanical Behaviour of Agricultural Materials

2.2.1 General

Studies by Zoerb and Hall (1960), Mohsenin et al (1963), Timbers (1964), and Morrow et al (1966) show that agricultural materials are viscoelastic. They are not purely elastic because of their structural complexity, rather they exhibit time - dependent properties which combine both liquid-like and solid-like characteristics. Using load-deformation tests on corn kernels, Mohsenin (1970) showed that the mechanical behaviour of the agricultural product was non-linearly viscoelastic. The hysteresis losses associated with the kernels were observed to decrease with repeated cycles of loading.

Zoerb and Hall (1960) stated that most agricultural materials show elastic properties at the initial part of a load-deformation curve but later exhibit a viscoelastic behaviour on increased loading. Hence after exceeding the elastic region, the properties become time-dependent, and the effects of the

deformation rate becomes more noticeable.

Mohsenin et al (1963) observed that the rate of deformation affected the maximum force of rupture of apples. The greater the deformation rate, the more the maximum force of rupture.

2.2.2 Studies on Mechanical Properties of Cereal Grains

A lot of studies have been carried out on cereal grains to determine the kernel damage, kernel strength or characterize the kernel mechanical properties because of the ultimate need of preserving the grain quality.

By applying Hertz theory of contact stresses assuming the kernels to be spherically shaped, Shpolyanskaya (1952) evaluated the modulus of elasticity of wheat kernels. He determined the modulus of elasticity by loading the individual kernel between two flat plates and measuring the resultant deformations. After several cycles of repeated loading and unloading of the kernel, the load-deformation behaviour approached that of an elastic body.

The load-deformation behaviour of soft winter wheat was studied by Zoerb et al (1960) using small core samples of kernel. They observed a non-linear elastic-plastic behaviour with strain hardening tendencies. The hysteresis losses associated with the first and the second load cycles were 46.3% and 26.4% of the expended loading energy, respectively.

Hysteresis losses were observed to increase with the moisture content of the grain. Similar behaviour was also observed with corn kernels.

Shelef and Mohsenin (1967) confirmed that the load deformation behaviour of wheat kernel was elastic-plastic with strain hardening. They obtained the modulus of elasticity of wheat by loading wheat kernels in various ways, namely: loading of whole kernel between two flat plates; loading with a spherical indenter 0.04 cm in diameter; loading with a cylindrical indenter, and compressing core between two parallel plates.

In recent studies Anazodo (1980) verified the Hertz theory of contact stresses as applied to cylindrical biological materials when he experimentally measured the contact width of maize cobs in radial compression by three methods and compared the measurements with the theoretical calculations. He found that there was good agreement between the theoretical and experimental values of contact width obtained. He found that the cob elastic modulus and crushing strength in radial compression had linear relationship with cob moisture content, while cob modulus of toughness had a nonlinear relationship with moisture content. The values of all the three mechanical properties determined in the tests were found to increase significantly with decrease in moisture content. He recorded the mean values of 33.7 MPa for elastic modulus, 6.1MPa for crushing strength and 0.117 for crushing strain at 10.3% moisture content, wet basis (Mc, wb).

In simple bending test of maize cobs, Anazodo (1980) again found that the moisture content had highly significant influence on the cob elastic modulus and bending strength, while the rate of loading did not significantly affect the mechanical properties. Maize variety and harvest date also had significant influence on the mechanical properties. He stated the mean values of cob mechanical properties in simple bending as 100MPa for elastic modulus and 4.3 MPa for the bending strength at the cob moisture content of 7.7%, wb.

In their studies on maize physical and mechanical properties as related to shelling performance of combine cylinder, Anazodo et al (1981) observed that the knowledge of the physical and mechanical properties of maize cobs can be used to select the variety of maize for optimum performance of the conventional combine cylinder. They found that the maize variety with the lowest value of cob mechanical properties suffered the highest cob break-up during shelling.

Balastreire et al (1982) studied fracture parameters of maize endosperm in bending and concluded that the progressive fracture in handling maize is proportional to maize kernel modulus of elasticity which is greatly influenced by the temperature and moisture content of maize.

2.2.3 Studies on Cowpea and other Related Legumes

The early research on beans was to determine the amount of damage caused by mechanical handling and find methods of reducing the damage. This study was stimulated in early 1930's when Harter (1930) observed that the injuries caused by threshing resulted in poor germination in beans.

Researchers like Borthwick (1932), Brown (1955), Perry and Hall (1966) and Judah (1970), studied the damages on beans due to mechanical handling. Judah (1970) evaluated the mechanical damage on beans from over 50 combine harvesters and reported that about 2.84% of the beans collected from the combines were mechanically damaged.

Early study on rupture force of beans was carried out by Brown (1955) who tested pea beans between pressure heads of varying shape. He reported that the forces required to crack the pea beans varied considerably.

Later Zoerb and Hall (1960) studied the basic rheological and mechanical properties of beans, maize and wheat grains and found that in all the grains the resisting force, the elastic modulus and stress decrease with increase in moisture content.

Bilanski (1966) applied compressive loads on soyabean kernels at the rate of 1.27mm/min to measure the force and work that would initiate seed coat rupture.

When loaded in horizontal hilum position, he found that the average force required to initiate rupture of the seed coat dropped from 57.8N at 1%, Mc, wb to 44.4N at 16%. The average work was 3.8mJ at 1%, and increased to 31.5mJ at 16%, Mc, wb.

Hoag (1972) studied the properties related to soyabean shatter by measuring the energy absorption with a ballistic pendulum and found that the energy necessary to cause the soyabean shatter was proportional to the moisture content of soyabean. He reported that the mean energy required for soyabean pod shatter at 10-15% Mc, wb was 0.0377J.

By uniaxial compression of remoistened soyabean kernels on Instron universal testing machine, Saxena (1972) studied the mechanical properties of soyabean kernel and the effect of the moisture content, temperature and the rate of loading on these properties. In his findings he established that soyabean kernel is a viscoelastic material sensitive to the changes in deformation rate, temperature and moisture content. He reported that the hysteresis loss in kernel at 11% moisture content, dry basis (Mc, db) and 21°C was 79%. The barrel effect increased with the moisture content being 2.01 at 30.2% Mc, db and 1.11 at 11% Mc, db. The degree of elasticity of the kernel was 45% and the rupture force at 1cm/min crosshead speed, 11% Mc, db and 21°C was 16.81kg. He also observed that the soyabean kernel had no well-defined bioyield point as shown by the force-deformation curves he obtained from 720 tests.

Hoki and Tomita (1976) observed that the ultimate strength increased as moisture content increased from 8-20% wb for rectangular parallelepiped soyabean specimens in compression at 10mm/min and 40mm/min. Slightly higher values of ultimate strength were obtained at 40mm/min deformation rate, while maximum values for toughness were observed at 10%, Mc, wb.

Paulsen (1978) measured the fracture resistance of soyabean in terms of average compressive force, deformation and toughness at seed coat rupture. He reported that the average force required to initiate seed coat rupture decreased from 144N to 38.2N as soyabean moisture content increased from 8 to 17% wb. More force was required for rupture when soyabean was loaded in horizontal hilum position than vertical position. He also observed maximum toughness at 11 to 14%, wb, moisture range. While smaller soyabeans had greater resistance to rupture than larger soyabeans.

By experimental determination of the modulus of elasticity of remoistened soyabean kernels at various moisture content, Misra and Young (1981) developed a model for predicting the effect of moisture content on the modulus of elasticity of soyabean. They applied Hertz elastic theory of contact stresses to calculate the elastic modulus of soyabean kernels assuming the kernels to be ellipsoidal in shape. From their study they found that the modulus of elasticity increases and approaches a constant maximum with a decrease in moisture content of the soyabean. They gave the average elastic modulus of soyabean kernel at 2.05% Mc, wb as 616.1 MPa while at 17.79% moisture the elastic

modulus was 39MPa.

The available recorded work on the engineering properties of cowpea was done by Ige (1977) who investigated the grain size and the effect of moisture content on the rupture strength of five varieties of cowpea. He observed that the size distribution curves approximated to the normal distribution curve, thus the results from size measurement could be used to determine the clearance distances in the threshing chamber. The varieties he studied include the Ife brown whose average grain size measurements were given as: length 7.58mm, width 5.84mm and thickness 4.36mm. He noted that the rupture stength of the grains was highly dependent on grain moisture content, and the size of the variety did not affect the rupture strength. And the cotyledons of cowpea is liable to high percentage of internal injury during mechanical handling. The rupture strength or rupture force of cowpea kernel was not indicated in his report, perhaps because of the imprecision of his simple apparatus which consisted of strain gauges mounted on a sensitive centilever and wired into a wheatstone bridge.

2.2.4 Crop Stalk

To improve crop harvesting systems, studies on mechanical properties of crop stalk, notably maize and sorghum, have been undertaken by researchers.

The mechanical properties of maize stalk was investigated by Pickett et al (1969) using laboratory and field testing procedures. They found that the mechanical properties of the stalk were closely related to the stage of development and radius of the stalk. The average compressive and tensile modulli of the stalk cortex were stated as 2379 MPa and 7653MPa, respectively.

Prince, Bartok and Bradway (1969) tested the dry nature maize stalk in compression and found that the average apparent modulus of the stalk was 2758 MPa, while that of the sections of cortex tested in tension was 1724 MPa.

The effect of perimeter and internode position on the mechanical properties of maize stalk was investigated by Prince, Bradway and Revaz (1969). They tested the maize stalk in bending and found that the elastic modulus of the stalk which averaged to 4723 MPa was significantly different at different positions on the stalk.

Prasad and Gupta (1975) investigated the mechanical properties of maize stalk as related to harvesting and observed that the cutting energy and maximum cutting force were inversely proportional to the moisture content and directly proportional to the cross-sectional area of the stalk. While the ultimate compressive stress in transverse direction and the modulus of toughness decrease with increase in the rate of deformation. They recorded the modulus of toughness of maize stalk as 0.084 X 10^6 N-m/m^3 at 10cm/min and 0.040 X 10^6 N-m/m^3 at 50cm/min rate of deformation.

Oke (1983) tested the compressive and tensile strength of two varieties of sorghum with Monsanto Tensometer W, universal testing machine, and noticed a significant difference in the values obtained for the two varieties. The values were also directly proportional to the radius and inversely proportional to the moisture content of the stalk.

2.2.5 How Moisture Content Influences Mechanical Properties of Biomaterials

It is seen from the above review that the moisture content of the crop is about the most important single crop factor influencing harvesting and post-harvest operations. Several explanations have been given on how moisture influences the mechanical properties of biomaterials. Barkas (1953) explained that the resistance of organic materials to deformation is largely dependent on the moisture held by molecular forces, the capillary water having little effect. Active polar sites of the bonding energy in molecular adsorption, are provided by hydroxyl anions in the molecular structure. Water molecules satisfy the active polar sites of the hydroxyl anions at moisture content close to saturation. Additional moisture is held by the formation of water molecule chains which are formed due to the dipolar nature of the water molecule. He further explained that the bonding forces between the hydroxyl anions become smaller when water chains are formed. When tension is applied the chain easily ruptures rejoining when the tension is removed. The water molecule in chains can jump from one anion group to another when subjected

to shear. This is not a completely elastic process since some energy is lost in the jump. The increase in plasticity of biomaterials with increase in moisture content is perhaps most plausibly explained by this slippage of anion bonds between neighbouring chains, rather than the slippage of entire cells over one another as might be suggested from a study of dislocation processes. As should be expected, increases in temperatures cause increased thermal agitation of water molecules resulting in more slippage of anion bonds. This accounts for the thermo-plastic behaviour of biological materials.

2.2.6 Justification for Study of Engineering Properties of Cowpea

From the above review, it is obvious that very little has been done on the engineering properties of cowpea. Most work on physical properties were mere pod and grain length measurements, and testa and hilum colour description by the agronomists and crop breeders.

Obviously more work is required to describe the rheological properties of the agricultural products. In particular very little is known of the engineering properties of cowpea. It has not been established whether cowpea is an elastic or a visco-elastic material. And, up to date information in the literature shows that no recorded attempt has been made in the study of the mechanical properties of cowpea stalk and pod, a knowledge necessary in improving the cowpea harvest and post-harvest systems.

2.3 Studies on Threshing of Grains

Campbell (1976) defined threshing as the removal of grains from the crop by striking, treading or rubbing. He stated that threshing is accomplished traditionally by treading the grains under the human feet or hooves of animals; by striking the crop with sticks and flails or by rubbing between stone or wooden rollers. He observed that the mechanical threshers are designed on the same striking, squeezing and rubbing principle. The spike and loop threshers thresh mainly by striking action while the rasp-bar threshes mainly by friction or rubbing.

Several investigators have studied the performance of various threshers, to determine the optimum cylinder diameter and speed, beater bar size and spacing, concave length and clearance, feed rate and direction of feed, blower shaft speed and air velocity, and power requirement for threshing various grains. These parameters have been found to affect thresher performance and efficiency (Arnold, 1964; Vas et al, 1969; Sharma et al, 1980; and Joshi, 1981).

In their study on the power requirements of the rasp-bar threshing drum, Arnold and Lake (1964) found that: cylinders of large diameters required less power for the same rates of feeding than small diameter cylinder; an open-grate concave required about 25% less power than a closed concave at cylinder speeds of 4500 to 6500 ft/min; and the power requirement was increased by 10% when an open-grate concave length was increased from 332.5mm to 500mm. They also observed that the threshing power increased with cylinder speed.

Vas and Harrison (1969) investigated the effect of selected machine parameters on kernel damage and threshability of wheat. They found that increase in feed rate decreased mechanical damage without a significant decrease in theshing efficiency. They explained that the decrease in mechanical damage was as a result of cushioning effect resulting from the increased materials, while the maintained threshing efficiency was because the increase in feed rate increased the crop stream density resulting in greater frictional forces between the particles. This maintained the threshing efficiency in spite of the increase in feed rate. They further observed that cylinder speed and concave clearance were the two machine parameters that caused significant variation in threshability.

Dodds (1968) compared the threshing action of spike-tooth and rasp-bar cylinders in self-propelled combine, and concluded that the spike-tooth cylinder had a more positive feeding action and consumed less power than the rasp-bar type. He also observed increased power requirement with an increase in feed rate.

Harrington (1970) designed and tested a multicrop thresher with a spike-tooth cylinder and fixed concave with 25mm clearance. He found that at a cylinder tip speed of 1,200 - 1,400m/min, the unthreshed rice paddy and wheat grain were less than 0.1% while at 800 - 1,00m/min the visible grain damage was less than 0.1% with less than 1% unthreshed grain.

Singh and Kumar (1976) studied the effectiveness of three types of cylinders in threshing of wheat, and concluded that the swinging hammer type cylinder consumed more power than the rasp-bar and spike-tooth cylinders.

Campbell (1976) compared the output of the International Rice Research Institute (IRRI) 2.2 kW engine-driven stationary rice thresher with the traditional methods. He reported that while IRRI thresher had an output of 250kg/hr, hand beating produced 17.20kg/hr, treading with bullocks 140kg/hr and pedal thresher 40.45kg/hr.

Ige (1978) tested a locally constructed cowpea pod thresher with toothed square drum and alternately toothed concave, at six drum speeds and two moisture levels. He found that there was an increase in threshing efficiency and mechanical damage with increase in drum speed. The threshing efficiency and grain damage increased from 78.3% and 1% at 141.4m/min to 98.4% and 6% at 259.2 m/min drum speed, respectively. He also observed a higher threshing efficiency with lower pod moisture content. The tests took place at average moisture content of 14.3 to 16.5% wb.

Singh et al (1978) designed and tested a rasp-bar groundnut decorticater and found that minimum breakage occurred at a cylinder tip speed of 142 m/min at a feed rate of 150kg/hr with 15mm cylinder-concave clearance. They recommended a clearance of 15mm at 15-18% MC, db for decorticating kernels for seed purposes and 7.5mm clearance at 5-8% MC, db for commercial purposes.

reduced grain damage; and the total no load power requirement increased from 688 to 2,353 watts per hour with change in cylinder speed from 350 to 570 rpm.

Sharma and Devnani (1980) conducted threshing trials on soyabean and cowpea in a rasp cylinder thresher and found that for the same cylinder tip speed and concave clearance, the visible grain damage was greater in soyabean while internal damage was greater in cowpea, and this affected seed germination. They also found out that the grain output during threshing was dependent upon crop variables rather than machine variables. They finally recommended a cylinder tip speed of 413.5 m/min and 330 m/min at 12mm concave clearance for soyabean for consumption and planting, respectively, at a moisture content of 6.1% wb. Using Deshi variety of cowpea at 6.5% moisture content, they recommended a concave clearance of 8mm, and cylinder tip speed of 496m/min and 288.5m/min for threshing grains for consumption, seeds for planting, respectively. Finally they developed a linear relationship

$$TE = 93.5819 - 0.1148FR + 0.0481CS - 0.5470CC \quad - - - \quad 2.4$$

for the cowpea variety

where TE = Threshing efficiency, %

FR = Feed rate, kg/hr

CS = Cylinder tip speed, m/min

and CC = Concave clearance, mm,

with correlation coefficient, R = 0.9517.

Singh et al (1981) studied the effect of moisture content and machine parameters on threshing effectiveness and seed quality of soyabean, and observed that unthreshed grain increased with an increase in pod moisture content and decreased with an increase in cylinder speed, while decrease in grain moisture content increased grain damage. They noted that the variety that was harder to thresh, had less damage and greater percentage germination. They finally developed linear relationships between the cylinder speed, S, grain damage, D, and grain moisture content, M for the two varieties studied, as follows:

$D_1 = -0.626 + 0.283\ S - 0.075\ M$ - - - 2.5

$D_2 = 0.929 + 0.426\ S - 0.235\ M$ - - - 2.6

where D_1 and D_2 = % grain damage for Ankar and PK71-21 variety of soyabean

S = cylinder speed, ms^{-1}

M = grain moisture content, % wb.

Design and evaluation of the performance of a stationary wheat thresher was carried out by Ghaly (1985). He found that the visible grain damage and power requirement increased with increase in cylinder speed.

The performance of rasp-bar and wire-loop cylinders for threshing rice was compared by Sarwar and Khan (1987) who found that although rasp-bar had greater threshing efficiency, it also had greater grain damage than the wire-loop cylinder. They suggested that increase in cylinder speed would increase the threshing efficiency of wire-loop thresher. They also observed decreased grain damage with increase in concave clearance.

While working on multicrop threshers, Harrington (1970) found that air velocity between 150 to 350 m/min reduced the chaff content in grain and grain loss due to clearing to 1%.

In their study on the aerodynamic separation of wheat, Misener and Lee (1973) observed a minimum grain loss when an air velocity of 9.2m/s was directed at an angle of between 40 - 45°.

Kashyap and Pathak (1976) investigated the winnowing of wheat grain in low speed, straight, suction type, horizontal wind tunnel of 4.57 by 1.22m, and found that an air velocity of 23 to 27 km/hr was optimal in winnowing threshed wheat.

Singh et al (1978) studied a rasp-bar groundnut decorticator and recommended a blower speed of 460m/min and an air flow rate of 12m^3/min for adequate kernel cleaning.

Igbeka (1984) developed and tested a cereal cleaner which used sieves and air blast to clean grains. Rice and cowpea were cleaned at moisture contents of 10.2 and 11% wb respectively. He found that the total cleaning efficiency was low at low speeds and at very high speeds, and that the efficiency increased with the sieve angle of tilt to a maximum of 4.5°. He therefore recommended a speed up 300 - 350rpm and a sieve tilt angle of 4° for his machine.

In recent study to develop a thresher with multicrop potential, Singhal et al (1987) reviewed thresher accident occurrence in India (Table 2.2) and showed that the spike-tooth thresher was the safest followed by the rasp-bar type.

Table 2.2 Thresher accidents for various types of threshers

Type	Percentage of accidents
Drummy	45.16
Syndicator type	37.42
Hammer mill type	14.19
Rasp-bar	1.94
Spike-tooth	1.29

Source: Singhal et al, 1987.

They tested a multicrop spike-tooth thresher with whole plant chickpea at 9 and 13% MC, wb. Their results confirmed that increase in moisture content reduces threshing and cleaning efficiency, and grain output.

2.3.1 Summary of Threshing Studies

It is necessary here to summarize the above review on threshing studies to highlight the salient points which might be necessary in the design of a cowpea whole shoot thresher. The review is summarized under the following sub-headings:

Type of cylinder: From the above review, it is seen that the spike-tooth and rasp-bar threshers are very safe for use among the village farmers (Singhal et al, 1987). This is important because stationary threshers are usually fed by hand.

The spike-tooth and rasp-bar cylinders have high threshing efficiency and low power consumption (Kepner et al, 1972; Singh and Kumar, 1976; Sarwar and Khan, 1987). Hence they are popular in combine harvesters; spike-tooth being used mainly for rice and windrowed beans (Kepner et al., 1972). It has been observed that the spike-tooth cylinder has more positive feeding action and consumes less power than the rasp-bar (Dodds, 1968). But the rasp-bar requires less maintenance (Kepner et al 1972).

Power requirement: The power requirement for threshing has been found to increase with cylinder speed, feed rate and concave length; while large cylinder diameter and open-grate concave reduce power requirement (Arnold and Lake, 1964; Dodds, 1968; Sharma and Devnani, 1980; Joshi et al, 1980; Ghaly, 1985).

Threshing efficiency: Threshing efficiency increases with increase in cylinder speed, reduction in concave clearance, feed rate and pod moisture content (Vas and Harrison, 1969; Ige, 1978; Sharma and Devnani, 1980; Singh et al, 1981; Joshi et al, 1981).

Grain damage: Grain damage increases with increase in cylinder speed, and decreases with increase in concave clearance, feed rate and moisture content (Vas and Harrison, 1969; Harrington, 1970; Ige, 1978; Singh et al, 1978; Joshi and Singh, 1980; Ghaly, 1985).

Pods that are hard to break incur less visible and internal damage during threshing (Singh et al, 1981). Cowpea tends to

have more internal damage than soyabean during threshing because of its loosely packed cotyledons (Ige, 1978; Sharma and Devnani, 1980). Grains, such as rice, with high ultimate stress can withstand greater mechanical impact during theshing (Hoki and Esmay, 1979).

Grain loss: Grain loss increases with cylinder and blower speed (Harrington, 1970; Misener and Lee, 1973; Kashyap and Pathak, 1976; Singh et al, 1978).

Feed rate: Feed rate increases with increase in cylinder speed and spike length (Joshi and Singh, 1980).

The above basic information on thresher parameters was used as guideline in the design of the whole shoot thresher reported in Chapter 5.

Chapter 3

THEORETICAL CONSIDERATIONS IN MECHANICAL PROPERTIES AND THRESHING OF COWPEA

3.1 Introduction

In this Chapter, the important terms used in the study are defined, some fundamental principles are explained and the mathematical formulae applied in the calculation of mechanical properties and some threshing parameters are discussed. Some of these formulae are very involving in their derivation, and are precisely discussed; but references where they could be read in greater detail are given.

Some of the equations were not directly applicable to the biomaterial under study. In such cases the equations were modified to suit the part of the cowpea under consideration. Such modifications are fully discussed. The mathematical formulae discussed in this Chapter were used in calculating the mechanical properties and some threshing parameters in Chapter 5.

3.2 Definitions

The following terms used in this study are defined below. Some of the terms are illustrated in Fig 3.1 and 3.2.

Bending strength σ_b : The bending strength, σ_b, is the maximum bending stress attained before the fracture of the material

subjected to simple bending.

Bioyield point: The point on the force - deformation curve at which an increase in deformation occurs when there is a decrease or no change in the applied force, is called the bioyield point (see Fig. 3.1). The presence of this point in any agricultural product, indicates an initial cell rupture in the material cellular structure.

Crushing strain (ε_c) and crushing strength(σ_c): For agricultural product subjected to compression the crushing strain, ε_c , is the strain obtained at the maximum crushing stress (termed the crushing strength, σ_c) which is the maximum stress attained before the rupture of the material.

Degree of elasticity (β): The degree of elasticity, β , of a biomaterial is given as the ratio of the elastic deformation to the sum of the elastic and plastic deformation obtained from force-deformation curve (Fig 3.2) when the material is loaded and completely unloaded.

Force-deformation curve (f-d curve): A graph plotted with the values of deformation as abscissae and the values of force as ordinates is called the force-deformation curve. In this study the force-deformation curves of all the tested specimens were automatically plotted during testing by the universal testing machine.

Hysteresis: The energy absorbed by the material in a loading and unloading cycle is known as hysteresis. It is calculated

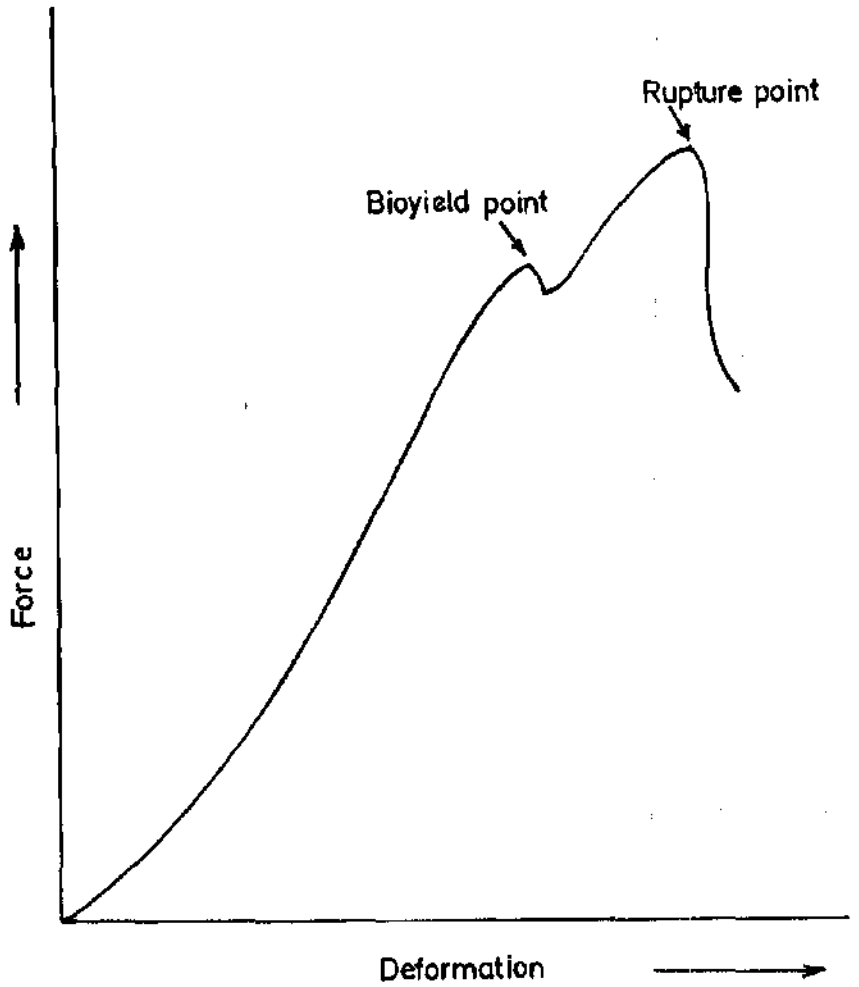


Fig. 3.1 A possible force-deformation curve of a biomaterial

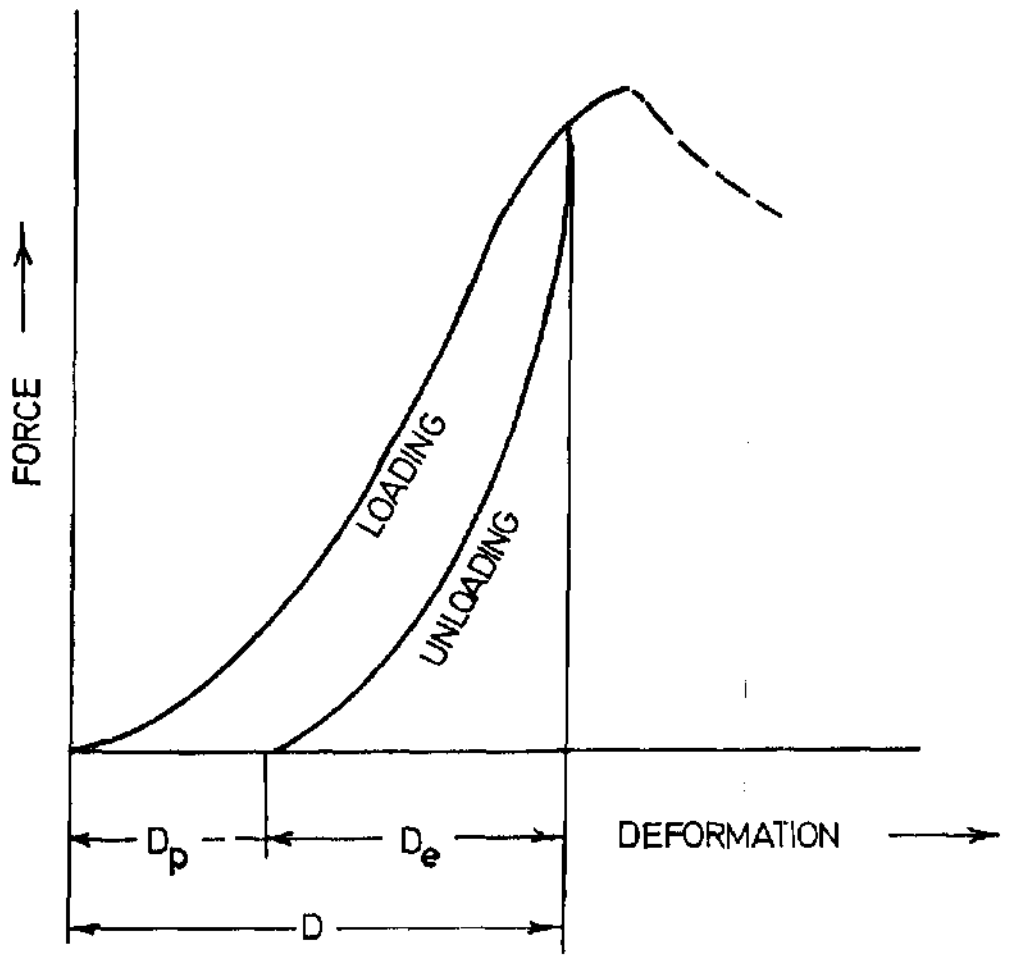


Fig.3.2 Loading and unloading curve of agricultural product in compression.
D = total deformation
D_e = elastic deformation
D_p = plastic deformation
β = degree of elasticity, % = 100 D_e / D

(Mohsenin, 1970)

as the area between the loading and unloading curve.

Modulus of elasticity (E): The modulus of elasticity is generally defined as the ratio of stress to the corresponding strain below the proportional limit. In the biomaterial the modulus of elasticity is usually calculated from an empirical formula derived from the stress-strain ratio and the Poisson's ratio using the degree of elasticity as a modifying factor to limit the calculation to the elastic zone of the force-deformation curve.

Poisson's ratio (μ): When an axial stress is applied to the body within the elastic region of the material, the ratio of the transverse strain to the axial strain produced is called the Poisson's ratio. Non-isotropic material will have more than one value of Poisson's ratio.

Rupture point: The point on the force-deformation curve at which the material ruptures under a load is called the rupture point. While the bioyield point is a failure in the microstructure of the specimen, rupture point is a failure in the macrostructure manifested by the cracking of seedcoat of the grain or pith of the stalk under radial compression.

Viscoelasticity: Viscoelasticity is generally defined as a combined solid-like, liquid-like behaviour in which the stress-strain relationship is time dependent. Linear viscoelasticity is defined as a viscoelastic behaviour in which the stress-strain ratio is a function of time and not stress magnitude.

3.3 Representation of Viscoelastic Behaviour

There are three basic levels at which the mechanism of response of an engineering material may be studied, namely: the molecular, structural and the phenomenological levels. The response of the material at the molecular level is inferred from the properties of its microscopic elementary particles. The structural level considers the material as being made up of visible non-homogeneous units whose interaction results in the observed behaviour. At the phenomenological level the material is assumed to be macroscopically homogeneous and isotropic. Its behaviour is assumed to be the same in every part of it and in every direction. Knowing that biomaterials are heterogeneous, the structural level of mechanism of response is adopted in this study. It is assumed that the observed behaviour is an interaction of the various heterogeneous units that make up the material.

A completely rigid body which is incompressible is the classical ideal Euclid solid while the incompressible liquid which offers absolutely no resistance to deformation is the Pascalian liquid. Next to Euclid is the Lockean solid in which the stress is directly proportional to the strain produced. While the Newtonian liquid in which the stress is proportional to the time rate of the strain produced, is next in the liquid hierarchy. St. Venant Solid represents another idealized behaviour in which the stress is directly proportional to the strain up to a certain stress called the yield stress after which the material deforms plastically at a constant stress.

The behaviour of real materials fall somewhere inbetween the idealized Euclid solid and Pascalian liquid. It is generally a complex combination of the many idealized responses mentioned above. Actually, any quantitative representation of this complex behaviour of materials, will in itself be idealized to some degree depending on the desired accuracy. In this study, the viscoelastic behaviour of cowpea was assumed linear in order to simplify the calculation since the theory of non-linear viscoelasticity has not been completely well analysed in the available literature. It is however known that most biomaterials exhibit non-linear viscoelastic behaviour.

3.4 Theoretical Considerations in Radial Compression of Cowpea Stalk

3.4.1 Hertz Linear Elastic Contact Theory

When two elastic bodies are in contact under an external force, local compressive stresses are set up and the surfaces are deformed. The contact stresses developed may be high even for small applied force owing to the small area of contact.

Although contact problems are often non-linear, Hertz in 1881 developed a classical solution for contact stresses and deformations developed when two elastic bodies are in contact, based on the linear theory of elasticity.

Fig 3.3 and 3.4 show two basic types of deformation considered in Hertz theory. When two spherical bodies with radii of

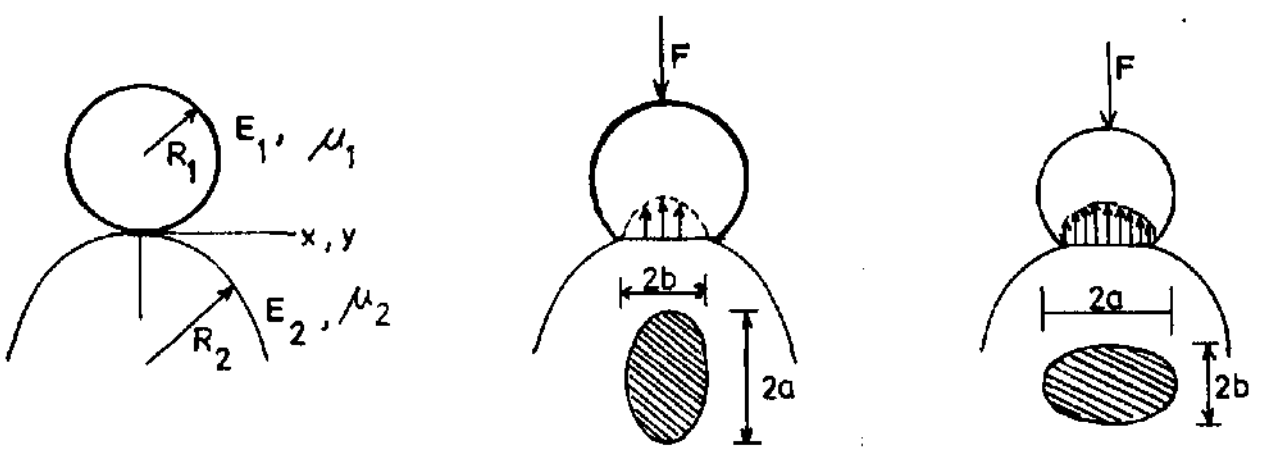


Fig. 3.3 Contact between two spherical elastic bodies illustrasting the contact area and distribution of contact pressure.

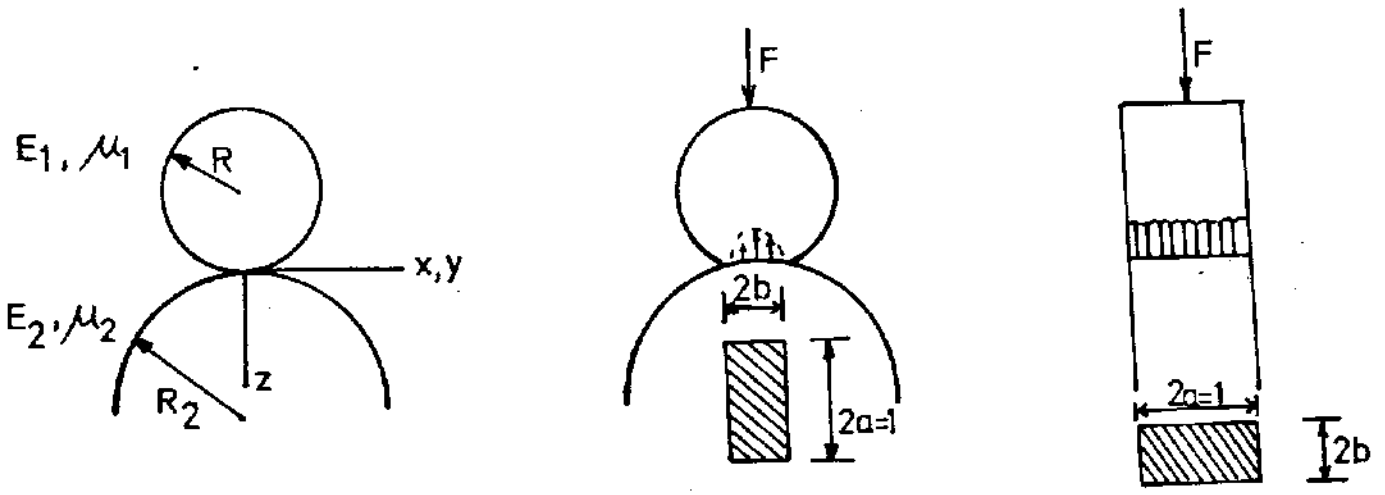


Fig. 3.4 Illustrative diagrams of contact between two cylindrical elastic bodies showing the contact area and distribution of contact pressure.

curvation R_1, R_2 are in contact, Hertz theory states that the contact area is elliptical (Fig 3.3). While for two cylinderical bodies with their axes parallel to each other, the contact area is rectangular. The cowpea stalk is roughly cylinirical. Its stress problems in radial compression was analysed using Hertz contact theory for cylindrical bodies.

From Hertz theory, the normal pressure distribution, q, developed at the contact surface of the two cylindrical bodies pressed together is given by

$$q = q_o \left[1 - (x/b)^2\right]^{\frac{1}{2}} \quad - - - 3.1$$

where q_o = maximum contact pressure

x = distance from centre of contact along x-axis

b = half the width of contact surface.

The maximum contact pressure, q_o, at the centre of the contact surface is given by Hertz as

$$q_o = 2F/\pi lb \quad - - - 3.2$$

where F = external normal force

l = length of the cylindrical body in y direction.

For long elastic cylinders in contact, Timoshenko and Goodier (1970) have shown that the half contact width, b, may be obtained from the expression

$$b^2 = \frac{4F\left[\left((1-\mu_1^2)/E_1\right) + \left((1-\mu_2^2)/E_2\right)\right]}{\pi l\left[(1/R_1) + (1/R_2)\right]} \quad - - - 3.3$$

where μ_1, μ_2 = Poisson's ratio for the two cylinders in contact (Fig 3.4)

E_1, E_2 = moduli of elasticity

R_1, R_2 = radii of curvature

If b is calculated from the above, the maximum stress can be obtained from Equation (3.2).

3.4.2 Application of Hertz Contact Theory to Agricultural Products

Hertz contact theory is applicable to elastic bodies. Its application to viscoelastic biomaterials under compression is based on the observation of Mohsenin (1970) that the force-deformation curve of the biomaterials tends to become sigmoidal under large strain so that the modulus of elasticity obtained from the slope would be greater for heavy loads and smaller for light loads. However, at the initial portion of the curve under small strains, linear elasticity exists to a greater extent. Hence at this region the application of Hertz theory is appropriate. Based on the above observation some researchers like Snobar (1973), Sherif (1976) and Amazodo (1981) have applied the Hertz contact theory for elastic materials to viscoelastic agricultural products. In the present study, Hertz contact theory was also used to analyse the contact stresses and modulus of elasticity **of cowpea stalk in** radial compression and the grain in uniaxial compression within the elastic region of their force-deformation curves.

Some simplifications are necessary in the application of the Equation (3.3) to cylindrical biomaterials. When a cylindrical body is compressed between two steel plates as shown in Fig 3.5, the steel plates are considered to have infinitely large radii of curvature, hence

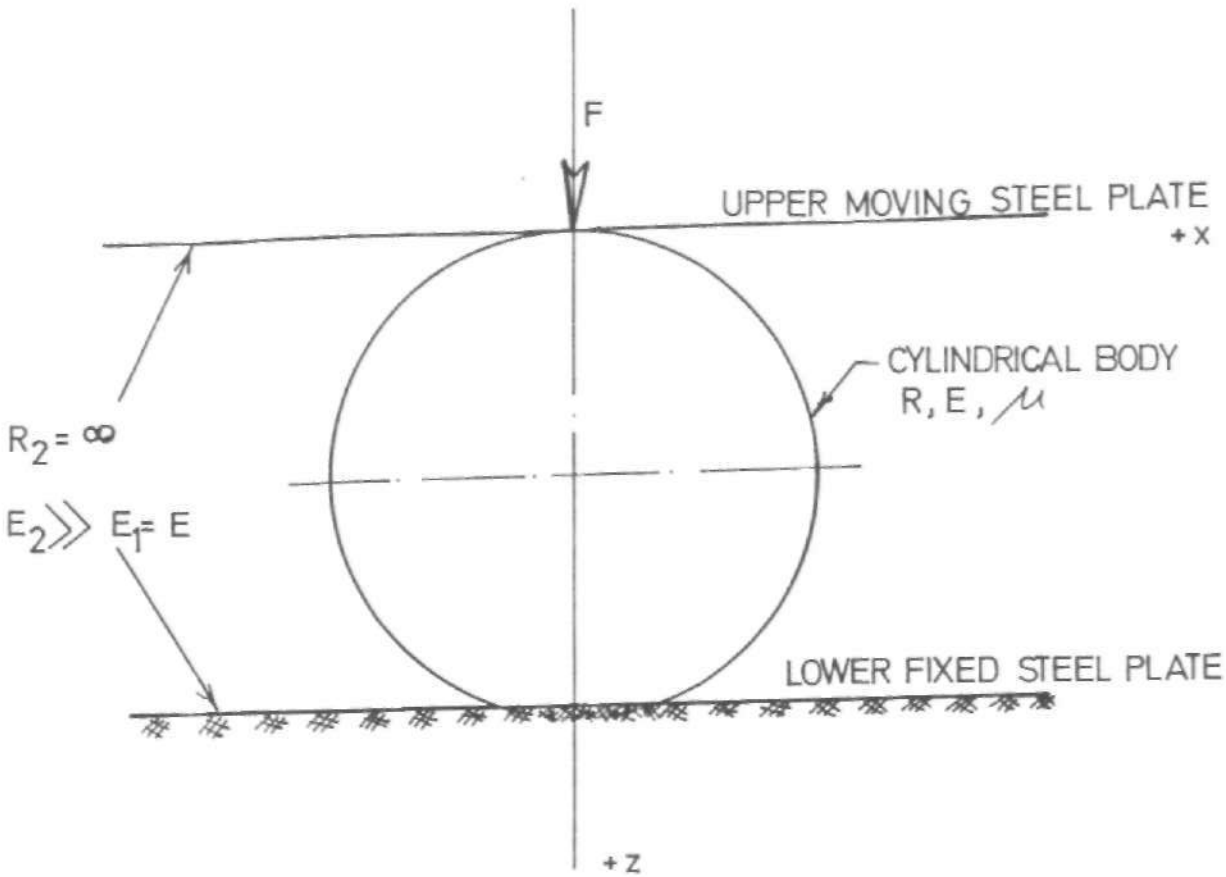


Fig.3.5 Compression of cylinder between two parallel flat steel plates.

$$R_2 = \infty \quad - - - 3.4$$

The apparent elastic modulus of the biomaterial, E, will be considered to be too small when compared to the elastic modulus of steel plates, E_2, hence

$$(1 - \mu^2)/E = (1 - \mu_1^2)/E_1 >> (1 - \mu_2^2)/E_2 \quad - - - 3.5$$

where $E = E_1$, $\mu = \mu_1$ and $E_2 >> E_1$

Since Poisson's ratio for most substances lies between 0.2 to 0.5 (Mohsonin 1970), and $R_2 = \infty$, the expression $(1 - \mu_2^2)/E_2$ will be very small and can be neglected, and $1/R_2 = 0$.

These assumptions reduce Equation (3.3) to

$$b^2 = 4FR(1 - \mu^2)/\pi lE \quad - - - 3.6$$

If the half contact width, b, could be obtained from the experimental measurement, then the modulus of elasticity of the biomaterial can be calculated using Equation (3.6). But accurate experimental measurement of the half contact width, b, is not always possible with most biomaterials because of the destructive nature of compressive tests.

A simplier formula for calculating the apparent elastic modulus of cylindrical biomaterial of length, l, under radial compression developed by Sherif et al (1976) is stated as follows:

$$E = 4FZ^2(1 - \mu^2)/\pi Rl \quad - - - 3.7$$

where Z is defined as

$$Z = R/b \quad - - - 3.8$$

and calculated from the expression

$$D/2R = (\ln(2Z) + \tfrac{1}{2})/2Z^2 \quad - - - 3.9$$

where D = total deformation

But for the application of Hertz contact theory, elastic

deformation, D_o, and not total deformation, D, is required. The elastic deformation, D_e, is obtained from

$$D_e = \beta D/100 \quad - - - \quad 3.10$$

where β = degree of elasticity, %, as illustrated in Fig 3.2.

The crushing strain, ε_c , is given as

$$\varepsilon_c = D_e/2R = \beta D/(100(2R)) \quad - - - \quad 3.11$$

Z is then estimated from

$$\varepsilon_c = (\ln(2Z) + \tfrac{1}{2})/2Z^2 \quad - - - \quad 3.12$$

The crushing stress, σ_c, is given by

$$\sigma_c = q_c = 2F_c/\pi lb \quad - - - \quad 3.13$$

where F_c = maximum crushing Force.

The crushing strain calculated from equation 3.11 is used to estimate Z from Equation (3.12). The crushing stress is calculated from Equation (3.13) using the half contact width, b, obtained from the Equation (3.8).

3.4.3 Basic Assumptions in Hertz Contact Theory

There are some fundamental assumptions originally made by Hertz in developing his theory of contact stresses. These are stated by Kosma and Cunningham (1962) as follows:

1. The materials in contact are homogeneous.
2. The applied loads are static.
3. Hooke's law is obeyed.
4. Contact stresses vanish at the opposite ends of contacting bodies.
5. The radii of curvatures of the contact area is small when compared with those of the bodies being compressed.

6. The contacting surfaces are sufficiently smooth to eliminate tangential forces.

Biomaterials are not homogeneous but if random in-homogeneity is assumed for the biomaterial under load, the mechanical behaviour may be assumed to approximate to that of a homogeneous body (Mohsenin, 1970).

3.5 Theoretical Consideration in Uniaxial Compression of Cowpea Grain

The following equation from Hertz contact theory obtained from American Society of Agricultural Engineers (ASAE) standard: ASAE S 368.1 (ASAE, 1983) was used to calculate the modulus of elasticity of cowpea grain in uniaxial compression (See Fig 3.6):

$$E = \frac{0.531}{D^{3/2}} F(1-\mu^2)\left[\left(\frac{1}{R_1}+\frac{1}{R'_1}\right)^{\frac{1}{3}}+\left(\frac{1}{R_2}+\frac{1}{R'_2}\right)^{\frac{1}{3}}\right]^{3/2} \quad - - - 3.14$$

where E = modulus of elasticity, MPa

F = force, N

μ = Poisson's ratio, dimensionless

D = deformation, mm

R_1, R'_1, R_2, R'_2 are radii of curvature as shown in Fig 3.7, mm.

Since the cotyledons of cowpea are symmetrical $R_2 = R_1$ and $R'_2 = R'_1$. Based on this the Hertz equation is reduced to

$$E = \frac{0.531}{D^{3/2}} F(1-\mu^2)\left[2\left(\frac{1}{R_1}+\frac{1}{R'_1}\right)^{\frac{1}{3}}\right]^{3/2} \quad - - - 3.15$$

$$\text{or} \quad E = 1.502\, F(1-\mu^2)\left[\left(\frac{1}{R_1}+\frac{1}{R'_1}\right)/D^3\right]^{\frac{1}{2}} \quad - - - 3.16$$

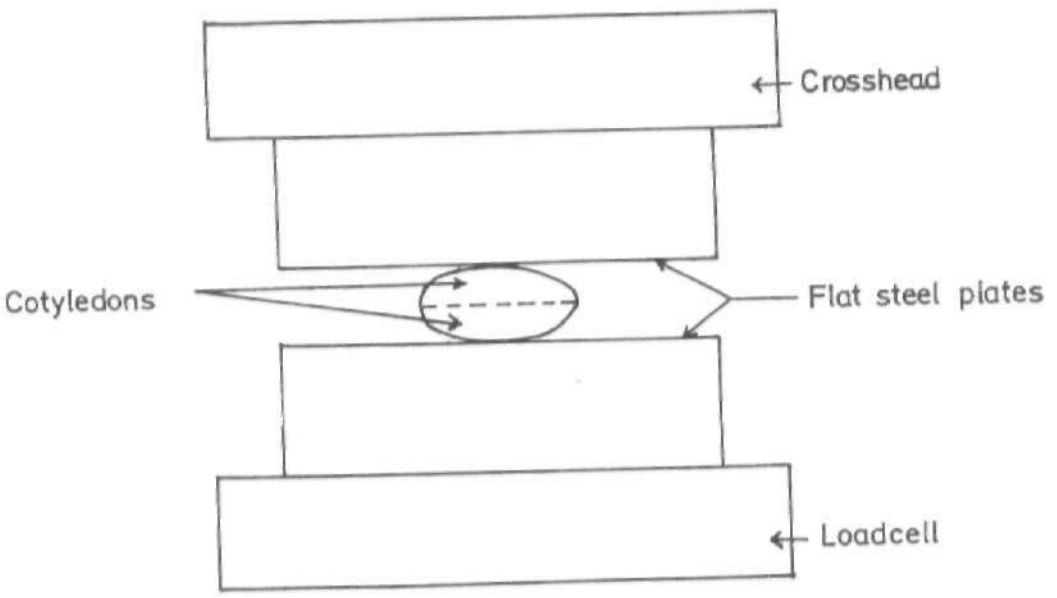


Fig. 3.6 Uniaxial compression of cowpea grain.

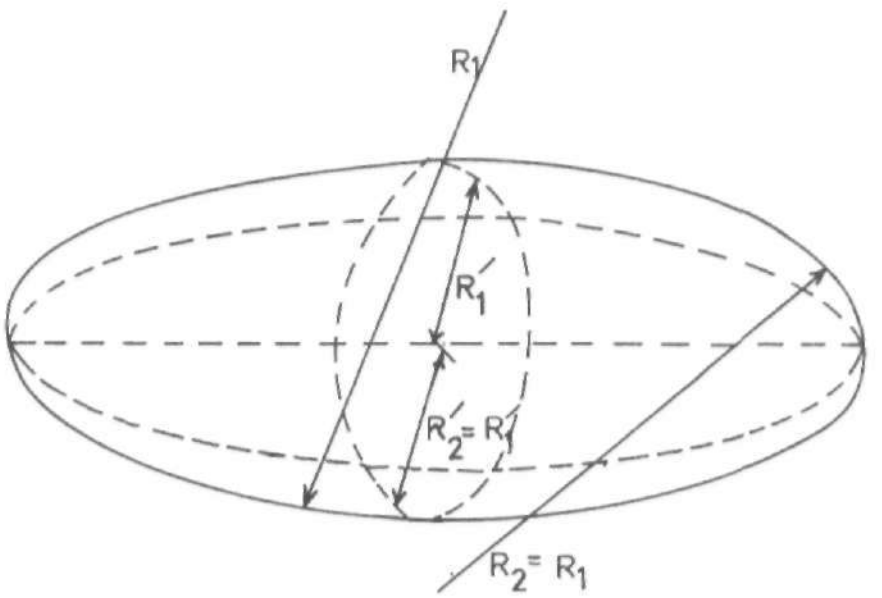


Fig. 3.7 Radii of curvatures of cowpea grain

It is necessary to limit the deformation to the elastic zone in applying the above formula to biomaterials. Hence elastic deformation, D_e, and not the total deformation, D, was used in calculating the elastic modulus of cowpea grain.

In the calculation, the cowpea grain was assumed to be elipsoidal in shape. Hence the major and minor radii of curvature R_1 and R_1' shown in Fig. 3.7 were calculated using the measurements of length, l, width, w, and thickness, t, of the cowpea grain (illustrated in Fig 3.8) as follows:

$$R_1 = \frac{l^2 + t^2}{4t} \quad - - - 3.17$$

$$R_1' = \frac{w^2 + t^2}{4t} \quad - - - 3.18$$

The above approach was used by Misra and Young (1981) to calculate the modulus of elasticity of soyabean grain in uniaxial compression.

3.6 Theoretical Considerations in Simple Bending of Cowpea Stalk

The theory of bending as applied to a hollow cylindor simply supported at both ends and loaded at the mid-span, was used in this study to analyse the response of the cowpea stalk in simple bending. The fundamental relationship between the bending stress, moment and the geometry of deformation, is given as follows:

$$\frac{M}{I} = \frac{\sigma_b}{y} = \frac{E}{R} \quad - - - 3.19$$

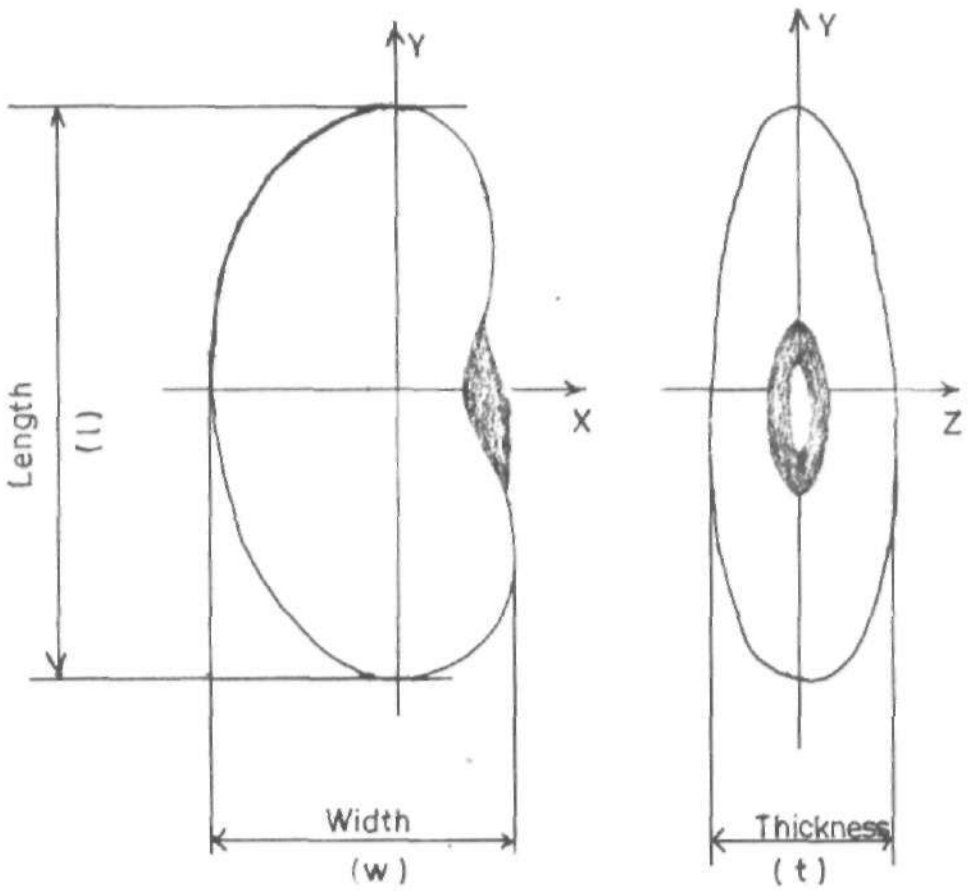


Fig. 3.8 The principal dimensions of cowpea grain

where M = maximum bending moment

I = moment of inertia

σ_b = maximum bending stress

y = distance of the extreme fibres from the neutral axis

E = modulus of elasticity

R = radius of curvature of neutral surface.

From the above, the maximum bending stress is

$$\sigma_b = \frac{My}{I} \quad - - - \quad 3.20$$

The moment of inertia of a hollow cylinder

$$I = \frac{\pi(d^4 - d_o^4)}{64} \quad - - - \quad 3.21$$

where d = diameter of cylinder

d_o = diameter of the hollow centre

y = d/2 and the bending moment

$$M = F_b l/4 \quad - - - \quad 3.22$$

where F_b = the maximum bending force and

l = the length of the cylinder.

Substituting the values above the bending stess becomes:

$$\sigma_b = 8F_b ld/\pi(d^4 - d_o^4) \quad - - - \quad 3.23$$

The radius of curvature, R, relates to the deflection of the neutral axis, ν, by the differential equation given by Benham and Warnock (1976) as

$$1/R = -\frac{d^2\nu}{dx^2} \quad - - - \quad 3.24$$

$$\therefore \quad \frac{d^2\nu}{dx^2} = -\frac{M}{EI} \quad - - - \quad 3.25$$

From the solution of the above differential equation the value of the maximum deflection at the mid-span of a simply supported

beam with centrally concentrated load is obtained as

$$\nu = F_b l^3/48EI \quad - - - \quad 3.26$$

This gives the modulus of elasticity as

$$E = F_b l^3/48\nu I \quad - - - \quad 3.27$$

But for biomaterials the elastic component of the deflection, ν_e and not the maximum deflection, ν, should be used. The elastic deflection is obtained by

$$\nu_e = \nu\beta/100 \quad - - - \quad 3.28$$

For simply supported hollow cylinder,

$$I = \frac{\pi (d^4 - d_o^4)}{64} \qquad (3.21)$$

$$\therefore \quad E = 4F_b l^3/3\,\nu_e\,\pi\,(d^4 - d_o^4) \quad - - - \quad 3.29.$$

3.7 Theoretical Considerations in Threshing of Cowpea

3.7.1 Definitions

Some terminology pertinent to thresher design and performance are defined in this Section. The definitions are in keeping with the ASAE Standard S343 (ASAE, 1983). Some of the terms are illustrated in Fig 3.9 and 3.10.

Threshing cylinder and concave: Threshing cylinder is a rotating element fitted adjacent to a stationary element called the concave for the purpose of promoting threshing. The concave is a concave-shaped stationary element adjacent to a threshing cylinder.

The crop being theshed is contained between the cylinder and concave for less than 360°. When the crop is contained between the two elements for one complete revolution, the rotating element is called a threshing rotor.

Cylinder diameter (d_c): The diameter of the circle made by the peripheral tip of the cylinder as it rotates about its on axis (Fig 3.9). In spike-tooth cylinders, it is the diameter of the circle made by the tip of the spikes when the cylinder is rotating.

Concave width or length (w): The external length of concave in millimetres measured parallel to cylinder axis.

Concave arc length (l): The internal arc length of concave in millimetres measured perpendicular to the cylinder (Fig 3.10).

Concave area: The product of concave width or length, w, and the arc length, l.

Concave grate: Perforated portion of concave area which is permeable for separation.

Threshing: Threshing is the removal of seed or kernel from the head, cob or pod.

Separating: Separating is the isolation of the detached seed, small debris or chaff, and unthreshed seeds from the rest.

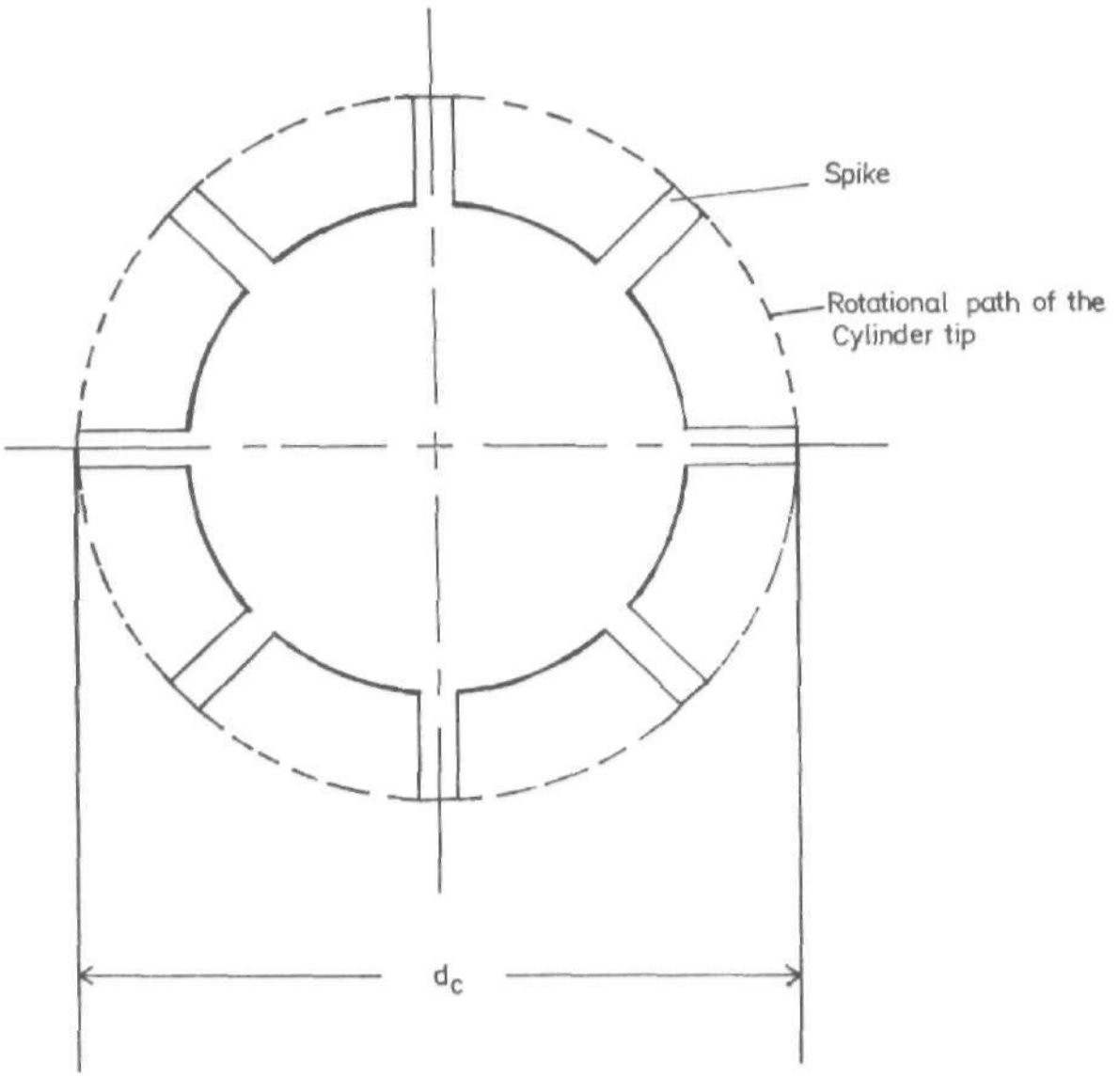


Fig. 3.9 CYLINDER DIAMETER

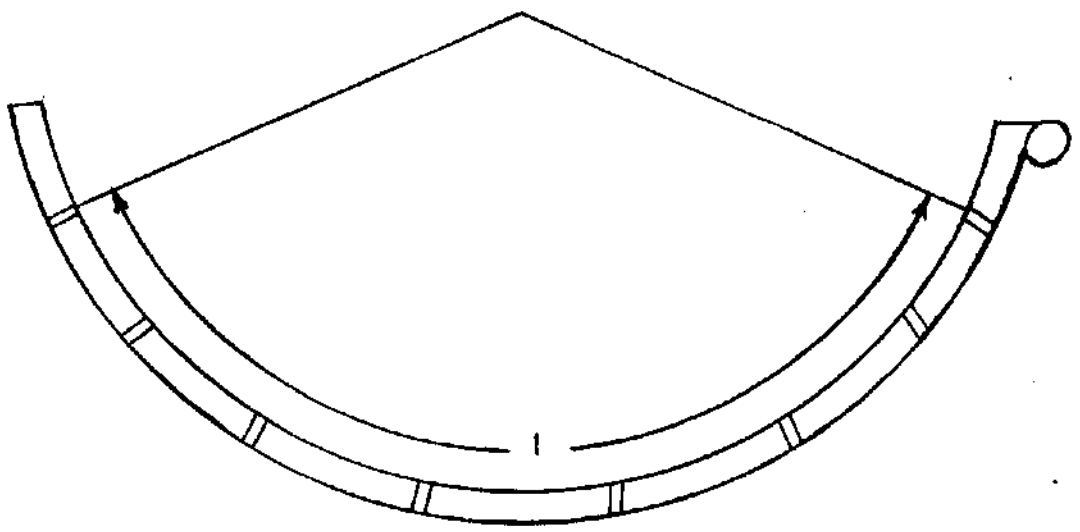


Fig. 3.10 CONCAVE ARC LENGTH

Cleaning: Cleaning is the isolating of the seeds from the mog (material-other-than-grain) and unthreshed material.

Sieving: Sieving is the isolating of the seeds by use of a perforated device called the sieve which permits the seeds to pass through it while the mog is carried over it.

Thresher capacity: In this study, the thresher capacity shall be defined as the maximum sustained feed rate at which the visible grain damage and processing loss should not exceed 2 and 1% respectively. For the combine harvester, the combine capacity is defined as the maximum sustained feed rate at which the processing loss shall not exceed 1% (for soyabean; ASAE, 1983). In thresher performance, limited grain damage is of great importance. Hence many investigators, like Kolganov (1958), Bunnelle et al (1961), Chestney (1969), Ige (1978), Sharma and Devnani (1979 and 1980), have used grain damage to determine the optimum cylinder speed and concave clearance for various threshers.

For grains for consumption, the recommended thresher cylinder tip speed and concave clearance shall be those at which the visible grain damage should be within 2%. (Kolganov, 1958, Bunnelle et al, 1959; King and Riddolls, 1960; Sharma and Devnani, 1979 and 1980). While the recommended speed and concave clearance should limit internal damage to within 5% for seeds for germination (Kolganov, 1958; Richey et al, 1961; Chestney, 1969; Sharma and Devnani, 1979 and 1980).

3.7.2 Calculation of Performance parameters in threshing

Threshing efficiency, T_e (%): Let the weight of grain collected in pan be W_1, the weight of unthreshed grain be W_2, the weight of grain blown out be W_3, then the total weight of grain, W, is given by

$$W = W_1 + W_2 + W_3 \quad --- \quad 3.30$$

The threshing efficiency, T_e, is calculated as

$$T_e = 100 (W_1 + W_3)/W \quad --- \quad 3.31$$

Processing loss, P_l (%): The percentage grain thrown or blown out called the processing loss, P_l, is calculated as

$$P_l = 100 W_3/W \quad --- \quad 3.32$$

Mog (material-other-than-grain) in grain, Mgr(%): The amount of non-grain materials in grain expressed in percentage is calculated as follows: Let the weight of mog collected with grain in pan be m_1, then mog in grain, M_{gr}, is calculated as

$$M_{gr} = 100 m_1/W_1 \quad --- \quad 3.33$$

Grain damage, Gd(%): Let the weight of damaged grain be W_4, the total weight of grain be W, then grain damage, Gd is given by

$$G_d = 100 W_4/W \quad --- \quad 3.34$$

Cleaning efficiency, C_e(%): Let the weight of total input of mog and grain be W_t, the weight of total mog input, m is given by

$$m = W_t - W \qquad \text{- - -} \quad 3.35$$

The weight of mog blown out, m_3 is calculated as

$$m_3 = m - (m_1 + m_2 + m_4) = (W_t - W) - (m_1 + m_2 + m_4) \qquad \text{- - -} \quad 3.36$$

where m_2 = weight of mog accompanying unthreshed grain

and m_4 = weight of mog withheld in machine as residue.

The cleaning efficiency, C_e, is given by

$$C_e = 100 \left[(W_t - W) - (m_1 + m_2 + m_4)\right] / (W_t - W) \qquad \text{- - -} \quad 3.37$$

or

$$C_e = 100 m_3/m \qquad \text{- - -} \quad 3.38$$

3.7.3 Calculation of Air Flow Through Thresher Blower

The required air discharge through a blower, Q_A, can be estimated on the basis of the cross-sectional area of the blower and the actual air velocity required for cleaning the grain, V. For a rectangular blower of width, w, and depth, h, the actual air discharge may be calculated as

$$Q_A = vwh \times 10^{-6} \qquad \text{- - -} \quad 3.39$$

where Q_A = actual air discharge, m^3/min

v = air velocity, m/min

w = width of blower, mm

h = depth of blower, mm

Assuming 30% efficiency for blowers (Joshi, 1981), then theoretical air discharge of the blower, Q_T, can be estimated as

$$Q_T = Q_A/0.3 \qquad \text{- - -} \quad 3.40$$

Alternatively, the theoretical discharge of the blower, Q_T, can be calculated as

$$Q_T = \pi d_1 w_1 v_1 \times 10^{-6} = \pi d_2 w_2 v_2 \times 10^{-6} \quad --- \quad 3.41$$

where Q_T = Theoretical air discharge, m^3/min

w_1, w_2 = width of blades (mm) at diameters d_1 and d_2 (mm)

v_1, v_2 = tangential component of absolute velocities, m/min

The tangential component of absolute velocity, v_2, can be approximated as 20% of the peripheral velocity of the impeller tip (Joshi, 1981), hence

$$v_2 = 0.2 \pi d_2 N \times 10^{-3} \quad --- \quad 3.42$$

where N = impeller speed, rpm.

3.7.3 Calculation of Threshing Energy and Work Done in Crushing and Breaking Cowpea Stalk

The total kinetic energy, K.E., generated by a rigid body in rotation equals the sum of kinetic energy of the particles that make up the body.

$$\therefore K.E. = \frac{1}{2}(m_1 r_1^2 + m_2 r_2^2 + \ldots)\omega^2 = \frac{1}{2}(\Sigma m_j r_j^2)\omega^2 \quad --- \quad 3.43.$$

where $m_1, m_2 \ldots m_j$ = mass of particle

$r_1, r_2 \ldots r_j$ = distance of particle from axis of rotation.

ω = angular velocity of body

The term $\Sigma m_j r_j^2$ usually denoted by I, is the sum of the moment of inertia of the particles at the fixed axis of rotation.

The total kinetic energy of the body therefore is expressed as:

$$K.E. = \frac{1}{2} I \omega^2 \quad - - - \quad 3.44$$

The rotating components that build up inertia for the threshing cylinder include; the shaft, the cylinder, and the pulley.

The total kinetic energy of the threshing cylinder will be the energy generated by these components, given as:

$$K.E. = \frac{1}{2} \omega^2 (I_s + I_c + I_p) \quad - - - \quad 3.45$$

where I_s, I_c, I_p = polar moment of inertia of shaft, cylinder and pulley respectively.

The polar moment of inertia of the shaft:

$$I_s = \frac{1}{2} m_s R_s^2 \quad - - - \quad 3.46$$

where m_s = mass of shaft

and R_s = radius of shaft.

The polar moment of inertia of the cylinder:

$$I_c = I_b + I_d \quad - - - \quad 3.47$$

where I_b, I_d = moment of inertia of the cylinder bars and the cylinder support discs respectively.

These are calculated from the expressions:

$$I_b = \tfrac{1}{2} m_b (R_{b1}^2 + R_{b1}^2) \text{ - - - } 3.48$$

where m_b = mass of bars

R_{b1} = distance of the centre of cylinder to the tip of spikes.

R_{b2} = the radius of the cylinder hollow;

$$I_d = \tfrac{1}{2} m_d R_d^2 \text{ - - - } 3.49$$

where m_d = mass of cylinder support discs.

R_d = radius of the disc.

The polar moment of inertia of pulley, I_p is given by:

$$I_p = \tfrac{1}{2} m_p R_p^2 \text{ - - - } 3.50$$

where m_p = mass of pulley

and R_p = radius of pulley.

The threshing energy, E_t, may be expressed as:

$$E_t = \tfrac{1}{2} I (\omega_o^2 - \omega_t^2) \text{ - - - } 3.51$$

where I = sum of polar moments of inertia of shaft, cylinder and pulley.

ω_o = Angular velocity of cylinder with thresher empty.

ω_t = Angular velocity of cylinder when loaded.

Assuming that the relationship between the feed rate and the threshing energy is linear in a given thresher design, then the energy for threshing whole shoot cowpea per kg/h feed rate (E_k) will be given as

$$E_k = E_t/_f \quad - - - 3.52$$

where f = feed rate, kg/h

The percentage energy used for threshing, % E_t, will be:

$$\% E_t = 100 E_t/K.E. \quad - - - 3.53$$

Work, W, done in crushing or breaking the cowpea stalk is given by

$$W = \int Fd_x \quad - - - 3.51$$

where x = deformation or deflection.

This is equal to the area under the f-d curve illustrated in fig 3.11.

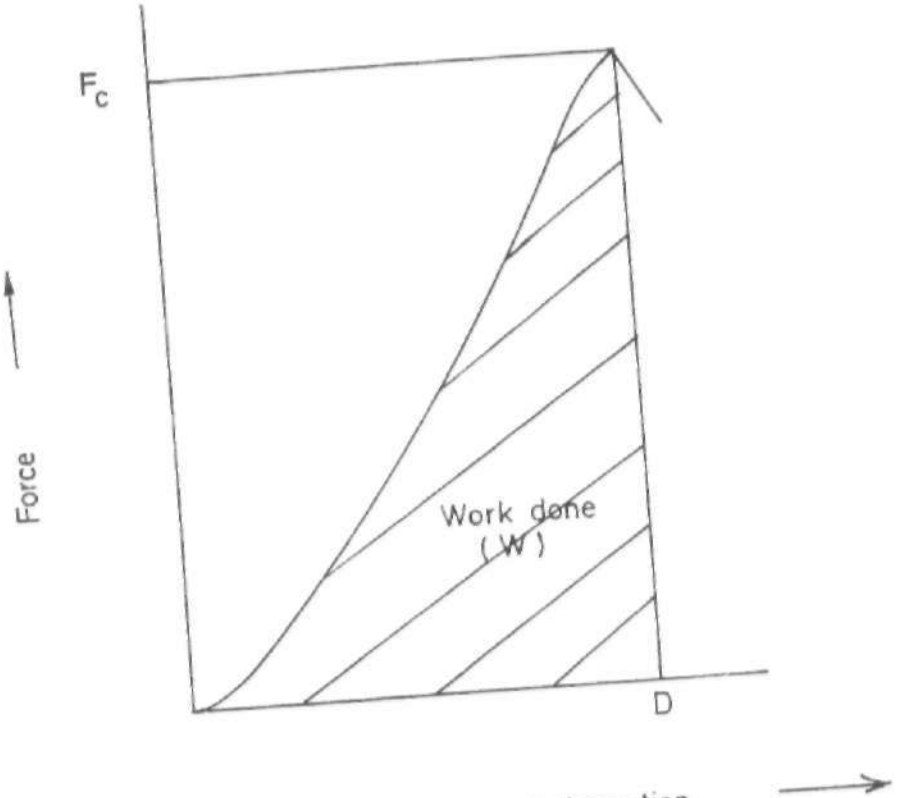


Fig. 3.11 F-d curve showing work done, W, as the (shaded) area under the curve

Chapter 4

MATERIALS AND METHODS

4.1 Introduction

The physical and mechanical properties of cowpea as related to mechanical whole shoot threshing were studied. Whole shoot threshing trials were carried out with a pod thresher which was finally redesigned to effectively handle the entire cowpea shoot. This chapter discusses the equipment, specimens and procedure used in the study.

The measurement of the physical properties of cowpea was limited to the grain size, pod pericarp (hull) thickness, moisture content of grain, pod and stalk, and the stalk diameter and length required for determination of the mechanical properties. The micrometer screw gauge and venier calipers were used for the dimensional measurements, and the moisture content was determined by by the oven dry method and expressed in % wet basis.

The mechanical properties of cowpea studied included; the stalk in radial compression, the stalk in simple bending, the minimum force of cracking of pod, and the uniaxial compression of the grain.

The Monsanto Tensometer W and the Instron, universal testing machines, were the main equipment used in the measurement of mechanical properties. In each measurement the force and deformation or deflection were recorded in graphic form by the instrument recorder.

The required mechanical properties were calculated using the equations discussed in Chapter 3.

The suitability of common varieties of cowpea to whole shoot threshing was studied. Experiment was conducted to study field shatter losses of three varieties, and seven varieties were tested for whole shoot threshing using the IAR pod thresher. Finally the pod thresher was redesigned to handle the entire shoot of cowpea.

4.2 Selection of Test Specimens

All cowpea samples used in this research were produced in the Ahmadu Bello University farm in Samaru, Zaria in 1986 and 1987 planting seasons. This was done to keep variations emanating from the soil type and cultural practices at minimum.

Sample selection was randomized all through the tests but care was taken to ensure that only good samples were used. This helped to eliminate variation that might be caused by defective samples.

All varieties of cowpea grown were given the same treatment. They were planted on ridges at 20cm spacing, two seeds per stand. The soil type was sandy loam and the soil characteristics are stated in Table B1, Appendix B. Single superphosphate fertilizer was applied during land preparation at the rate of 200kg/ha. The crop was manually weeded twice. It was protected from insect pests by the use of cymbush 10EC and dimethoate 40EC, and

against fungi by the application of Benlate using the knapsack sprayer. Spraying was frequent particularly from flowering, to ensure that the crop remained healthy until harvest.

Beside grain size measurement, all other measurements reported in this work made use of cowpea samples grown in 1987 planting season. The 1986 products were mainly used in preliminary studies which were very useful in the selection of varieties, proper timing of experiments at different moisture levels, and in instrumentation. The 1987 crops were planted between the 17th and 20th of July. And beside IT 82E- 60 (IT 60) which matured earlier, and the local white variety which matured later, all other varieties planted, matured in about 12 weeks.

Seven common cowpea varieties in Zaria locality were selected for the grain size measurement and threshing tests. These included; TVX 3236, Ife brown, IT81D -985 (IT 985), IT 60, Samaru 48, Samaru 341, and the local white variety. The seven varieties were chosen in order to cover the common grain sizes of cowpea in the locality. For the determination of the mechanical properties, the variety with the smallest grain size (TVX 3236), intermediate grain size (Ife brown) and largest grain size(IT 985) were used.

Specimens from mature crops were used in all the tests to eliminate developmental variations, and all stalk specimens were obtained from the main stalk of mature cowpea.

4.3 Selection of Moisture Content and Rate of Loading of Test Specimens

The grain size and pod pericarp thickness were measured at the equilibrium moisture content of dry cowpea grain and pod during the threshing period in Zaria which falls within the dry harmattan period of November and December. The moisture content ranged between 6.5-8% wb.

The moisture content of the stalk was monitored from harvest to observed the drying pattern. Three different moisture levels were then selected for determination of stalk mechanical properties. The moisture contents ranged from 60.5 - 70% wb for wet specimens, 20 - 23% for intermediate and 7 - 8% wb for the dry specimens.

The threshing tests were performed at low moisture contents to avoid clogging of the pod thresher used for the tests. The moistures ranged from 5 - 6% wb for stalk, 6.6 to 7.4% for the pod and 6.6 to 8% for grain. Such moisture were attainable by air drying during December harmattan in Zaria.

Mechanical properties were measured in three rates of loading which were the available cross-head speeds of the measuring instrument used. The speeds were 12.5mm/min, 25mm/min and 50mm/min. The instrument had no further speed reducers. Preliminary tests however indicated that the speeds were adequate.

4.4 Physical Properties

4.4.1 *Grain size and shape*

For the measurement of the grain size and pod pericarp (hull) thickness, 25mm micrometer screw gauge of 0.01mm accuracy was used. The grain size of seven varieties of cowpea were measured at between 6.5 - 8% moisture content wet basis. The varieties used were as follows: TVX 3236, Ife brown, IT 81D - 985 (IT 985), IT 60, Samaru 48, Samaru 341, and the local white variety.

One hundred grains were randomly selected from each variety and each grain was measured for the length, width and thickness as shown in Fig 3.8. The data collected were later analysed using the computer Statistical Package for the Social Sciences (SPSS)

programmes for the analyses of variance and Duncan's new multiple range test.

To determine the shape of cowpea grain, the grains of the seven varieties of cowpea mentioned above were compared with the existing geometrical shapes. The existing geometrical shape closest to the shape of the grains was chosen. This is necessary in order to facilitate the calculation of grain mechanical properties, basing the formulae on existing geometrical shape. The approximate shape of cowpea grains determined, was used to calculate the modulus of elasticity of the grain under uniaxial compression presented in Chapter 5.

4.4.2 Pod Pericarp (hull) Thickness

The 25mm micrometer screw gauge was used to measure the pod pericarp thickness. TVX 3236, Ife brown and IT 985 were used and 50 pods were randomly selected from each of the three varieties. Each of the pods was carefully broken by hand and the thickness of each hull or pericarp was measured close to the head (point of attachment to peduncle), mid region and tail or the apex. These measurements were taken at the pod moisture content of 6.9 to 7.3% wb, and grain moisture content of 7.2 to 7.3% wb.

4.4.3 Diameter and Length of Stalk

The diameter and the length of cowpea stalk prepared for mechanical property measurements, were determined using the 160mm venier calipers of 0.1 mm accuracy. Cowpea stalk dimensions were measured for the radial compression and bending. The details of these measurements will be given under mechanical properties.

4.4.4 Moisture Content of Grain, Pod and Stalk

The moisture content was determined by oven-dry method using American Society of Agricultural Engineers (ASAE) standard. Grains weighing 15g were heated in the oven at 103 $\pm$ 1°C for 72 hours. The grain was allowed to cool in a laboratory desicator and reweighed. All weighing was done with the electronic weighing balance (model Metler P.N:1210) of 0.01 g accuracy. The moisture content was calculated on wet basis.

The moisture content of the pods was determined in the same way by heating 25g of the pods in the oven maintained at 103°C $\pm$ 1°C for 72 hours. For the stalk, 25g was heated at 103°C $\pm$ 1°C for 24 hours (ASAE S358.1, ASAE 1983).

4.5 Mechanical Properties of Cowpea

4.5.1 Selection of Varieties and testing Instruments

Three varieties of cowpea were used for the determination of the mechanical properties. These were selected according to

grain size from the size measurement made in 1986. They include TVX 3236 (small grain), Ife brown (medium-sized grain) and IT 985 (large grain). The grains are shown in plate II.

Two universal testing instruments shown in plates III and IV were used for the determination of the mechanical properties of cowpea. The Instron universal testing machine available had no speed reducers. Its minimum speed of 50mm/min was too high for the measurement of force and deformation of such agricultural products as stalk and grains (Saxena 1972, Anazodo 1980, ASAE 1983). This limited its use in the experiments. The Monsanto universal testing machine was mainly used. However, owing to its very high sensitivity at low load levels, the Instron machine was still used to measure the minimum cracking force of pods and to cross-check the accuracy of the Monsanto instrument in the measurement of the grain crushing force.

The Monsanto universal testing machine (Monsanto Tensometer W) is a highly sensitive motorized tensometer with both manual and automatic recorders. Basically it operates at three cross-head speeds: 50mm/min, 25mm/min and 12.5mm/min. The motor speed alteration is effected by the change of vee belt on a three-step pulley fitted to the motor shaft. A steady speed is then transmitted to the crosshead of the tensometer. Further reductions in the crosshead speed is possible by the use of the countershaft assemblies which are additional machine accessories. This was however not available during the tests. During operation a motor driven gear box of high mechanical advantage applies a force,

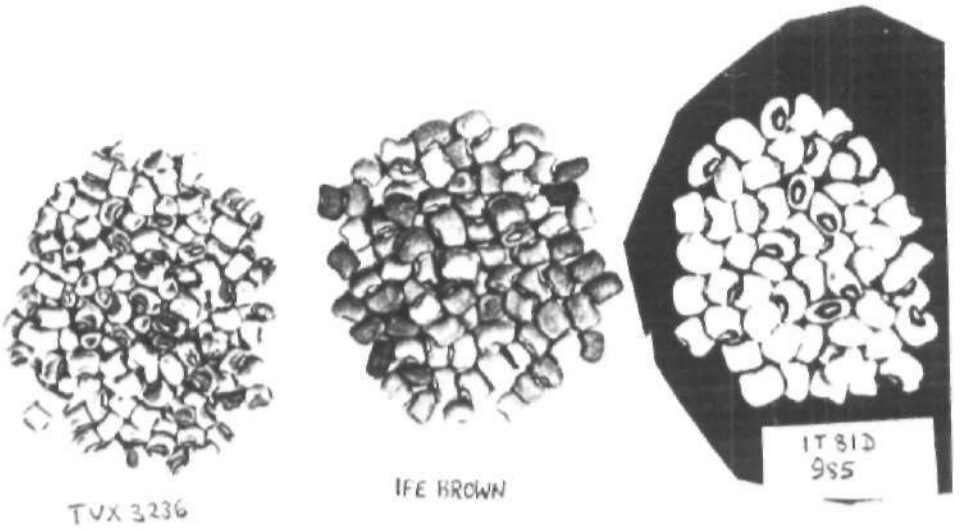


Plate II - Grains of the three varieties of cowpea selected for mechanical tests

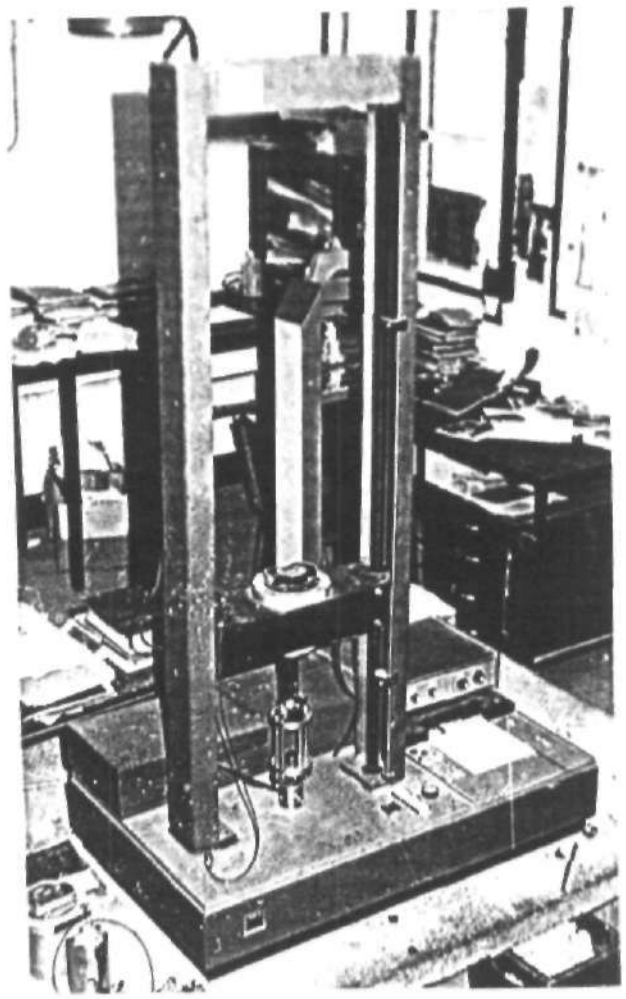


Plate III - Instron universal testing machine, table model

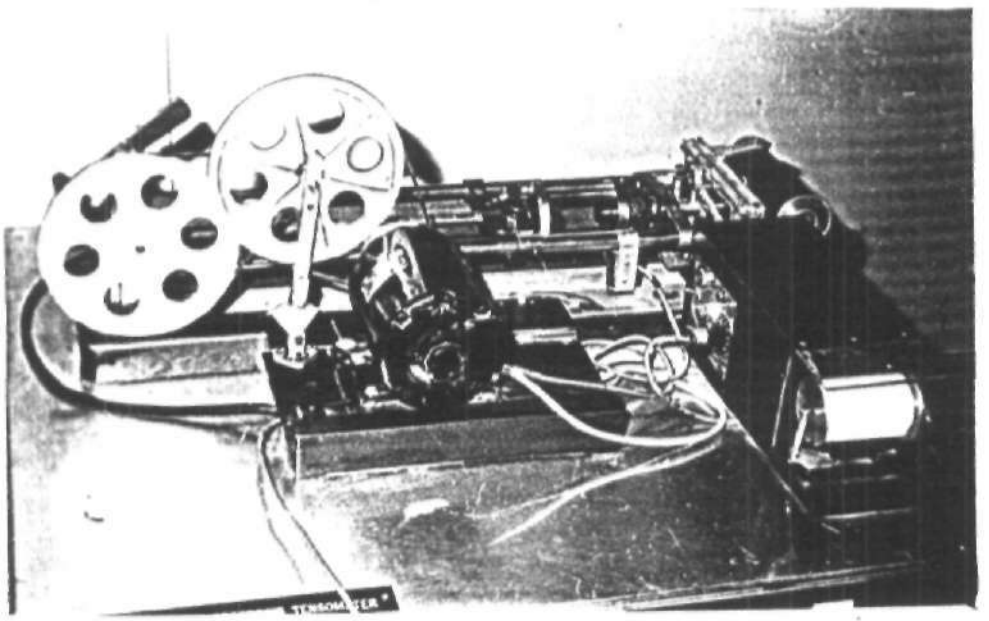


Plate IV - Monsanto Tensometer W, universal testing machine

ranging from 75N to 20kN to a test piece held in the chucks. The force set up deflects the spring beam. Direct magnification of this deflection causes a heated stylus to draw a graph on a heat sensitive paper. The force-deformation graph drawn can be read by overlaying the transparent plastic scales shown in Appendix C on the graphs.

Available magnifications of the spring beam deflection are 16:1, 8:1, 4:1, 2:1 and 1:1.
The machine is compact with overall dimensions of approximately 965mm X 235mm X 230mm and a weight of 21kg. It is versatile and accurate with very high cost/performance rating.

To operate the machine, the correct attachment is fitted. A suitable spring beam (load) is chosen and fitted. The required crosshead speed is selected by changing the vee belt on the three-step pulley. A suitable chart/crosshead speed ratio is chosen by changing the chart speed gears. The chart paper is fitted. The pen heater is switched on. The crosshead limit switches are adjusted to limit the excessive movement of the crosshead. The test sample is placed on the attachment. The pen is lowered and the crosshead switch is turned on to forward. When the sample fails the crosshead switch is turned off. Otherwise the limit switches will stop the crosshead from further movement.

4.5.2 Radial Compression Tests of Cowpea Stalk

Radial compression of stalk was carried out with the Monsanto Tensometer W motorized universal testing machine. The varieties

TVX 3236, Ife brown and IT 985 were tested at three moisture levels three loading rates and three replications. Eighty-one samples were crushed altogether; 27 of each variety, 9 of which were tested at each crosshead speed.

The test was performed with a maximum load of 300N for wet and 600N for dry stalks and the chart-crosshead speed ratio of 8:1. The chart speed ratio and the maximum force were chosen from 1986 preliminary tests.

The crushing force and deformation were obtained from the force-deformation curve drawn by the automatic recorder. Preliminary test in 1986 had shown that a sample length of 20mm was adequate for the test. This length could be conveniently cut from some internodes of cowpea varieties used and also could fit the 25mm compression surfaces of the testing machine (plate V). All samples were of about 20mm long and were cut from the internode of the main stalk of the cowpea at a given moisture content. The first crushing test was performed about 14 hours after harvest. The harvested stalks were spread on a secure wire-netted house corridor; and the samples for test were taken at two intervals of time. The test dates were 28th of October, 2nd of November and the 12th of November, 1987.

The cutting of the specimens was very carefully done. Using a sharp knife the cutting was performed with moderate pressure round the stalk working towards the pith until the stalk was completely cut. This was to avoid end cracks. Specimens were cut and measured just before the tests. The average diameter

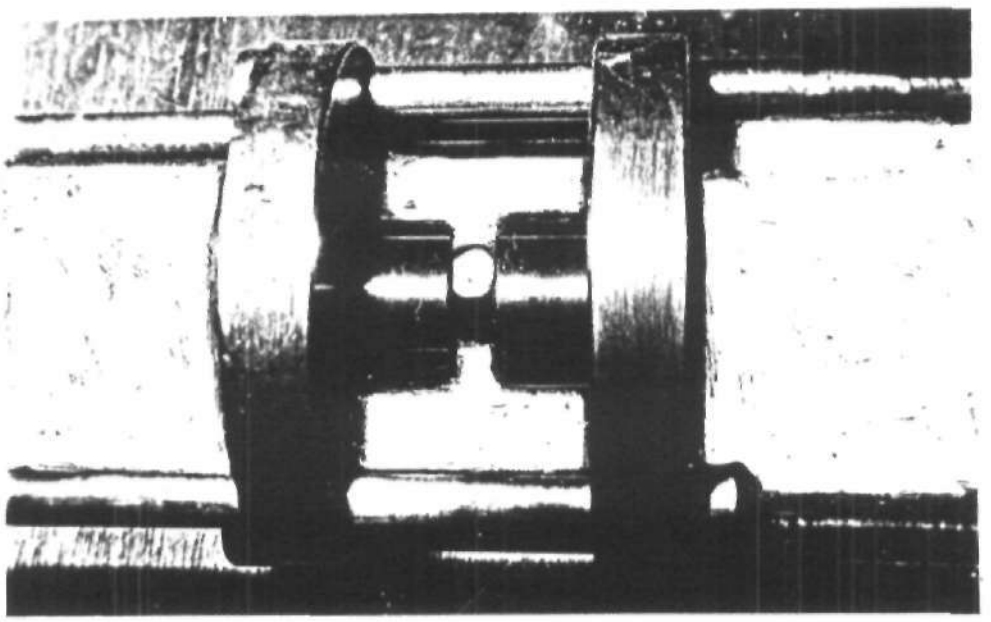


Plate V - Radial compression of cowpea stalk

of the specimens were measured by taking four measurements near each end of the sample. Two measurements were taken at a plane with one taken at a perpendicular direction to the other using the 160mm venier calipers of 0.1mm accuracy. In addition, the exact length of the sample was measured. The moisture content of each set of specimens was measured during the testing period by oven-dry method using 25g of the stalk. The moisture contents of each variety at different test dates were as follows:

Table 4.1: Variety moisture content at each test date of cowpea Stalk in radial compression

	Moisture content % wet basis		
	Test dates		
Variety	28/10/87	2/11/87	12/11/87
TVX 3236	61.2	19.5	7.6
Ife brown	61.7	20.1	7.9
IT 985	60.6	20.0	8.3
Mean	61.2	19.9	7.93
S.D.	0.551	0.321	0.351

TVX 3236 lost moisture faster than Ife brown and IT 985. In order to maintain the same test dates and similar moisture content, TVX 3236 was harvested in two batches. One was harvested on the 27/10/87 with other varieties and tested on the 28/10/87. The second batch of TVX 3236 was harvested two days later on the 29/10/87 and kept in the shade of the house corridor. This second batch was tested on the test dates with Ife brown and IT 985

harvested 2 days before (27/10/87). The drying pattern of these stalks were studied in 1986 harvesting season and the same pattern was again observed in 1987.

During each test, loading and unloading experiment was performed for each variety and moisture content in order to determine the degree of elasticity of the trial specimens.

4.5.3 Test of Stalk in Simple Bending

Tests in simple bending were carried out with Ife brown variety. Ife brown was chosen because the dry stalk was more woody than the other two varieties. And the internode at the main stalk was long enough for cutting of 60mm stalk for the bending tests. The stalk was cut as in the crushing test. The diameter of the stalk sample was calculated from four measurements as in crushing test but in addition, the pith diameter was also measured from both ends of the stalk using venier calipers.

The Monsanto Tensometer W was used to measure the force and deflection in simple bending. The stalk sample was simply supported by two steel plates mounted as shown in Plate VI . The bending force was applied using 5mm diameter steel rod. The supports were positioned 50mm apart so that the span of the stalk under bending was 50mm long. The plates were held in position with a thick sellotape. The bending test was carried out at three moisture levels and three rates of loading allowing three replications in each case. The moisture contents were 70%, 22.5% and 7.88% wb, and the rates of loading were 12.5mm/min, 25mm/min and

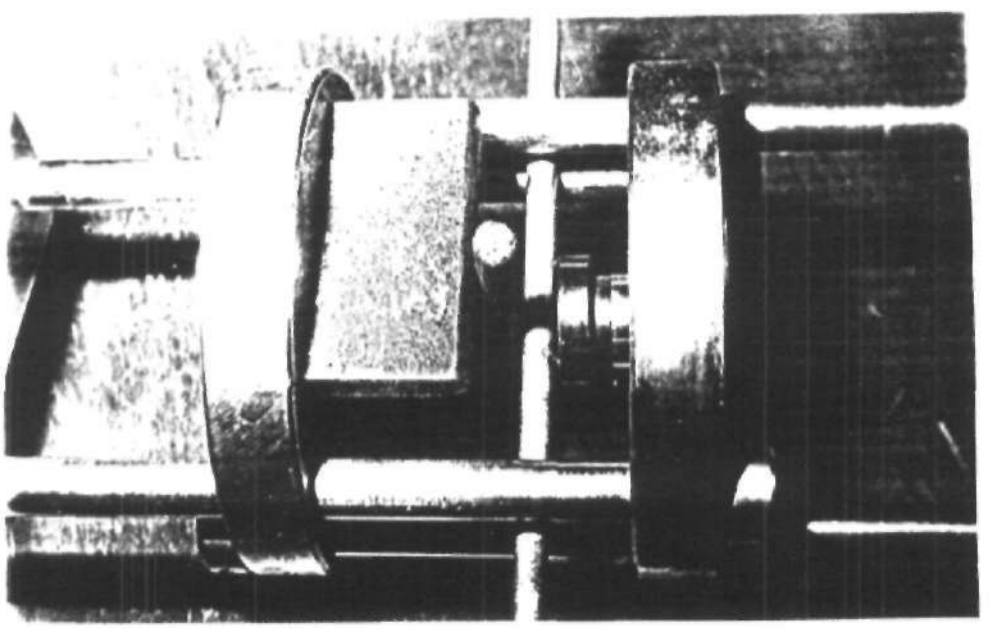


Plate VI -- Bending of cowpea stalk

50mm/min.

The maximum load used in the Tensometer was 300N and the chart speed ratio was 8:1. The tests were carried out on the 4th, 9th and 19th November, 1987. The stalks for the test were harvested on the 4/11/87 and kept on the house corridor to dry. Test samples were taken on the test dates.

On each test date, loading and unloading trials were performed in order to determine the degree of elasticity of the test specimens.

4.5.4 Measurement of Minimum Cracking Force of Pods

Instron 1026 table model (Plate III) was used for this test. The Instron machine had no accessories for speed reduction and compression. Hence the experiment was performed at the least obtainable crosshead speed of 50mm/min. Instron is preferred in this experiment because the instrument can measure very low forces required to crack the pods with good accuracy. Preliminary tests had shown that the force required to break the pods was very small.

The compression gadget of the Monsanto Tensometer was used for the measurement. The gadget was connected to the Instron by the use of two adapters (shown in Fig 4.1) constructed with steel rods to exactly fit the upper and lower chucks.

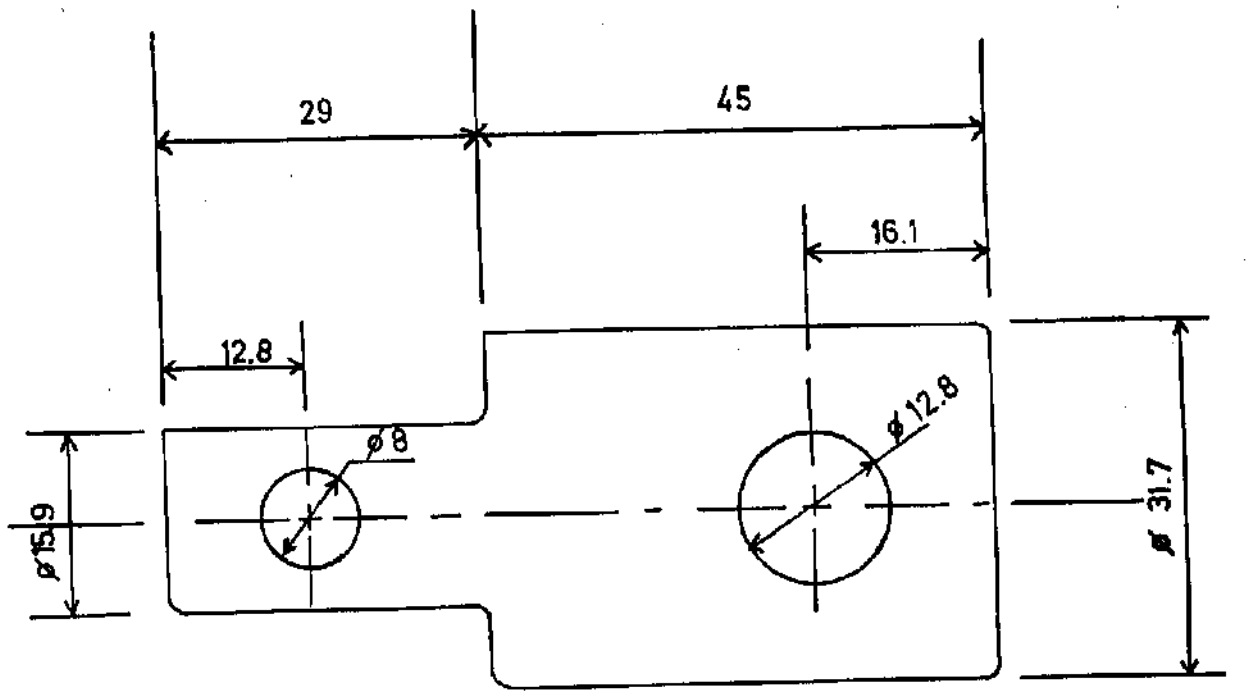


Fig. 4.1 Drawing of the adapters for the compression unit used in Instron machine. (A) Lower adapter (B) Upper adapter

To prepare the machine for operation, a load cell of 50kg was installed and the compression gadget was fitted. The recorder pen was zeroed using the push button and the cell was carefully balanced and calibrated using a 5kg weight. The calibration was done with the load selector switch at 5kg and load cell carefully balanced at the zero point, 5kg weight was put on the load sensitive table. The calibration control was adjusted until the recorder pen was at the extreme end of the chart. Then 4:1 chart speed ratio was selected.

During testing the pod was carefully inserted with the mid section between the two compression plates in such a way that the pod sutures were vertical (plate VII). The pen and crosshead switch was then turned off. The minimum cracking forces of the pods were read from the strip chart drawn by the Instron recorder on a roll of graph paper.

This measurement was done for the three varieties of cowpea (TVX 3236, Ife brown and IT 985) at two levels of moisture. Because the pods could only crack at low moisture contents, the difference in the two ranges of moisture (maximum 9.30%, minimum 6.98% wb) was small.

4.3.5 Uniaxial Compression of Grain

The uniaxial compression tests were performed using the Monsanto Tensometer W with 300N maximum load and 16:1 chart speed ratio. The tests were performed with three varieties of cowpea at the grain moisture content of 7 – % and three rates of

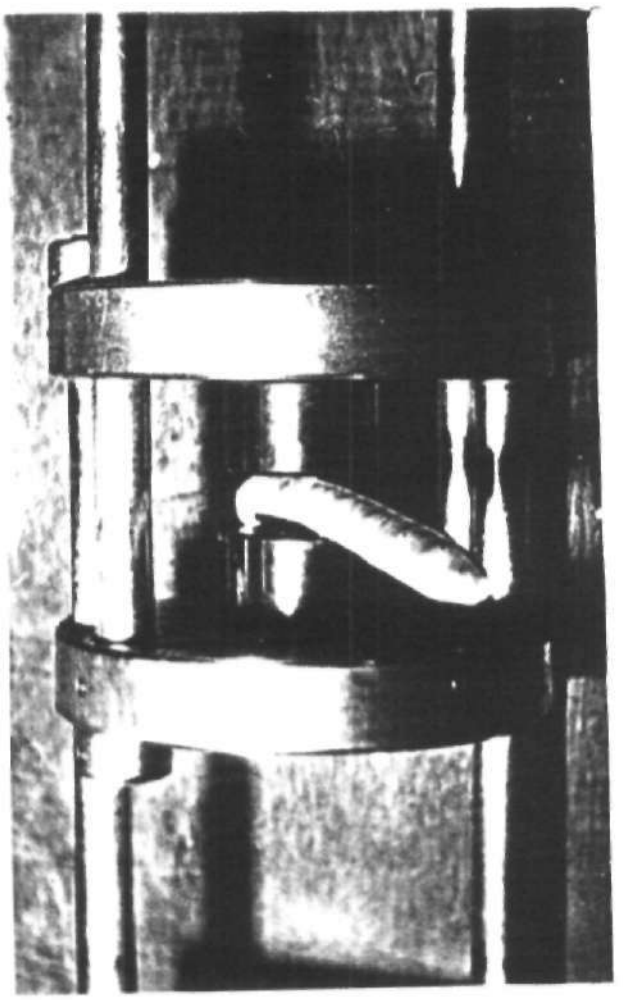


Plate VII - Pod between two compression plates for measurement of minimum cracking force

Loading (12.5, 25 and 50mm/min).

Grains for the crushing tests were hand-shelled and randomly selected from healthy pods. After the random selection they were finally examined with the hand lens to ensure that they had no cracks. Their length, width and thickness were then measured with the micrometer screw gauge.

During the test, the grain was held between the compression plates with a pair of forceps until the compression began. The machine was switched off when the grain cracked. The compression was in the natural rest position of the grain on the long axis with the hilum on the side as shown in Fig 4.2. Four grains were tested from each variety at each rate of loading. Hence a total of 12 tests were conducted for each variety and there were 36 tests in all.

During the 1986 preliminary tests, readings obtained with the Monsanto Tensometer W at 50mm/min cross-head speed, was cross-checked with the Instron Machine. This was necessary because grains required small force to crack, and the Instron machine is highly sensitive at low loads. The accuracy of the Monsanto Tensometer W was found to be adequate.

4.5.6 Laboratory Environment During Mechanical Tests

A wet-and-dry bulb thermometer was used to monitor the temperature and relative humidity of the laboratory during the mechanical tests. The temperature of the laboratory ranged between 24 - 27^{o}C and the relative humidity between 27 - 48%.

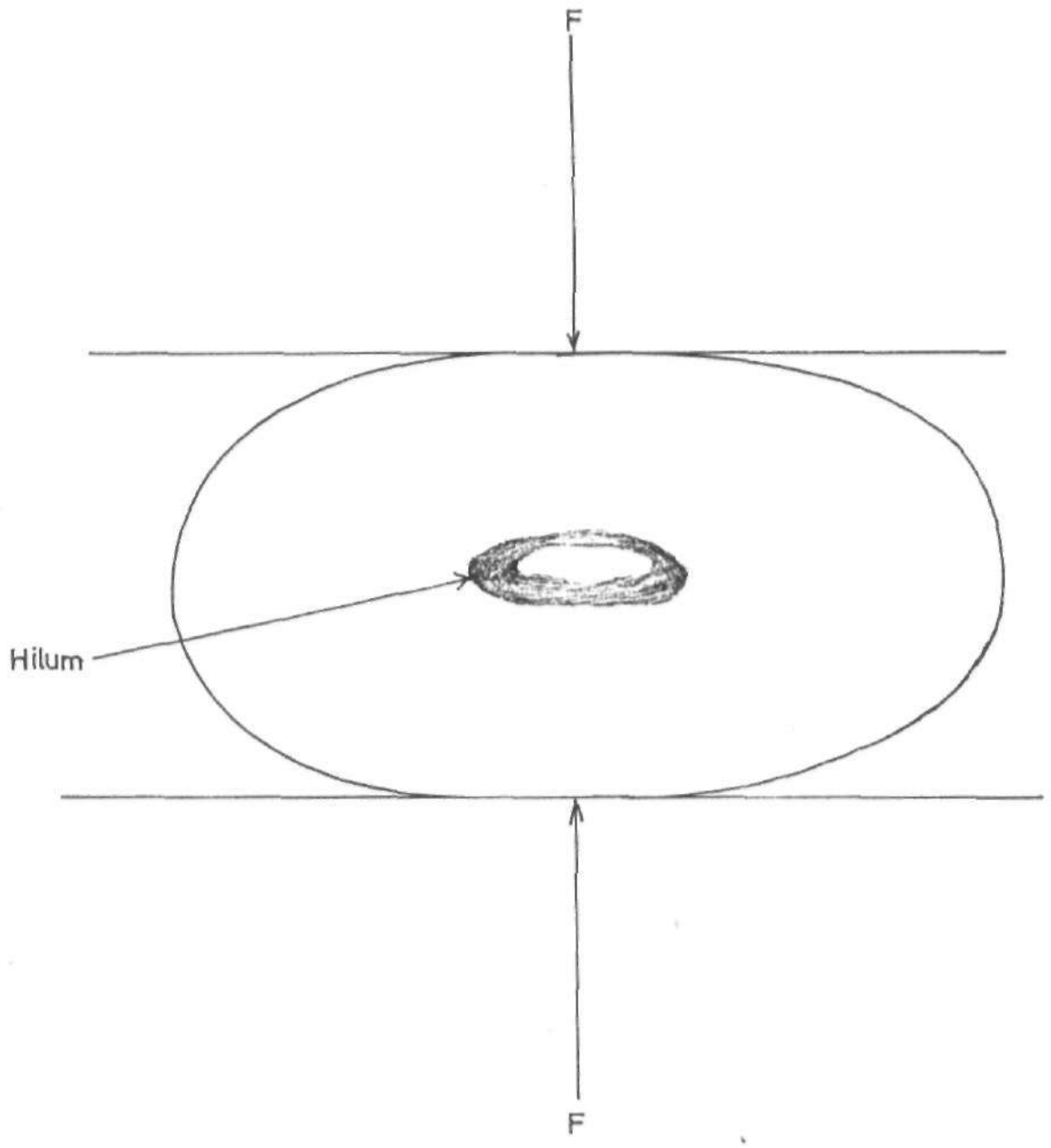


Fig. 4.2 Compressive test position of grain

4.5.7 Analyses of Data in Mechanical Property Measurement

Mechanical properties like stress and modulus of elasticity of the test specimens were calculated from the measured force and deformation/deflection and the dimensions of the specimens for various experiments using the computer Microstat Package programmes. Also the linear regression, analyses of variance and Duncan's new multiple range test were done where necessary with the computer. Sample calculations of the mechanical properties are presented in Chapter 5.

4.6 Whole Shoot Threshing Trials

4.6.1 Test Thresher

IAR cowpea pod thresher designed in the Agricultural Engineering Department of Ahmadu Bello University was used for the tests. Its cylinder contained 16mm long, 16mm diameter cylindrical spikes made from hot-rolled steel rods. The cylinder was made up of six spike bars, each containing 16 spikes in two staggered rows of eight per row. The machine was also provided with a blower. Both the blower and the cylinder were powered with 1.49 kW electric motor which transmitted average speeds of 320 rpm and 470 rpm to the cylinder and fan spindles respectively, at no load using "v" belts and pulleys. The thresher is shown in Plate VIII and its specifications is given in Table 4.2. The frame was made of welded 38.2 x 38.2 x 4mm mild steel angle iron.

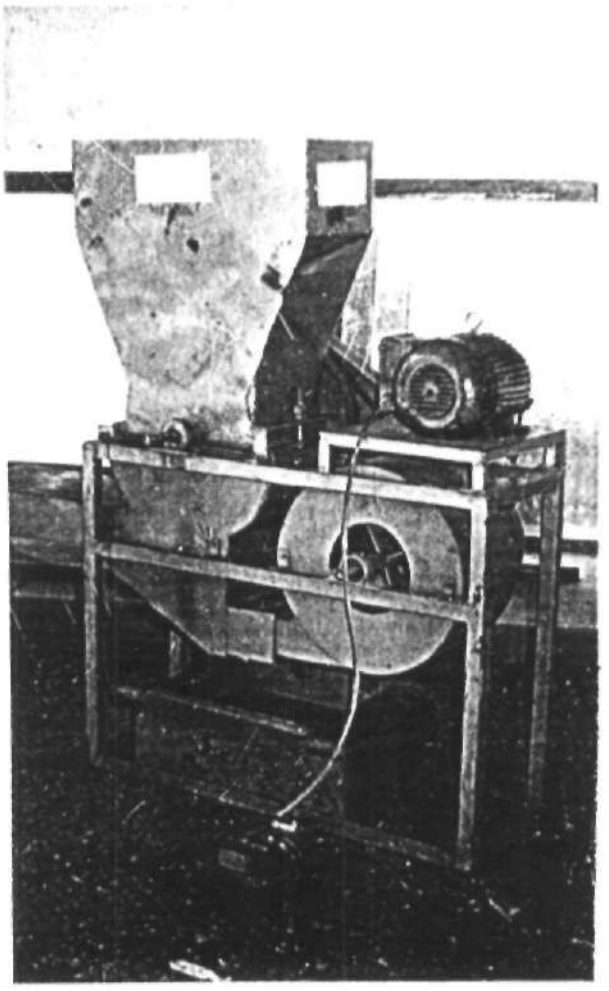


Plate VIII - IAR cowpea pod thresher

Table 4.2 contd.

Item	Specification
Concave grate	Circular holes 2.5mm apart, 2 sizes: 8 and 10mm dia
Fan housing	Circular
Fan blade	Straight type, rectangular 200 x 156mm, 4 in number
Fan diameter	438 mm
Fan speed	647 m/min (470 rpm)
Air channel	Rectangular, 275 x 80mm
Sieve	Circular holes, 2.5mm apart; 2 sizes: 8 and 10mm dia
Driving power	1.49kW (2 hp) electric motor
Motor shaft speed	1490 rpm
Main drive pulley	87mm dia
Fan pulley	275mm dia
Cylinder drive pulley	131 mm dia
Cylinder pulley	195 mm dia

The hopper, lower cylinder housing, chaff chute, grain chute and fan housing were made of 1.5mm hot-rolled flat steel. The blower or fan housing was circular with a rectangular horizontal air discharge duct positioned at its lower part. A centrally mounted fan rotated freely in the housing on 24mm diameter shaft made of hot-rolled iron rod. The fan was made up of four straight rectangular fan blades constructed from 1.5mm flat steel and bolted on 25 x 4mm steel bar supports. Beside the concave grate, the thresher had a sieve positioned on the grain pan.

Although there was no recorded evaluation of its performance, the IAR cowpea pod thresher was a popular machine for threshing cowpea pods around Zaria. The thresher was so effective that it was being constructed in the Department of Agricultural Engineering Workshop for sale to farmers. But the harvest problem still remained since the farmers had to pick the pods from their farms before threshing. It was on this basis that the thresher was selected for whole shoot threshing trials, and subsequent modification.

4.6.2 Test Specimens and Procedure

Whole shoot threshing trials of cowpea was performed using seven varieties at the stalk, pod and grain moisture content shown in Table 4.3.

Table 4.3 Variety and moisture content of specimens for whole shoot threshing trials

Variety	Stalk	Pod	Grain
TVX 3236	5.90	6.74	7.14
Ife brown	5.40	6.60	6.59
IT 985	5.63	6.81	6.72
IT 60	5.11	7.09	6.75
Samaru 48	5.05	7.35	8.05
Samaru 341	5.39	6.91	6.77
Local White	5.70	6.90	6.67
Mean	5.45	6.91	6.96
S.D.	0.311	0.245	0.513

During the tests 10kg of material (stalk and pods) were fed gradually into the running machine until the grains ceased to drop. The time taken for the operation was recorded with a stopwatch. The weight of threshed grains, chaff in grain, unthreshed grain, damaged grain and the remaining residue in the machine concave were recorded. From these, the feed rate, thresher through-put, threshed grain, kg/min, % chaff in grain were calculated using the formulae discussed in Chapter 3.

When the machine stopped before the end of the trial as happened with some varieties, the time of operation was noted. The remaining materials were weighed. The materials obtained from the machine were fed back after weighing.

The machine was run until no grain dropped. The residue was then collected and weighed. Before the operation, a tachometer was used to measure the speeds of the motor, fan and cylinder shafts at no load.

A germination test was carried out with the grains to determine the percentage internal damage. A hundred grains were randomly selected from each of the seven varieties. The grains were examined with a hand lens to ensure that they were healthy and without external cracks or bruises. They were then sowed in well-prepared regularly moistened flat seed-beds. After two weeks the sprouted seedlings of each variety were counted. The seeds which apparently failed to sprout were dug out and examined. Those starting to germinate were counted among the germinated seeds. The number of seeds that failed to germinate out of the hundred, was taken as the percentage damaged internally.

The performance of the IAR pod thresher during these trial tests and the determined physical and mechanical properties of cowpea, formed the basis for the redesign of the machine presented in Chapter 5.

Chapter 5

RESULTS AND DISCUSSION

5.1 Introduction

The results of the experiments reported in Chapter 4 are presented and discussed in this Chapter. The presentation of the results is mainly in tabular form, with some graphic and pictorial illustrations. The mechanical properties and threshing parameters discussed here, were calculated by the application of the mathematical formulae presented under Theoretical Considerations in Chapter 3. In all cases, statistical analyses were applied to evaluate the results.

Some properties of the studied cowpea varieties that are related to whole shoot threshing are summaried and the characteristics of cowpea variety suitable for mechanization generally discussed. Finally the redesign of the I A R pod thresher to adapt it to whole shoot threshing, is presented and discussed.

5.2 Physical Properties

The size measurement of cowpea grain and pod pericarp thickness are summarized in Tables 5.1 to 5.4.

5.2.1 Kernel Size Measurements

Table 5.1 shows the average kernel size measurements for seven varieties of cowpea. The variation in the kernel size was

Table 5.1: Average measurements of kernel size of seven varieties of cowpea

Variety	Dimensions+ (mm)	Mean	S.D.	Range	95% conf. int. for mean
TVX 3236	Length	6.36	0.427	5.50-7.58	6.28-6.45
	Width	5.24	0.327	4.46-6.97	5.18-5.31
	Thickness	4.00	0.254	3.31-4.60	3.95-4.05
Samaru 341	Length	7.69	0.793	6.16-9.92	7.53-7.84
	Width	6.02	0.574	4.81-7.84	5.90-6.13
	Thickness	4.30	0.375	3.24-5.11	4.22-4.37
Ife brown	Length	7.90	0.902	6.38-10.2	7.60-8.10
	Width	6.06	0.462	4.74-7.03	5.97-6.15
	Thickness	4.44	0.381	3.33-5.38	4.30-4.52
IT 60	Length	8.14	0.909	5.29-10.4	7.96-8.32
	Width	6.19	0.568	4.76-7.78	6.08-6.31
	Thickness	4.85	0.407	3.73-5.58	4.76-4.93
Samaru 48	Length	8.49	0.846	7.21-11.7	8.33-8.66
	Width	6.69	0.440	5.75-7.86	6.60-6.77
	Thickness	4.21	0.386	3.34-5.08	4.14-4.29
Local White	Length	9.08	0.806	7.24-11.1	8.92-9.24
	Width	7.44	0.620	5.62-9.06	7.32-7.57
	Thickness	5.82	0.612	4.07-7.22	5.70-5.95
IT 985	Length	9.18	0.698	7.45-10.8	9.04-9.31
	Width	7.39	0.425	5.85-8.58	7.31-7.48
	Thickness	5.42	0.366	4.09-6.25	5.34-5.49

+Number of measurements per dimension per variety = 100

Total number of measurements per dimension = 700

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very highly significant (at 0.0001 level) in all varieties as indicated in Table 5.2.

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The 95% confidence interval for the mean which gives the size interval that will allow about 95% of the grains to pass through a sieve without damage is shown in Table 5.1. The IT 985 and the local white varieties which gave the highest values of interval 9.04 - 9.31 and 8.92 - 9.24 respectively, were among the largest size of cowpea grains being cultivated in the country. It therefore becomes reasonable to limit the thresher concave sieve size to 10mm for the varieties with large grains and 7mm for the varieties with small grains.

The shape of cowpea grain was determined in this study by approximating it to an existing geometrical shape (as discussed in Chapter 4). The grains of many varieties of cowpea were found to be approximately ellipsoidal in shape. Holes on the sieves should be elliptical, or for easy construction, circular.

The Duncan's new multiple range test (Table 5.3) grouped the seven cowpea varieties into five according to their grain size. This grouping aided the selection of the three varieties used for mechanical tests. The Table shows that the difference in the sizes in the same grouping, is not significant at 0.05 level, which indicates that the same thresher sieves will be adequate for the grains of the same grouping.

Table 5.2: Summary of the analyses of variance of kernel size[+]

Source of variation	Degree of freedom	F ratio		
		Length	Width	Thickness
Total	699			
Variety	6	133.07****	255.55****	273.86****
Residue	693			

[+]Analyses of variance performed on mean measurements (on Table 5.1) from 100 test samples of cowpea kernel from 7 varieties of cowpea.

**** Significant at 0.0001 level.

Table 5.3: Main effect of variety on cowpea kernel size[+]

Variety	Length	Width	Thickness
TVX 3236	6.36 a	5.24 a	4.00 a
Samaru 341	7.69 b	6.02 b	4.30 b
Ife brown	7.90 b	6.06 bc	4.44 c
IT 60	8.14 c	6.19 c	4.85 d
Samaru 48	8.49 d	6.69 d	4.21 b
Local white	9.08 e	7.44 e	5.82 e
IT 985	9.18 e	7.39 e	5.42 e

[+]Each value is a mean of 100 measurements

In each column, mean values with the same letter are not significantly different at 0.05 level as determined by Ducan's new multiple range test.

5.2.2 Pod Pericarp Thickness

Table 5.4 shows the average pod pericarp (hull) thickness for three varieties of cowpea. Analysis of variance showed that the difference in pericarp thickness in the different varieties is very highly significant. It was observed that the pericarp thickness was closely related to the shatter losses in the field. Cowpea with very thin pod pericarp, easily shattered at high sunshine when dry, while those with thick pericarp (such as IT 985) did not shatter in the field (see Table 5.5). It will be shown that the pericarp thickness is also closely related to the minimum force required to crack the pods during threshing.

5.3 Mechanical Properties of Cowpea

Measurements of the mechanical properties of cowpea are summarized in Tables 5.6 to 5.19. In each case the force and deformation/deflection were measured directly with instruments as described in Chapter 4. The Poisson's ratios were estimated. The degrees of elasticity, strain, stresses and elastic moduli were determined for various experiments following the theoretical considerations presented in Chapter 3. The calculation procedures for some of the mechanical properties are illustrated in Appendix G.

Table 5.4: Average pod pericarp thickness for three varieties of cowpea

Variety	Pod pericarp thickness, mm			No. of cases
	Mean	S.D.	Range	
TVX 3236	0.346	0.158	0.11 - 0.97	150
Ife brown	0.425	0.265	0.11 - 1.19	150
IT 985	0.824	0.231	0.35 - 1.42	150
Entire pop.	0.532	0.292	0.11 - 1.42	450

Table 5.5: Percentage field shatter losses of three varieties of cowpea

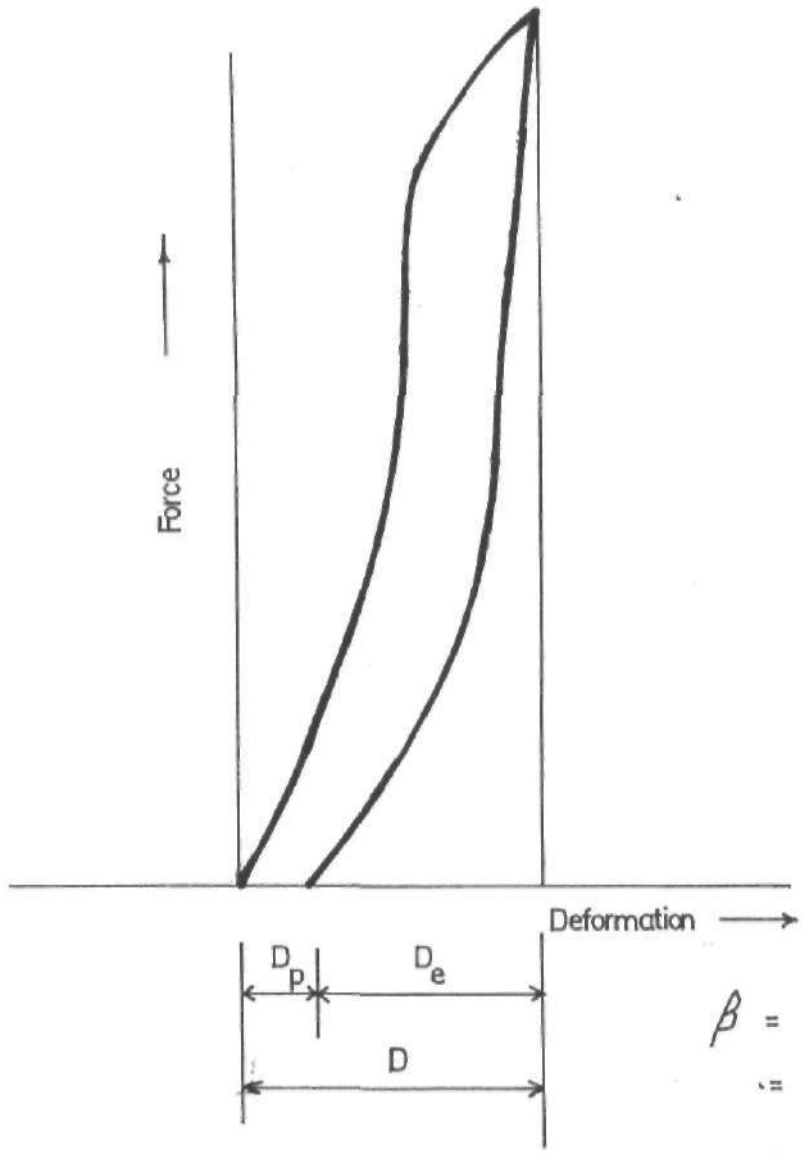
Variety	Moisture content, %, wb.		Shatter losses,* %
	Pod	Grain	
TVX 3236	6.70	6.81	31
Ife brown	6.67	6.63	18
IT 985	6.80	6.70	NIL

* These losses occurred by natural shatter of the pods, no handling.

5.3.1 Determination of Degree of Elasticity, β and Poisson's Ratio, μ, of Cowpea Stalk and Grain

The degree of elasticity, was determined from loading and unloading tests performed for each specimen variety and moisture content. The degree of elasticity was calculated as illustrated in Fig 3.2. An experimental sample graph for determination of degree of elasticity of cowpea stalk in radial compression is shown in Fig 5.1.

The moisture content and variety were the two most important factors affecting the degree of elasticity, with the moisture content having greater influence. Hence different values were obtained for different varieties at different moisture levels for the cowpea stalk. But for the grains which were approximately at the same moisture level, the degree of elasticity of 50% was obtained.



$$\beta = 100\ D_e / D$$
$$= \frac{100 \times 3.12}{4}$$
$$= 78\ \%$$

Fig. 5.1 TYPICAL EXPERIMENTAL LOADING AND UNLOADING CURVE FOR DETERMINATION OF DEGREE OF ELASTICITY OF COWPEA STALK IN RADIAL COMPRESSION.
Variety = IT 985 MC; ∠ 10 % wb

The determination of the Poisson's ratio of biomaterials is usually very involving. Trials with available instruments did not yield acceptable results. In the absence of adequate instrumentation, it was decided to choose appropriate values of Poisson's ratios for this work considering the values for similar materials recorded in literature. Consequently a Poisson's ratio of 0.39 was chosen for stalk in radial compression and 0.35 for grain in uniaxial compression. The chosen Poisson's ratio of cowpea stalk falls within 0.3 - 0.5 which is the range of Poisson's ratio for wood (Mohsenin, 1970). The Poisson's ratio of maize stalk was given as 0.34 (Prince and Bradway, 1959) and maize cob 0.35 (Amazodo and Chikwendu, 1983). The chosen value is reasonable since cowpea stalk has less air spaces than the maize stalk and cob.

For grain, Mohsenin (1970) gave the Poisson's ratio of maize as 0.32. Misra and Young (1981) assumed a Poisson's ratio of 0.4 for soyabean grain based on the fact that the elastic modulus calculated would change by only about $\pm$ 10% if the Poisson's ratio varied from 0.25 to 0.49 which is the range of Poisson's ratio for the agricultural products (Mohsenin, 1970).

5.3.2 Mechanical Properties of Cowpea Stalk in Radial Compression

Tables 5.6, 5.7 and 5.8 show the mechanical properties of three varieties of cowpea stalk in radial compression at three loading rates (crosshead speeds) and three moisture levels.

From Table 5.8 the mean crushing strain of cowpea stalk was obtained as 0.099 (S.D. 0.024), mean elastic modulus as 30.4 MPa (S.D. 4.93) and crushing strength as 5.10 MPa (S.D. 1.15), at 7.9% MC, wb and 25mm/min rate of loading.

The Tables show the effect of the variety, moisture and rate of loading on the mechanical properties. The analyses of variance summarized in Table 5.9, indicate that the difference in crushing strain in different varieties was significant at 0.01 level while the differences in elastic modulus and crushing strength were not significant. Variations caused by the moisture content was significant at 0.05 level with the crushing strain and elastic modulus and at 0.01 level with the crushing strength. While variations by the rate of loading was significant at 0.05 level with the elastic modulus and at 0.01 level with the crushing strength but insignificant with the crushing strain. The interaction between the moisture content and the rate of loading is significant at 0.01 level with the crushing strain and crushing strength.

Table 5.6: Mechanical properties of three varieties of cowpea stalk in radial compression at three loading rates and 61.2% moisture content, wet basis+

Loading rate, mm/min	Variety	Measurement: Stalk dia., 2R, mm		Crushing force, F_c, N		Crushing Strain, ε_c		Elastic modulus, E, MPa		Crushing Strength, σ_c, MPa	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D
12.5	TVX 3236	6.78	1.05	99.5	22.5	0.10	0.03	19.4	3.33	3.21	0.251
	Ife brown	7.66	0.308	67.3	18.1	0.068	0.006	18.9	6.80	2.51	0.821
	IT 985	9.43	0.855	69.2	17.8	0.054	0.002	20.7	5.07	2.36	0.513
	Entire pop.	7.96	1.36	78.6	23.1	0.074	0.026	19.7	4.62	2.69	0.634
25	TVX 3236	6.63	1.54	82.7	54.2	0.097	0.015	15.2	4.94	2.54	0.966
	Ife brown	8.82	1.99	102	36.6	0.079	0.006	19.6	0.70	2.86	0.053
	IT 985	9.47	1.20	82.3	38.7	0.070	0.016	17.5	5.88	2.57	1.13
	Entire pop.	8.30	1.88	89	39.2	0.082	0.017	17.4	4.30	2.59	0.774
50	TVX 3236	6.55	0.804	111	8.74	0.115	0.017	19.1	2.95	3.49	.225
	Ife brown	8.95	1.45	83.7	34.1	0.080	0.015	16.5	6.84	2.48	1.20
	IT 985	9.14	0.656	90	8.23	0.062	0.008	23.5	6.56	2.89	0.576
	Entire pop.	8.21	1.54	95	22.0	0.086	0.026	19.7	5.81	2.95	0.804

+ Each value is a mean of three tests. There are nine tests per population.

Table 5.7: Mechanical properties of three varieties of cowpea stalk in radial compression at three loading rates and 19.9% moisture content wet basis+

Loading rate, mm/min	Variety	Measurement									
		Stalk dia., 2R, mm		Crushing force, F_c, N		Crushing strain, ε_c		Elastic modulus, E, MPa		Crushing Strength, σ_c, MPa	
		Mean	S.D	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
12.5	TVX 3236	6.58	1.09	101	6.81	0.01	0.014	20.3	2.17	3.42	0.128
	Ife brown	8.50	0.265	98.0	12.4	0.088	0.006	17.9	1.37	2.62	0.543
	IT 985	7.50	0.872	80.5	17.4	0.072	0.009	21.3	3.75	2.94	0.70
	Entire pop.	7.53	1.09	93.3	14.8	0.087	0.015	19.8	2.74	2.99	0.568
25	TVX 3236	6.60	0.361	125	12.0	0.099	0.016	25.6	4.05	4.24	0.231
	Ife brown	8.72	0.416	137	10.0	0.087	0.014	24.0	3.33	3.69	0.208
	IT 985	7.53	0.751	97.2	9.57	0.087	0.015	20.0	1.21	3.08	0.232
	Entire pop.	7.62	1.03	120	20.1	0.091	0.014	23.2	3.67	3.67	0.537
50	TVX 3236	6.56	0.680	197	90.1	0.104	0.012	35.4	10.9	6.19	2.20
	Ife brown	8.65	0.377	170	53.3	0.078	0.015	36.8	14.8	5.17	1.03
	IT 985	7.80	0.90	96.0	5.96	0.069	0.019	27.0	7.60	3.48	0.409
	Entire pop.	7.67	1.09	154	69.3	0.084	0.021	33.1	10.9	4.95	1.84

+ Each value is a mean of three tests. There are nine tests per population.

5.8: Mechanical properties of three varieties of cowpea stalk in radial compression at three loading rates and 7.9% moisture content, wet basis+

Loading rates mm/min	Variety	Measurement: Stalk dia, 2R, mm Mean	S.D.	Crushing force, F_c, N Mean	S.D.	Crushing strain, ε_c Mean	S.D.	Elastic modulus E, MPa Mean	S.D.	Crushing Strength, σ_c, MPa Mean	S.D.
12.5	TVX 3236	6.57	1.06	127	26.0	0.121	0.002	19.9	1.10	3.79	0.247
	Ife brown	8.73	0.473	125	26.8	0.098	0.006	19.2	2.11	3.21	0.439
	IT 985	5.98	0.166	95.7	5.86	0.092	0.008	23.7	3.90	3.76	0.423
	Entire pop.	7.10	1.38	116	24.3	0.104	0.015	21.0	3.09	3.59	0.433
25	TVX 3236	6.48	0.625	194	31.4	0.121	0.012	31.0	6.58	5.84	0.859
	Ife brown	8.50	0.52	202	74.4	0.098	0.029	31.6	0.819	5.28	1.10
	IT 985	6.28	0.155	103	29.0	0.079	0.005	28.5	6.70	4.17	1.07
	Entire pop.	7.09	1.14	166	65.9	0.099	0.024	30.4	4.93	5.10	1.15
50	TVX 3236	6.49	0.807	293	47.7	0.099	0.031	65.0	26.5	10.3	2.16
	Ife brown	8.77	0.495	290	95.5	0.082	0.018	56.7	5.74	8.47	1.98
	IT 985	5.98	0.410	109	21.2	0.066	0.02	41.6	5.79	5.30	0.497
	Entire pop.	7.08	1.59	231	106	0.082	0.025	54.5	17.3	8.02	2.64

+ Each value is a mean of three tests. There are nine tests per population.

Table 5.9: Summary of analyses of variance on effects of variety, moisture content and rate of loading on mechanical properties of cowpea stalk in radial compression.

Source of variation	Degree of freedom	F ratio		
		Crushing strain	Elastic modulus	Crushing strength
Total	80			
Variety	2	30.352**	1.0209 ns	2.7226 ns
Moisture content (MC)	2	3.293*	3.3953*	13.8474**
Rate of loading	2	2.559 ns	3.4767*	9.8744**
Replication	2	0.5880 ns	1.1173 ns	0.86673 ns
MC X Variety	4	0.8004 ns	0.9929 ns	1.0820 ns
MC X Rate	4	3.7764**	2.1636 ns	4.0251**
Rate X Variety	4	0.7961 ns	1.0359 ns	1.3776 ns
MC X Rate x Variety	8	0.4629 ns	1.0134 ns	1.0813 ns
Residue	52			

** Significant at 0.01 level

* Significant at 0.05 level

ns Not significant at 0.05 level

This interaction shows that the effect of the loading rate was significantly different at different moisture level for cowpea stalk in radial compression. Other interactions: rate of loading X variety and moisture content X rate of loading X variety were not significant.

From the examination of the f - d curves of the stalk in radial compression, it was found that the cowpea stalks had no bioyield point. A typical f - d curve of stalk in radial compression from the tests is shown in Fig 5.2.

5.3.3 Mechanical Properties of Cowpea Stalk in Simple Bending

Table 5.10 shows the effects of the moisture content and the rate of loading on the mechanical properties of cowpea stalk in simple bending. It was found that the mechanical properties increased with decrease in moisture content and increase in the rate of loading.

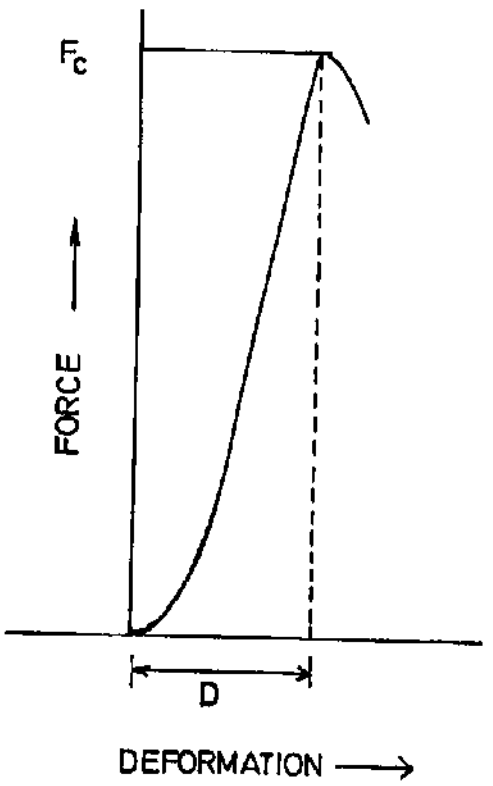


Fig. 5.2 Typical experimental force-deformation curve of cowpea stalk in radial compression — no bioyield point.

Table 5.10 Effects of moisture content and rate of loading on mechanical properties of cowpea Stalk in simple bending+

	Test date								
	4/11/87			9/11/87			19/11/87		
Stalk moisture content, % wb	70.0			22.5			7.88		
Rate of loading, mm/min	12.5	25	50	12.5	25	50	12.5	25	50
Stalk diameter, d, mm	8.57	9.22	9.91	7.8	8.20	8.50	6.90	6.80	7.55
Hollow pith dia, d_o, mm	2.02	1.78	1.87	1.75	1.79	1.88	1.75	1.64	1.98
Max. bending force, F_b, N	21.8	38.7	68.0	60.1	75.2	99.0	86.2	105	126
Max. deflection, V, mm	1.53	1.88	2.44	1.52	1.85	1.75	1.51	2.04	1.00
Degree of elasticity, β, %		32.9			47.5			62.0	
Elastic modulus, E, MPa	393	498	483	1220	1160	1440	2320	2380	7810
Bending strength, σ_b, MPa	4.26	6.17	8.62	16.4	18.8	21.5	34.1	44.6	37.2

+Each value is the mean of three tests. Variety-Ife brown. Loading span = 50mm

The analyses of variance (Table 5.11) however shows that the loading rate did not significantly affect the mechanical properties. While the moisture content significantly affected the properties at 0.01 level. Using Duncan's new multiple range test (Table 5.12). It was found that the elastic modulus at the lowest moisture content (7.88% wb) was significantly higher than those of the other two moisture levels (22.5 and 70% wb) at 0.05 level. While there was no significant difference between the values at the two higher moisture levels. All the mean crushing strength at the three moisture levels (7.88, 22.5 and 70% wb) were significantly different at 0.05 level.

Under the rate of loading, only the mean elastic modulus of the highest rate (50mm/min) was significantly different at 0.05 level, all other values were not significant.

Fig 5.3 shows the force-deflection graphs of cowpea stalk in simple bending at three levels of moisture. It was observed that at high moisture content (70% wb) the stalk required very small force to bend and continued to bend at a constant force without breaking. At intermediate moisture (22.5% wb), the stalk required a higher force to bend and continued to bend for some time at a constant force before breaking. But the dry stalk (7.88% wb) would require the highest force to bend but would break instantly at the maximum bending force. This behaviour of cowpea stalk, as will be seen later, was very useful in the design of the whole shoot thresher.

Table 5.11: Summary of analyses of variance on effects of moisture content and rate of loading on mechanical properties of cowpea stalk in simple bending

Source of variation	Degree of freedom	F ratio	
		Elastic modulus	Bending stength
Total	26		
Moisture content (MC)	2	8.467**	7.664**
Rate of loading	2	2.711 ns	3.334 ns
Replication	2	1.186 ns	0.933 ns
MC X Rate	4	2.325 ns	2.61 ns
Residue	16		

** Significant at 0.01 level

ns Not significant at 0.05 level

Table 5.12: Main effects of moisture content and rate of loading on stalk mechanical properties in simple bending+

Test date	Stalk moisture content, % wb	Elastic modulus, MPa	Bending strength, MPa
4/11/87	70.0	458 a	6.35 a
9/11/87	22.5	1273 a	18.9 b
19/11/87	7.88	4170 b	38.6 c
	Rate of loading, mm/min	Elastic modulus MPa	Bending strength, MPa
	12.5	1311 a	19.1 a
	25	1346 a	23.2 a
	50	3244 b	22.4 a

+Each value is the mean of nine tests. In each column means with the same letter are not significantly different at 0.05 level as determined by Ducan's new multiple range test.

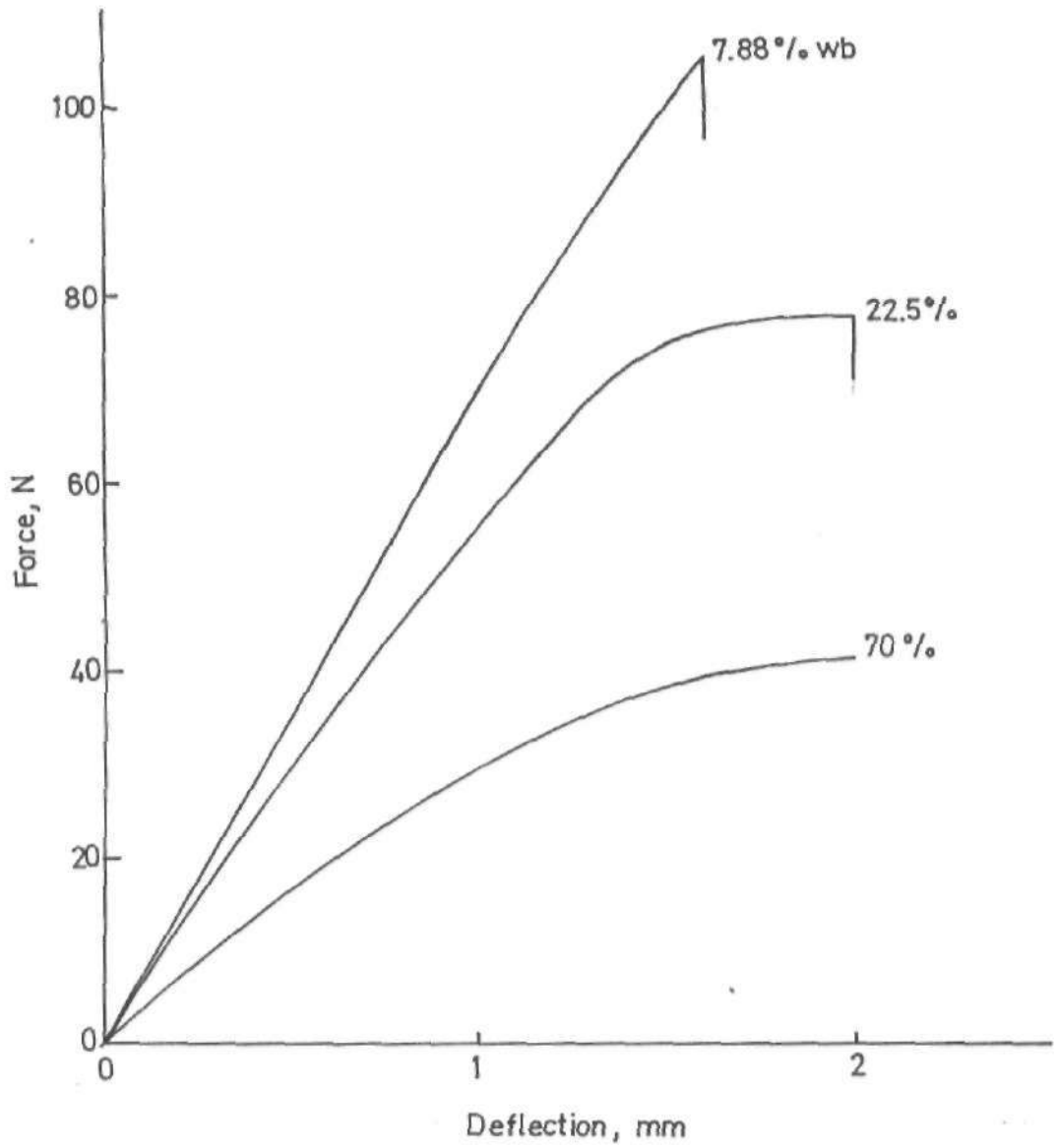


Fig. 5.3 Typical force-deflection graphs of cowpea stalk in simple bending at three levels of moisture
Variety: Ife brown, loading rate: 25 mm/min

5.3.4 Minimum Cracking Force of Pods

Table 5.13 gives the effects of variety and moisture content on the minimum cracking force of the cowpea pods. It was found that the minimum cracking force of TVX 3236 was 7.25N (S.D. 2.31), Ife brown, 13.8N (S.D. 3.80) and IT 985, 29.0N (S.D. 4.76)

The analysis of variance (Table 5.14) shows that the effects of variety and moisture content on the cracking force were very highly significant at 0.01 level. The influence of moisture on pod cracking force was very high, little moisture differences created highly significant differences in the cracking force. Cowpea pod cracked easily at low moisture contents of about 10% wb and below. They did not readily crack at higher moistures. When the moisture content was about 20% wb, the cowpea pod did not crack but tended to crush when force was applied.

Because of the pod high sensitivity to moisture, it was possible to develop a regression model for predicting the minimum cracking force from the moisture content for the three varieties of cowpea tested. The regression models are stated in Table 5.15. The models are reliable as can be seen from their high probability and correlation coefficients, r, which ranged between 0.8253 for IT 985 to 0.9106 and 0.9395 for the Ife brown and TVX 3236 respectively.

It was observed (Table 5.16) that the minimum cracking force was closely related to the pod pericarp thickness.

Table 5.13: The effects of variety and moisture content on the minimum cracking force of cowpea pods

Variety	Moisture content, % wb	Minimum cracking force, N		
		Mean	S.D.	No. of cases
TVX 3236	9.30	9.33	0.937	6
	7.25	5.17	0.708	6
	Entire variety	7.25	2.31	12
Ife brown	8.98	17.3	1.55	6
	7.15	10.3	0.663	6
	Entire variety	13.8	3.80	12
IT 985	9.21	32.7	3.27	6
	6.98	25.2	2.28	6
	Entire variety	29.0	4.76	12
Entire pop.	8.15	16.7	9.92	36

Table 5.14 : Summary of analysis of variance on effects of variety and moisture content on minimum cracking force of cowpea pods

Source of variation	Degree of freedom	F ratio Minimum cracking force
Total	35	
Variety	2	431.431 ***
Moisture content (MC)	1	100.447 ***
Replication	5	0.825 ns
MC X Variety	2	2.806 ns
Residue	25	

*** Highly significant at 0.01 level

ns Not significant at 0.05 level.

Table 5.15: Regression of the minimum cracking force (F) of cowpea pods on moisture content:

Variety	Regression equation	S.E. of Estimate	F Probability	Correlation Coeff., r
TVX 3236	F = 2.0285 MC - 9.538	0.8303	0.00001	0.9395
Ife brown	F = 3.7905 MC - 16.7689	1.1906	0.000001	0.9106
IT 985	F = 3.3722 MC + 1.6621	2.8181	0.00095	0.8253

MC = Moisture content (% wb), $6.9\% \leq MC \leq 9.3\%$

Table 5.16: Relationship between pod pericarp thickness and minimum cracking force of pods in three varieties of cowpea

Variety	Pod pericarp thickness, mm			Minimum cracking force, N		
	Mean	S.D.	No. of Cases	Mean	S.D.	Number of Cases
TVX 3236	0.346	0.158	150	7.25	2.31	12
Ife brown	0.425	0.265	150	13.8	3.80	12
IT 985	0.824	0.231	150	29.0	4.76	12
Entire pop.	0.532	0.292	450	16.7	9.92	36

The variety with thin pod pericarp (TVX 3236) had low minimum cracking force. IT 985 with thick pericarp exhibited high cracking force, while the Ife brown with intermediate value fell inbetween.

5.3.5 Mechanical Properties of Cowpea Grain in Uniaxial Compression

The mechanical properties of cowpea grain in uniaxial compression is recorded in Table 5.17. The Table gives the mean crushing force of cowpea grain as 69.3N (S.D. 24.7) and mean elastic modulus as 454 MPa at 7.5% Mc, wb. This value is comparable to the elastic modulus of soyabean which was stated by Misra and Young (1981) as 435.8 MPa at 7.22% wb moisture content.

Analysis of variance showed that the effect of variety on the elastic modulus of cowpea grain was not significant at 0.05 level.

Table 5.17: Effects of variety and rate of loading on mechanical properties of cowpea grain in uniaxial compression+

	Variety									Population	
	TVX 3236			Ife brown			IT 985			Mean	S.D.
Grain moisture content % wb	7.47			7.50			7.63			7.53	0.085
Rate of loading, mm/min	12.5	25	50	12.5	25	50	12.5	25	50	29.2	16.5
Elastic deformation, D_e, mm*	0.245	0.335	0.384	0.297	0.230	0.253	0.260	0.228	0.313	0.283	0.081
Crushing Force, F, N	53.3	61.1	91.3	82.6	58.5	61.8	65.0	54.8	75.8	69.3	24.7
Elastic Modulus, E, MPa	442	452	407	509	517	459	429	470	403	454	94.0

+Each value is a mean of four tests. The compression was along the long axis of the grain with the hilum out on one side, at 7.5% moisture content, wet basis.

*$D_e = D\beta/100$, $\beta = 50\%$

5.3.6 Effects of Variety, Moisture Content and Rate of Loading on Mechanical Properties of Cowpea

In the experiments, it was generally found that the mechanical properties increased with decrease in moisture content and increase in the rate of loading. The effect of moisture content on mechanical properties was found to be statistically significant in all the experiments. The properties increased with decreasing moisture content. This is in agreement with the findings of other researchers like Zoerb and Hall (1960), Shelef and Mohsenin (1969), Saxena (1972), Paulsen (1978) and Anazodo (1980). The relationships between properties and moisture content were found by regression analyses (Tables 5.15, 5.18 and 5.19; and Fig 5.4 - 5.5) to be linear. These linear relationships gave simple regression models for predicting the mechanical properties of stalk in radial compression, the crushing strain

$$\varepsilon_c = 0.09457 - 0.0002337MC \quad \text{--- 5.1}$$

The elastic modulus

$$E = 34.5236 - 0.2704MC \quad \text{--- 5.2}$$

and the crushing strength

$$\sigma_c = 5.4377 - 0.04651MC \quad \text{--- 5.3}$$

at moisture content between 7.6 and 61.2% wb.

Table 5.18: Regression of mechanical properties of cowpea stalk in radial compression on moisture content

Stalk mech. property	Regression equation	Corr. coef., r
Crushing strain,	ε_c = 0.09457-0.000234MC	-0.9245
Elastic modulus, E, MPa	E = 34.5236-0.2704MC	-0.9099
Crushing strength, MPa	σ_c = 5.4377-0.04651MC	-0.9102

MC = moisture content % wb, $7.6\% \leq MC \leq 61.2\%$

Table 5.19: Regression of mechanical properties of cowpea stalk in simple bending on moisture content

Stalk mech. property	Regression equation	Corr. coef., r
Elastic modulus, E, MPa	$E = 3614.6846 - 49.2434MC$	-0.8198
Bending strength, σ_b, MPa	$\sigma_b = 36.5492 - 0.4562MC$	-0.9115

MC = moisture content, %wb, $7.88\% \leq MC \leq 70\%$

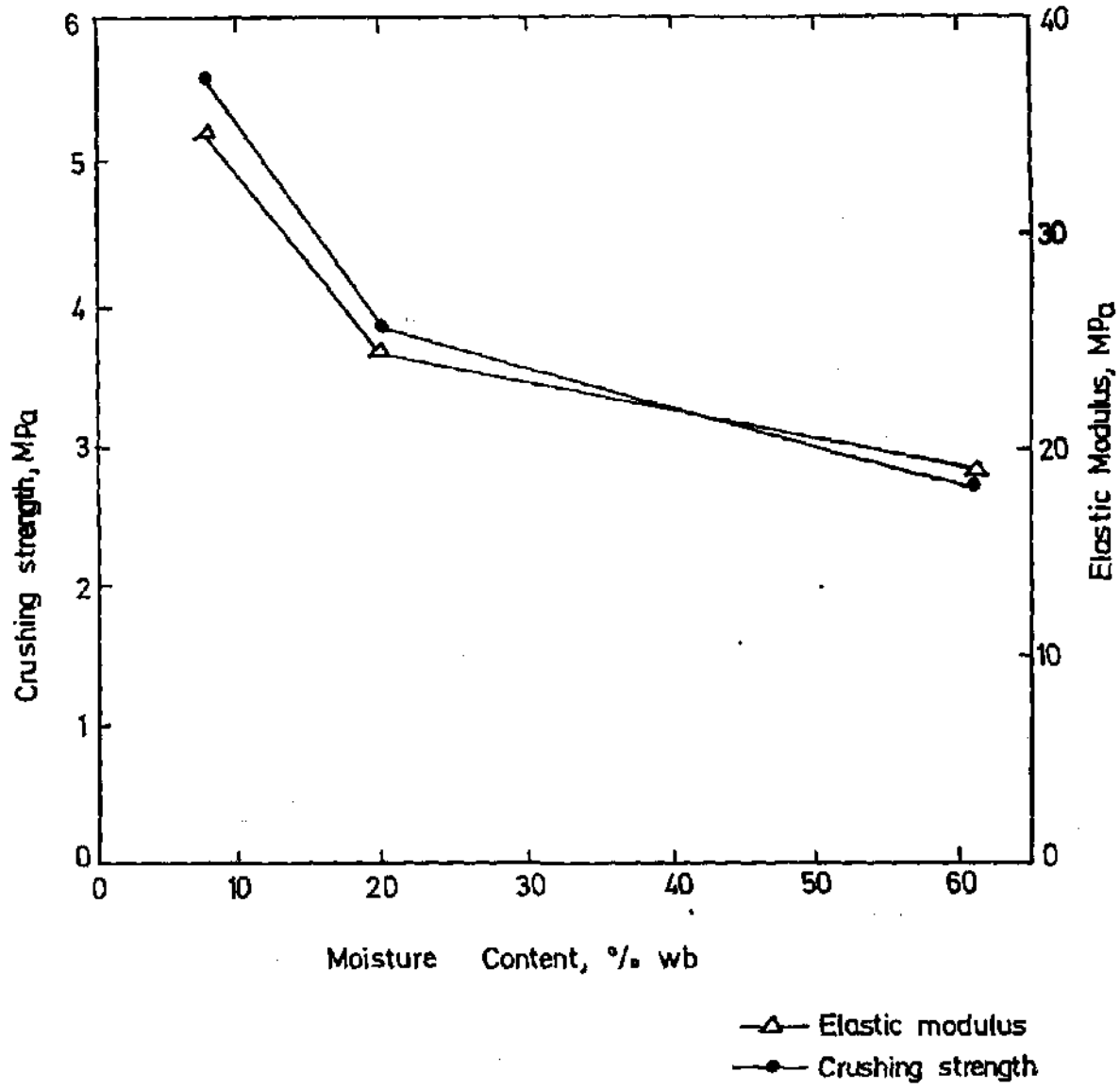


Fig. 5.4 EFFECT OF MOISTURE CONTENT ON ELASTIC MODULUS AND CRUSHING STRENGTH OF COWPEA STALK IN RADIAL COMPRESSION. Each point is a mean of 27 tests.

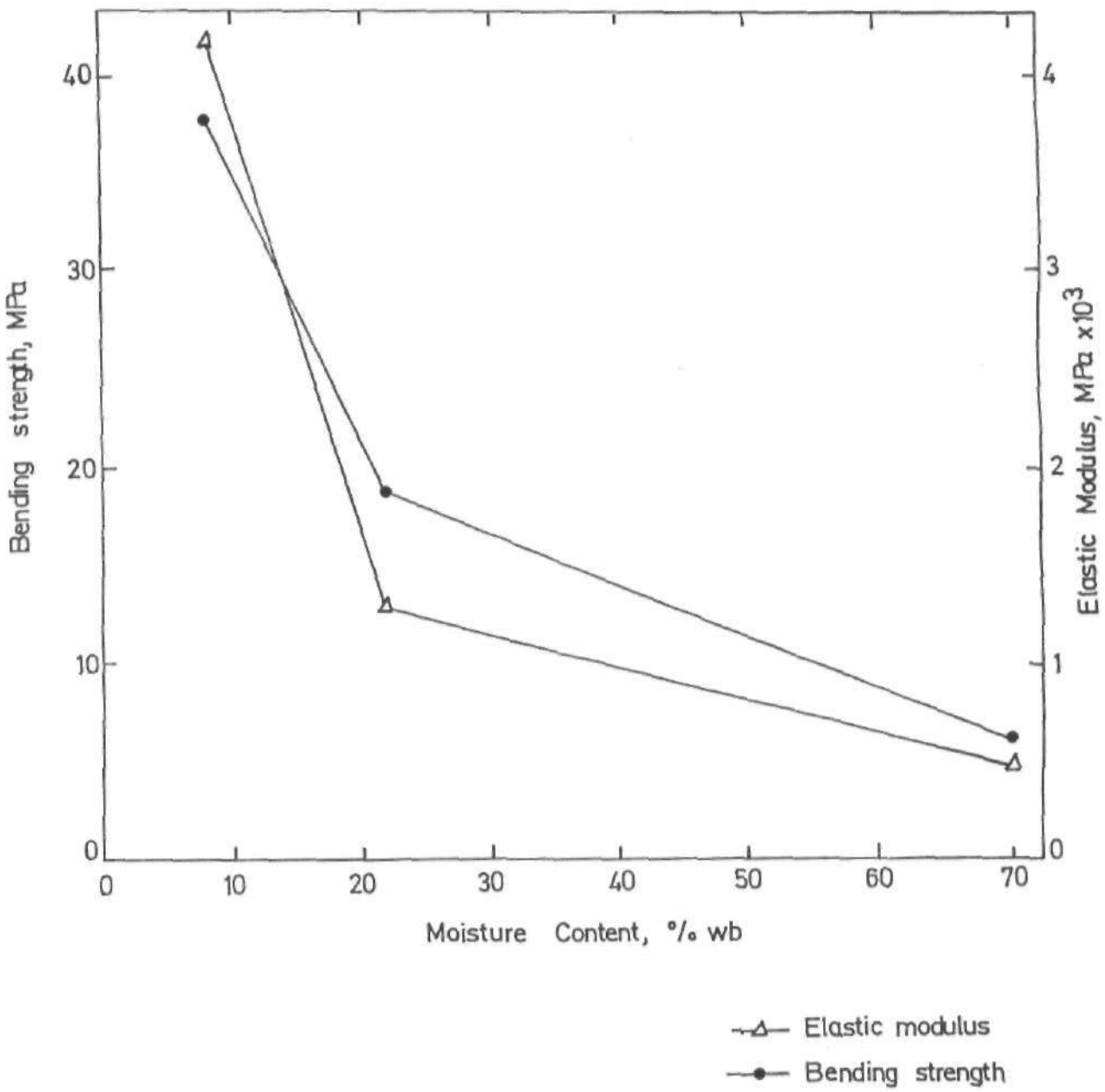


Fig. 5.5 EFFECT OF MOISTURE CONTENT ON THE ELASTIC MODULUS AND BENDING STRENGTH OF COWPEA STALK IN SIMPLE BENDING. Each point is a mean of nine tests

For stalk in simple bending, elastic modulus

$E = 3614.6846 - 49.2434\ MC$ --- 5.4

and bending strength

$\sigma_b = 36.5492 - 0.4562\ MC$ --- 5.5

at moisture content between 7.88 and 70% wb.

There was linear relationship between minimum cracking force of pods, F, and moisture content, MC as follows:

$F = 2.0285\ MC - 9.538$ --- 5.6

$F = 3.7905\ MC - 16.7689$ --- 5.7

$F = 3.3722\ MC + 1.6621$ --- 5.8

For TVX 3236, Ife brown and IT 985 respectively at moisture content between 6.9 to 9.3% wb.

The rate of loading was found to have significant effect on some mechanical properties, while the variety had no significant effect on most mechanical properties of cowpea. In summary, moisture content was the most influencing factor on mechanical properties of cowpea, followed by the rate of loading. The effect of variety was mostly insignificant. The effect of loading rate on the elastic modulus and crushing strength of cowpea stalk in radial compression is shown in Fig 5.6.

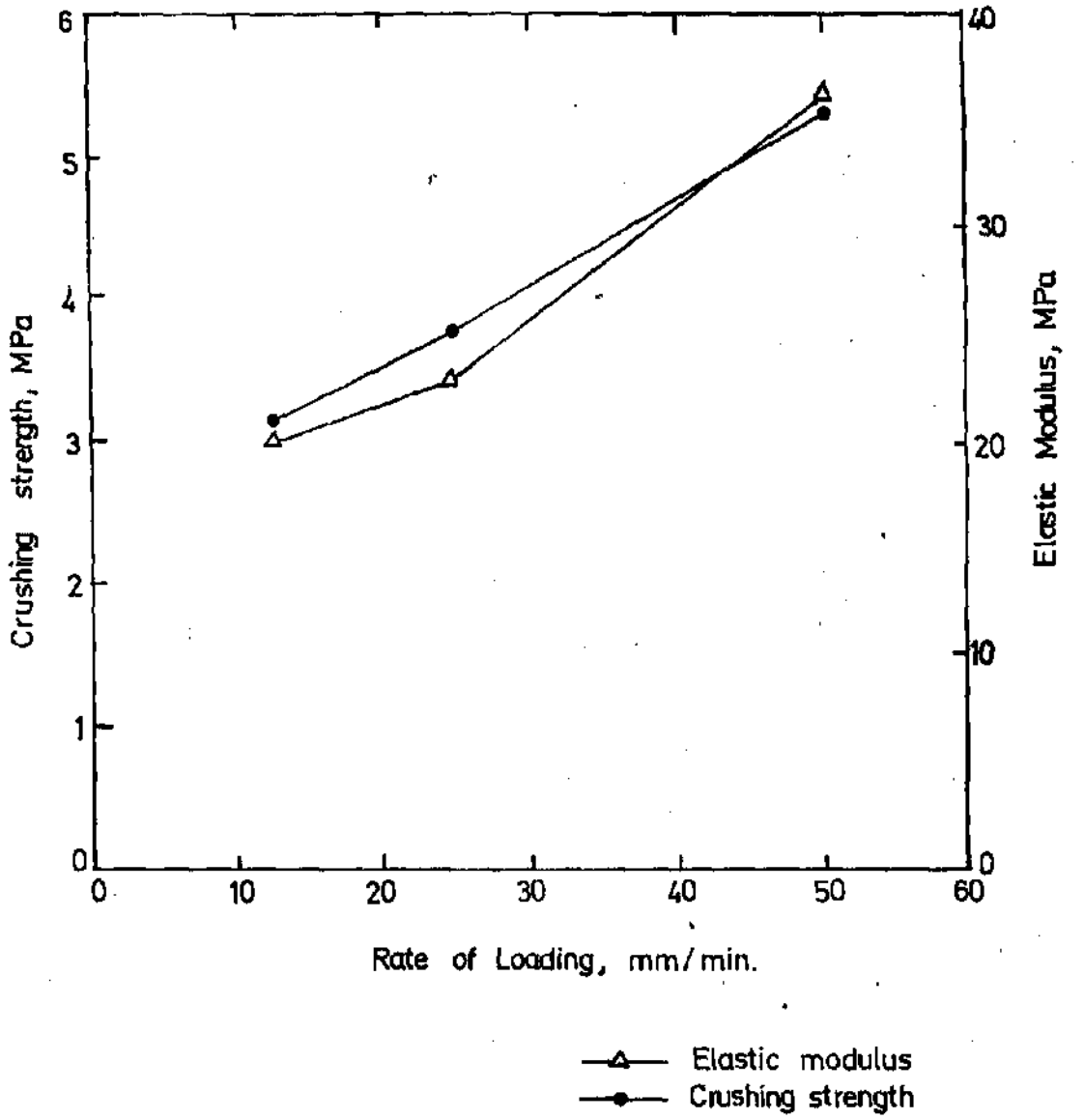


Fig. 5.6 EFFECT OF LOADING RATE ON ELASTIC MODULUS AND CRUSHING STRENGTH OF COWPEA STALK IN RADIAL COMPRESSION. Each point is a mean of 27 tests

5.4. Threshing Trials and Redesign of Pod Thresher

5.4.1 Introduction

Whole shoot threshing trials were carried out using the IAR pod thresher as discussed in Chapter 4. The thresher was selected because of its effectiveness in threshing cowpea pods. But the problem of pod-picking as a harvesting method, had to be solved. Hence it became necessary to redesign the pod thresher to handle the entire crop shoot. This would change the harvesting system from the tedious pod-picking to cutting of cowpea stalk which is a much lighter job, and can also be mechanized. This section discusses the results of the threshing trials and the redesign of the pod thresher which was based on the determined properties of cowpea and the results of the threshing tests. The characteristics of cowpea variety suitable for whole shoot threshing, specifications and the expected performance of the redesigned thresher are also discussed.

5.4.2 Threshing Trials

The threshing trials of whole shoot of cowpea in the IAR pod thresher basically showed that the whole shoot could be threshed successfully at low moisture levels. The result of the trial with seven varieties of cowpea are shown in Table 5.2. The trials showed a high degree of success. The feeding rate was however, kept low to avoid clogging. In spite of this, machine stoppage still occurred in four varieties due to clogging of the threshing cylinder.

Table 5.20 The output and efficiency of seven varieties of cowpea in whole shoot threshing trial using IAR cowpea pod thresher+

Variety	Feed rate, kg/min	Thresher through-put kg/min	Threshed grain kg/min	% damage Ext.	% damage Int.	Threshing efficiency, %	% mog* in grain	Concave Residue kg	Remark
TVX 3236	0.727	0.355	0.182	0	1	99.5	3.60	3.72	Machine stopped in 1.67min.
Ife brown	1.03	0.595	0.496	0.152	1	99.6	3.24	0.35	stopped in 5.5min.
IT 985	1.18	1.14	0.766	0	0	99.2	2.69	0.35	
IT 60	1.14	1.10	0.447	0	1	99.4	2.75	0.36	
Samaru 48	1.02	0.595	0.407	0.241	2	99.0	3.21	0.25	stopped in 7.2min.
Samaru 341	0.835	0.471	0.194	0	1	98.6	3.51	3.64	stopped in 2.50min.
Local white	1.12	1.08	0.434	0	1	99.0	2.75	0.35	
Average	1.01	0.877	0.418	0.056	0.86	99.2	3.12	1.29	low feed rate to avoid clogging

+Trial was for 10min, but was broken in four varieties owing to clogging.
Average drum speed = 250 rpm, 320 rpm at no load
Average fan speed = 400 rpm, 470 rpm, at no load

*Mog = material - other - than - grain

The degree of clogging varied with varieties. Tables 5.20 and 5.3 show that varieties with small grains exhibited the highest degree of clogging as could be noticed with TVX 3236 and Samaru 341 which were in groups (a) and (b) respectively according to Duncan's new multiple range test grading of kernel size. Clogging did not readily occur with the large grain varieties (IT 985 and the local white), and very little clogging tendency was noticed in the grains of intermediate size (Samaru 48). There was no clogging with IT 60 because the variety, though of intermediate-sized grains, had less amount of small stalk owing to limited vegetative growth occasioned by its fast maturity in 60 days.

Small grain varieties had large amount of small diameter stalks which tended to pulp instead of breaking in the thresher concave (see Plate IX). Big stalks were easier to handle as they readily broke on bending in the cylinder concave and were blown out. Although very big pieces were withheld as residue, they did not clog the machine. Clogging occurred whenever crushed spongy residues accumulated in the cylinder-concave, which readily happened with small grain varieties.

It was easily observed that the grain size was related to the pod pericarp thickness. Cowpeas with small grain (TVX 3236) had thin pericarp while those with large grains (IT 985) had thick pericarp. Table 5.5 shows that small grain varieties had greater shatter losses. grain flow in TVX 3236 stated in Table 5.20, was partly because of heavy loss of grain during cutting and drying; and partly

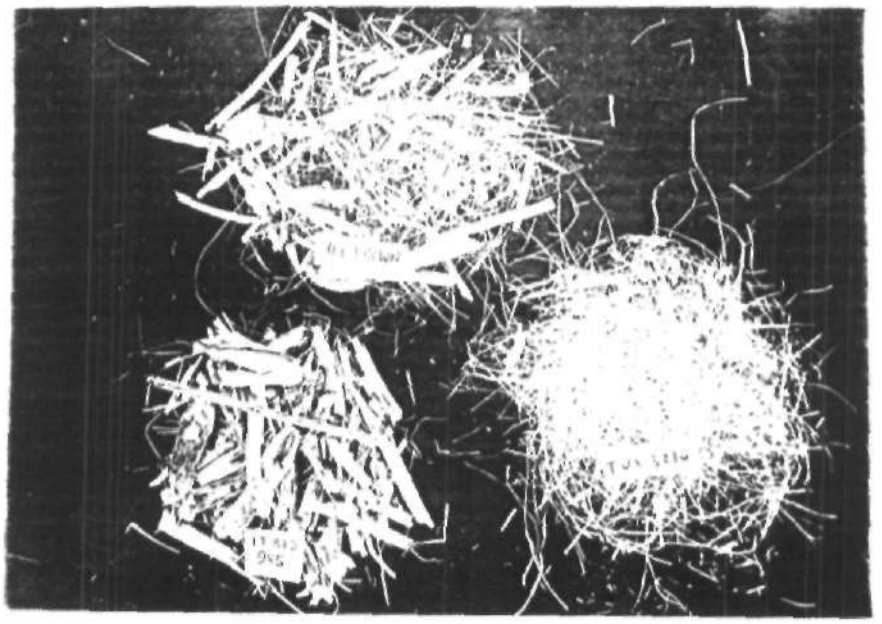


Plate IX - Thresher concave residue of three varieties of cowpea.

N/B: Large grain variety (IT 985) had broken stalks, medium grain (Ife brown), semi-crushed stalks, while small-grain variety (TVX 3236) had its stalks crushed to spongy mass.

because of slow feeding rate. IT 985 had no field loss by pod shattering, as could be seen from Table 5.5.

In summary, the following observations were made from the threshing trials using the pod thresher:

1. The thresher could basically extract the grains from the materials without damage to the grains.

2. The thresher was too small to handle the entire plant material.

3. The thresher cylinder required to be redesigned. Since the small stalks could not break, a device for cutting them was essential.

4. There was no way of evacuating the threshing chamber of large broken and crushed stalks except by occasional dismantling which was cumbersome and time-consuming. An evacuating device was necessary.

5. The cleaning system required modification. Table 5.20 shows that about 3.12% chaff was in the grains. This was too high.

6. Right sieve sizes were not available for various grain sizes tested. It would be necessary to develop five sieve sizes in keeping with the Duncan's new multiple range grading of the grain sizes of the seven varieties of cowpea tested (Table 5.3).

The redesign of the pod thresher was based on the above observations.

5.4.3 Characteristics of Cowpea Variety Suitable for Whole Shoot Threshing

From the discussions so far, it could be observed that a cowpea variety suitable for whole shoot threshing should have the following characteristics:

1. It should have large grains, large pods and thick pod pericarp to avoid field losses by pod shatter and rake loss.

2. The stalk when woody should have a sizable hollow pith to reduce the bending and crushing strength and the diameter of the stalk on drying. A high pod content on a limited stalk would be of great advantage.

3. It should be high yielding at first flowering so that a large number of pods should mature at the same time.

4. It should be erect to facilitate harvesting by cutting.

5. Finally it should be of high quality and high market acceptability.

Table 5.21 summarizes the characteristics of the three varieties of cowpea studied to show their suitability for whole shoot threshing.

Table 5.21: Mean properties of three varieties of cowpea at low moisture levels+

Variety	Grain size, mm			Pericarp thickness, mm	Pod cracking force, N	Main stalk diameter mm	Stalk crushing strength, MPa
	Length	Width	Thick-ness				
TVX 3236	6.36	5.24	4.00	0.346	5.17	6.48	5.84
Ife brown	7.90	6.06	4.44	0.425	10.3	8.50	5.28
IT 985	9.18	7.39	5.42	0.824	25.2	6.28	4.17

+ 6.5 - 8% wet basis

* At 7.9% moisture content, wet basis and 25mm/min loading rate

From the Table, it is obvious that the IT 985 was the most suitable among the varieties studied. This was confirmed by the threshing trials in Table 5.20.

5.4.4. Redesign of Cowpea Pod Thresher to Handle the Entire Plant Shoot

Based on the results of the trial tests with the pod thresher and the measured properties of cowpea, the following modifications were made in redesigning the thresher (Fig 5.7):

1. Machine size: The width of the thresher was increased by 1½ times. This brought the total dimensions of the machine to 1500 x 680 x 1440 mm when fully assembled. This would enable the machine accommodate the bulky stalks which would now be fed into it with the pods.

2. Evacuation chute: A gated stalk evacuation chute of 150 x 420 x 60mm was installed above the chaff chute. This opened at the upper part of the chamber. It should be opened when necessary to evacuate the threshing chamber with the machine running.

Trial tests have shown that some broken and crushed stalks accumulated in the machine as residue required evacuation from time to time to avoid machine stoppage by clogging. Some broken stalks were too big to go through the concave grate and required special outlet of this nature.

3. Threshing cylinder: The threshing cylinder was redesigned to include eight knives staggered on two opposite threshing bars. The knife angle was made 60° to optimize cutting. Studies by Feller (1959) and Prasad et al (1975) have shown that a knife angle of $55 - 60^{\circ}$ is optimal for cutting. There were six threshing bars in all making up the cylinder, only two contained knives. Four of the bars contained 24 spikes each, staggered in two rows. The two knife bars contained 12 spikes each, staggered between the knives. The spikes were 16 mm in diameter and 16 mm high, about half the height of the knives. Both the spikes and the knives should be strongly welded on the bars. The details of the design are shown in the drawings.

The insertion of knives in the cylinder was necessary to cut the fluffy small stalks which pulped in the cylinder-concave and caused clogging. Mechanical tests of cowpea stalks (discussed in Section 5.34) has shown that the bigger stalks readily broke at maximum bending force at about 8% wb stalk moisture content (Fig 5.3). But the small stalks did not readily break and required cutting. The insertion of the knives would enable the machine to thresh all varieties of cowpea.

4. Sieves: An additional sieve should be installed in the blower chamber at the grain chute to delay the grain fall so that the blower could clean the grains better. There should be two sieves in addition to the concave grate ;

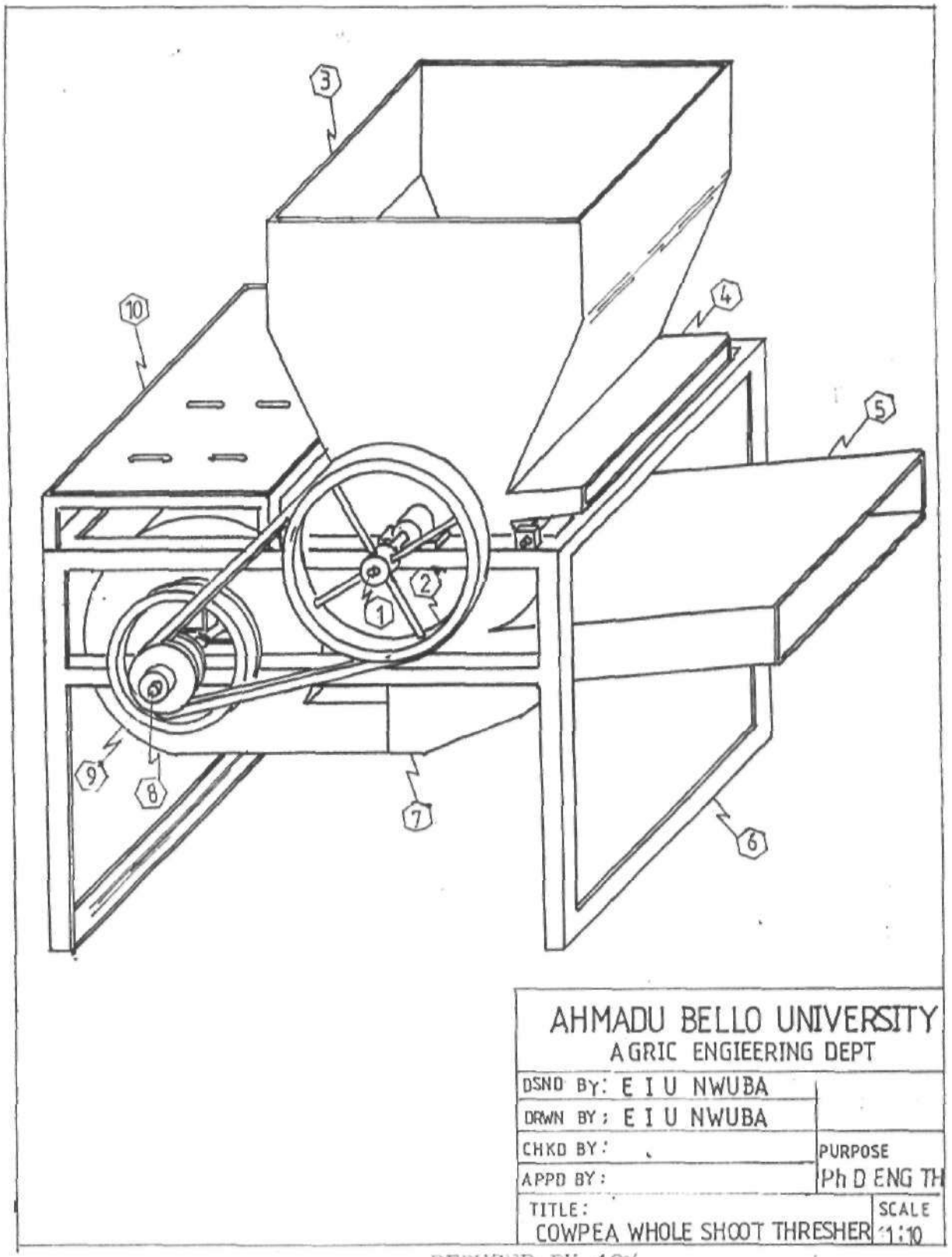


FIG 5·7 DESIGN DRAWINGS FOR COWPEA WHOLE SHOOT THRESHER

Part No	Name
1	Cylinder (Drum) shaft
2	Cylinder pulley
3	Hopper
4	Stalk evacuation chute
5	Lower cylinder housing/chaff chute
6	Frame network
7	Grain chute
8	Fan shaft
9	Fan housing
10	Seat for prime mover

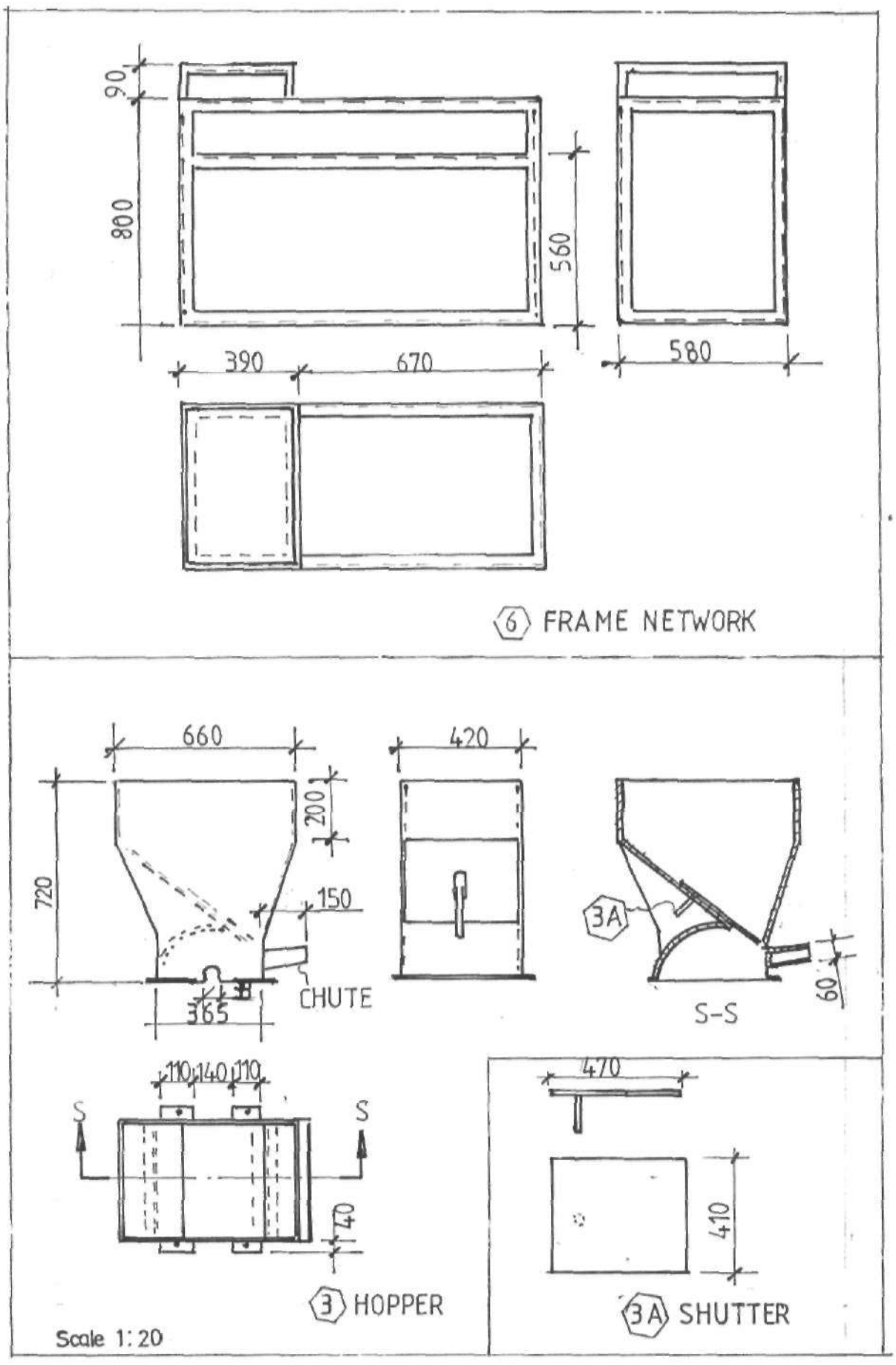
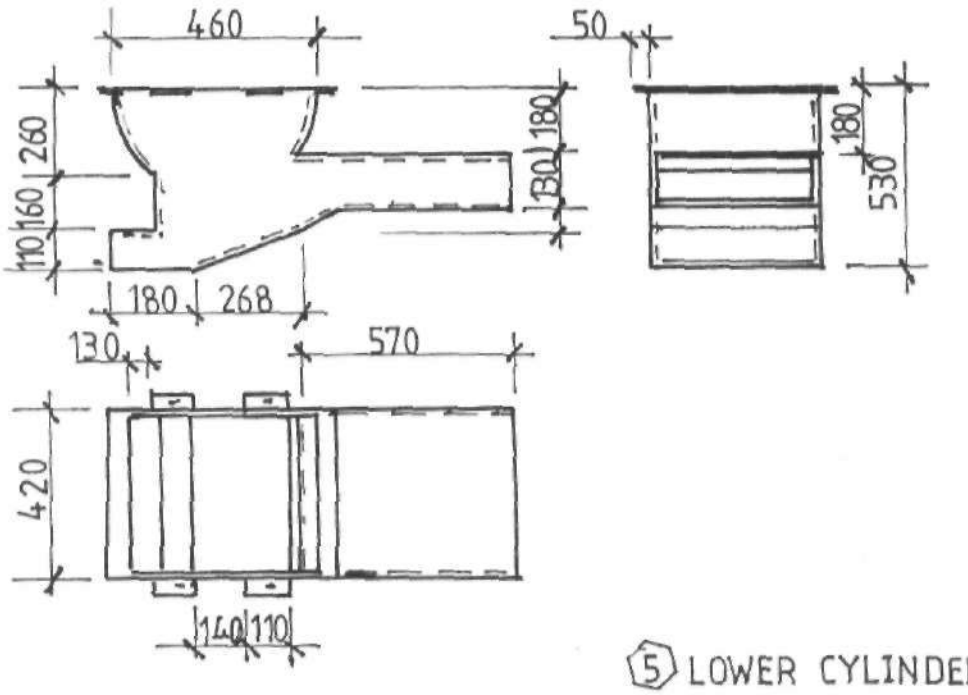
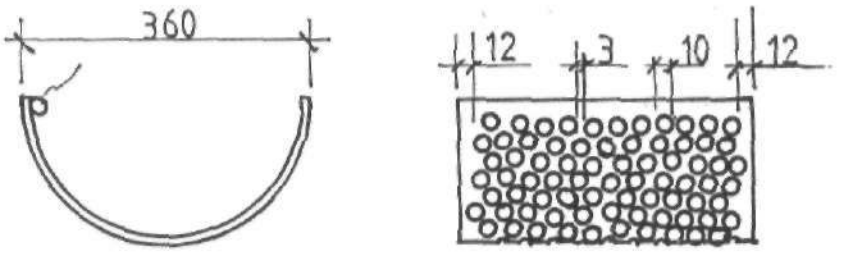
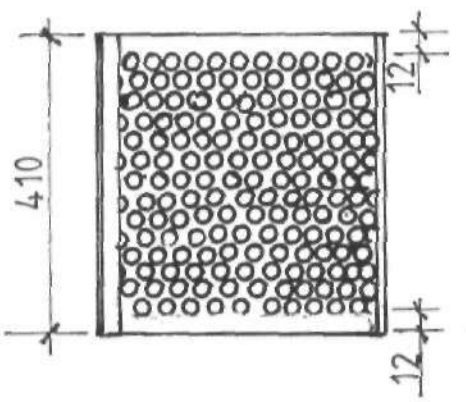


FIG 5.7 CONTINUED



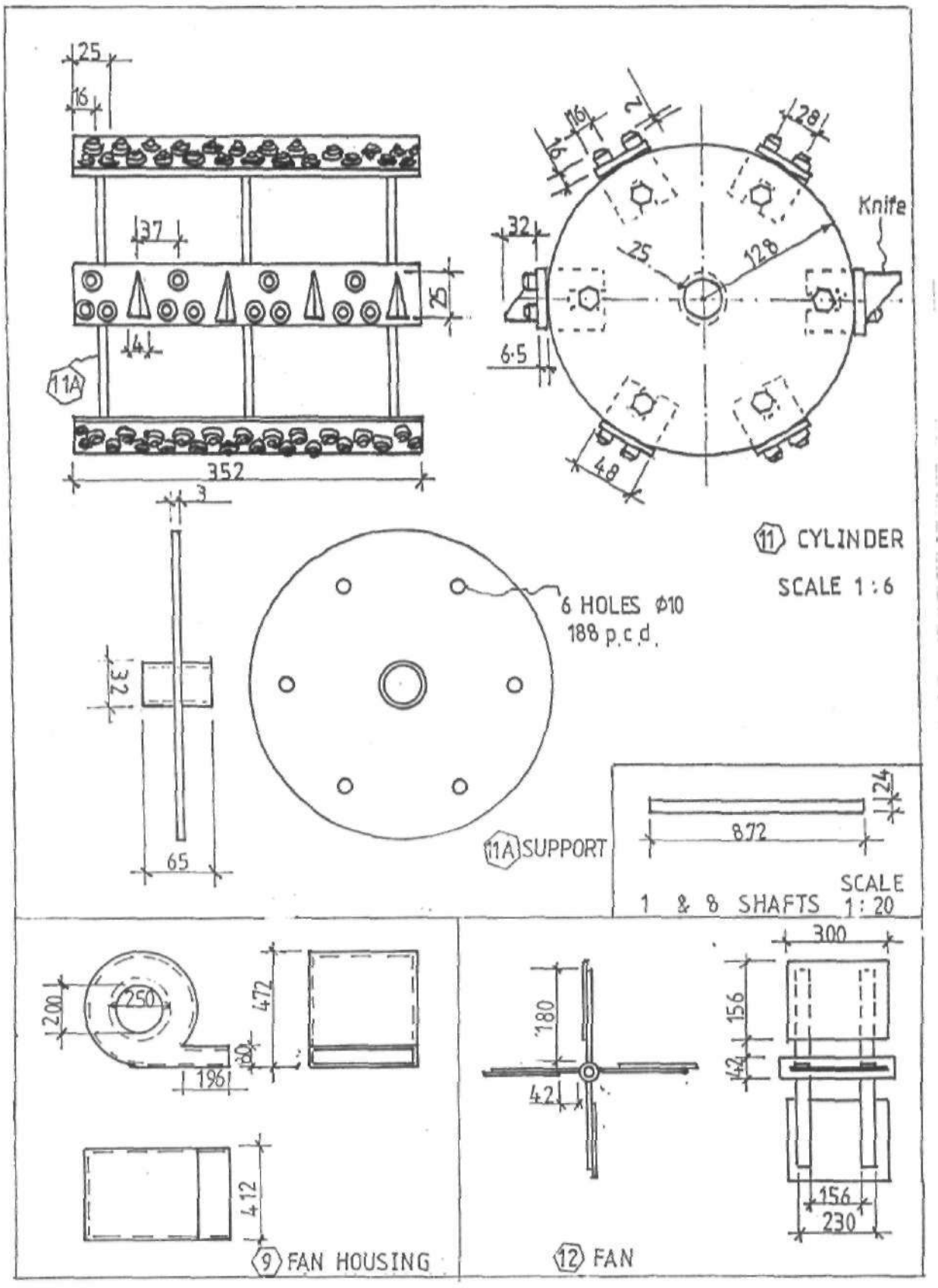
(5) LOWER CYLINDER HOUSING / CHAFF CHUTE (Scale 1:20)





(13) SIEVE

FIG 5.7. CONTINUED



REDUCED BY 10%

FIG 5·7·CONTINUED

Bill of quantities

Part No	Name	Qty	Dimension, mm	Material
1	Cylinder shaft	1	24 dia	Hot rolled iron rod
2	Pulley	2	25 thick	Hot rolled flat mild steel
3	Hopper	1	1.5 thick	Hot rolled flat steel
4	Stalk evacuation chute	1	1.5 thick	Hot rolled flat steel
5	Lower cylinder housing	1	1.5 thick	Hot rolled flat steel
6	Frame network	1	38.2 x 38.2 x 4	Mild steel (MS) angle iron
7	Grain chute	1	1.5 thick	Hot rolled flat steel
8	Fan shaft	1	24 dia	Hot rolled iron rod
9	Fan housing	1	1.5 thick	Hot rolled flat steel
10	Seat for prime mover	1	25.5 x 25.5 x 2.8	MS angle iron
	For the top	1	25 thick	Wooden plank
11	Cylinder			
	Bar	6	48 x 6.5 thick	Hot rolled steel bar
	(A) Support	3	3 thick	Hot rolled flat steel
	For fixing on shaft	3	25 dia	Standard iron pipe
	Spike	120	16 dia	Hot rolled iron rod
	Knife	8	25 x 4	Hot rolled steel bar
12	Fan			
	Blade	4	1.5 thick	Hot rolled flat steel
	For fixing on shaft	1	25 dia	Standard iron pipe
	Blade support	8	25 x 4	Hot rolled steel bar
13	Concave sieve	1	2 thick	Hot rolled flat steel
	Grain sieve	2	1.5 thick	Hot rolled flat steel

the sieves should be of the same size. One sieve should be at the grain chute and the other on the grain pan.

Results of the threshing tests (Table 5.20) have indicated a high percentage of chaff (mog) in grain (3.12%). To ensure better grain cleaning an additional sieve at the grain chute should be necessary. Five sets of sieve and two sets of concave grate were recommended for the thresher. The sieve should be of the following sizes: labelled sieve A to E, corresponding to Duncan's multiple range test grading of the grain size of varieties of cowpeas, shown in Table 5.3:

Sieve A: 7mm circular holes, 3mm apart.

Sieve B: 8mm circular holes, 3mm apart.

Sieve C: 8.5mm circular holes, 3mm apart.

Sieve D: 9mm circular holes, 3mm apart.

Sieve E: 10mm circular holes, 3mm apart.

The two sizes of concave grate should have circular holes of 8.5 and 10mm diameter, bored 3mm apart. The distance of 3mm was chosen between the holes in the sieve and grate for dual reasons: Firstly to strengthen the sieve. Narrower distances would easily break up. Secondly, 3mm was less than the least dimension of the cowpea grain (3.31mm, Table 5.1), and much less than the least width (4.46mm). With the little vibration transmitted during operation, no grain would hang between the holes. The diameters of the sieve sizes were approximated from the 95% confidence interval for the mean given in Table 5.1.

It has been shown in Section 5.2.1. that grain size varies in different varieties of cowpea. The five sieve sizes recommended would make efficient threshing of different varieties of cowpea possible.

5. Power requirement:

In this study, a design of a whole shoot thresher was proposed. The machine was not constructed and tested to establish the actual power requirement and optimum cylinder speed. However, the increased length of the cylinder-concave and capacity of machine, and the introduction of cutting knives would demand an increase in power. Such increase in power could be met by increasing the cylinder speed or changing to a higher prime mover, or both. Based on literature review and observations during threshing trials with the I.A.R, pod thresher, an electric motor of 2.24Kw (3hp) was suggested for the whole shoot thresher.

6. Cylinder speed:

Increases in cylinder speed was found to be necessary. The speed (303m/min) of the IAR pod thresher was rather low. For the whole shoot thresher, a cylinder speed of 350m/min. (370rpm) at 26mm concave clearance was put forward for threshing seeds for planting. For general purpose grains, a cylinder speed of 450m/min (475rpm) was suggested. Further increases could be made when grains are for consumption only

or for immediate industrial use. The suggested threshing speed for seeds for planting, was low because cowpea is susceptible to internal injuries which hampers germination (Ige, 1978; Sharma and Devnani, 1980). The suggested increases in speed were also based on the threshing trials with the IAR pod thresher and literature review as will be discussed in Section 5.4.7.

Two or more cylinder pulley diameters are therefore necessary: a slow speed pulley of 166mm diameter, a general-purpose pulley of 130mm diameter, and further smaller diameter pulley for faster threshing.

5.4.5 Calculation of some Whole Shoot Thresher Parameters from Measured Data.

The threshing energy of the IAR thresher is calculated in Appendix H using Equation (3.51) as discussed in Section 3.7.4. The threshing energy was then expressed as a percentage of the total kinetic energy of the thresher and this was found to be 39%. The relationship between the feed rate and the threshing energy was assumed linear and the energy expenditure per kg/h feed rate wa obtained as 0.74J per kg/h. Since the redesigned whole shoot thresher is a modification of the IAR thresher chamber. Hence, the percentage threshing energy and energy per kg/h feed rate obtained for the IAR thresher was applied to estimate the energy requirement and feed rate of the whole shoot thresher at given cylinder speeds.

Total kinetic energy of the designed whole shoot thresher:

For the whole shoot thresher, the total kinetic shoo energy, (K.E.), is given by:

$$K.E. = \tfrac{1}{2}\,\omega_o{}^2(I_s + I_c + I_p) \quad (3.45)$$

where $I_s = 0.00020232$ kg-m^2

$I_c = 0.25336$ kg-m^2

$I_p = 0.03544$ kg-m^2

$I = I_s + I_c + I_p = 0.289$ kg-m^2 as calculated in Appendix H.

At 5.17 r/s (370 rpm)

$$K.E. = \tfrac{1}{2} \times 0.289 \times \left(\frac{370 \times 2\pi}{60}\right)^2 J$$

$$= \underline{216.93\ J}$$

Similarly, at 7.92 r/s (475 rpm)

$$K.E. = \underline{357.53\ J}$$

Threshing energy requirement and feed rate of the whole shoot thresher:

Assuming that 38.96% of the K.E. will be used for threshing at the rate of 0.74J per kg/h, the threshing energy E_t, at 5.17 r/s (370 rpm) is obtained as

$$E_t = 216.93 \times 0.3896\ J = \underline{84.52\ J}$$

The feed rate at 6.17 r/s (370 rpm)

$$f = 84.52/0.74 = \underline{114.21 \text{ kg/h}}$$

Similarly, at 7.92 r/s (475 rpm):

$$E_t = \underline{139.44 \text{ J}}$$
$$f = 188.43 \text{ kg/h}$$

Blower air flow rate for whole shoot thresher:

The required air flow rate through a blower, Q_A, can be estimated from Equation (3.39). Since blowers have efficiency of about 30% (Joshi, 1981), the theoretical air discharge, Q_T, of the blower is calculated using Equation (3.40) or Equation (3.41).

The tangential component of absolute velocity, v_2, can be approximated as 20% of the peripheral velocity of the impeller (fan) tip (Joshi, 1981), hence using Equation (3.42):

Diameter of fan, $d_2 = 438\text{mm}$, $N = 470$ rpm therefore

$$V_2 = 0.2\pi \times 0.438 \times 470 \text{m/min} = \underline{129.346 \text{m/min}}$$

From Equation (3.41),

width of the fan blade, $w_2 = 300\text{mm}$, therefore,

$$Q_T = \pi \times 0.438 \times 0.3 \times 129.346 \text{ m}^3/\text{min}$$
$$= 53.3947^3/\text{min}$$

Required air flow rate

$$Q_A = 0.3Q_T = \underline{16.0184\ m^3/min}$$

The air velocity, v, can be calculated using Equation (3.39):

$$v = Q_A/wh \times 10^{-6}$$

Width of air channel, w = 412mm, the depth, h = 80mm, therefore

$$v = \frac{16.0184}{0.412 \times 0.08}\ m/min$$

$$= \underline{485.995 m/min}$$

5.4.6. Relationship between Work Done in Crushing and Breaking of Cowpea Stalk and Threshing Energy Requirement

The average work done in crushing and breaking of single cowpea stalk at about 8% MC, wb and 25mm/min rate of loading, are given in Table 5.22. These were estimated graphically as the area under the f - d curves obtained from compression and bending tests. The average values recorded were 0.00393J for crushing and 0.109 J for bending.

However, the actual energy expended in crushing and breaking the stalks is more than recorded, for during threshing a bunch of stalks (main and branch stalks) and grain-bearing pods is fed into the chamber. Hence the actual crushing and breaking energy, E_{cb} may be expressed as

Table 5.22: Work done in compression and bending at 8% MC, wb, and 25mm/min loading rate.

Variety	Compression* Force, N	Deformation, mm	Work done, J
TVX	194	0.108	0.0043
Ife brown	202	0.086	0.00389
IT 985	103	0.076	0.0036
Average	166	0.09	0.00393

Variety	Bending Force, N	Deflection, mm	Work done, J
	102	1.98	0.098
Ife brown	120	2.10	0.125
	93	2.04	0.104
Average	105	2.04	0.109

*Each value is a mean of three tests.

$$E_{cb} = \left[\sum (W_c + W) \right] k \quad - - - 5.9$$

Where k is an undetermined factor (whose value depends on the vegetative growth of cowpea and capcity of thresher) and W_c, W_b, are work done in crushing and breaking single main stalk.

Beside the energy for crushing and breaking stalks and pods, threshing energy includes the energy expended in overcoming the friction generated by the relative movements of materials within threshing chamber. The threshing energy, E_t, may therefore be expressed as

$$E_t = E_f + \left[\sum (W_c + W_b) \right] k \quad - - - 5.10$$

where E_f = energy expended in overcoming friction.

5.4.7 Specifications and Expected Performance of Redesigned Thresher

Table 5.23 gives the specifications of the redesigned cowpea thresher, These specifications were based on the threshing tests, studies on the crop properties and relevant literature. Some of the specifications are discussed below:

Type of cylinder: The spike-tooth cylinder has been found to be safe for the village farmer (Singhal and Thierstein, 1987); to have positive feeding action and

Table 5.23 Specifications of whole shoot cowpea thresher

Item	Specification
Overall dimension	1,500 x 680 x 1,440 mm
Type of cylinder	Spike-tooth, 120 spikes and 6 knives
Cylinder diameter	301mm at spike tip, 333mm at knife end.
Cylinder speed	350m/min (370 rpm) for seeds for planting. 50m/min (475 rpm) general-purpose grains.
Cylinder length	352mm
Cylinder bar	352 x 48 x 6.5mm steel bar, 6 in number
Type of concave	Open-grate
Concave width	410mm
Concave arc length	500mm
Cylinder-concave clearance	26mm at spike tip, 10mm at knife end
Concave grate	Circular holes 3mm apart, 2 sizes: 8.5 and 10mm dia
Fan housing	Circular
Fan blade	Straight type, rectangular 300 x 156mm.
Fan diameter	438mm

Table 5.23 contd.

Item	Specification
Fan speed	647m/min (470 rpm)
Air channel	Rectangular, 412 x 80mm
Air flow rate	16m^3/min
Capacity	141kg/hr at 350m/min 188kg/hr at 450m/min
Sieve	Circular holes 3mm apart, 5 sizes: 7, 8, 8.5, 9 and 10 mm dia
Driving power	3hp electric motor or internal combustion engine
Motor shaft speed	1490 rpm
Knife	3 in number, 32mm long, staggered on 2 opposite bars
Knife angle	60^o
Spike	Iron rods 16mm dia, 16mm long, 24 on 4 bars and 12 on 2 knife bars, 120 in all.
Main drive pulley	87mm dia
Fan pulley	275mm dia
Cylinder drive pulley	131mm dia
Cylinder pulley	166mm for 370 rpm, 130 mm dia. for 475 rpm.

low power consumption (Dodds, 1968; Singh and Kumar, 1976); and to be very effective in threshing of pods (Kepner et al, 1972) hence it is popular in legume combine harvesters. For these reasons the spike-tooth cylinder was selected.

Cylinder speed: Various studies have shown that the major limitation in increasing the thresher cylinder speed is grain damage since increased cylinder speed has positive effects of increases in power, capcity and output of the thresher and a negative effect of increased grain damage (Vas and Harrison, 1969; Harrington, 1970; Ige, 1978; Joshi and Singh, 1980; Ghaly, 1985). Since grain damage from the thresher trials was low (external: 0.06%, internal 0.86%), there was still room to increase the cylinder speed. It should be recalled that the recommended cylinder speed and concave clearance should be such that would limit the external damage to within 2% for grains for consumption (Kolganov, 1958; Bunnelle et al, 1959; King and Riddolls, 1960; Sharma and Devnani, 1979 and 1980), and internal damage to within 5% for seeds for germination (Kolganov,

1958; Richey et al, 1961; Chestney, 1969; Sharma and Devnani, 1979 and 1980). It is however known that cowpea grain is susceptible to internal damage owing to its loosely packed cotyledons (Ige, 1978, Sharma and Devnani, 1980). Also cowpea and soyabean, unlike rice, cannot resist high impact in cylinder-concave owing to their low compressive strength (Hoki and Esmay, 1979). The average compressive force of cowpea grain as found in this study was 69.3N and mean elastic modulus was 454 MPa. This is comparable to the elastic modulus of soyabean determined by Misra and Young (1981) as 435.88 MPa at 7.22% MC, wb.

High cylinder speed would subject the cowpea grain to high mechanical impact in the cylinder-concave and this would increase mechanical damage. None-the-less, the cylinder speed was increased slightly from 320 rpm (303m/min) to 370 rpm (350m/min) for threshing seeds for planting, and to 475 rpm (450m/min) for general purpose grains, at a concave clearance of 26mm, in order to

attain optimum thresher capacity and output.

Type of concave: The open-grate concave chosen is known to reduce power consumption and grain damage (Arnold and Lake, 1964). The concave grate being used as a separating device, eliminated the use of reciprocating rods and separating screens. This made the machine simple, less complicated and less costly.

Concave clearance: Threshing tests showed that a cylinder-concave clearance of 26mm from the tip of the spike, was adequate for threshing. This clearance gave low average grain damage (0.06%) and high threshing efficiency (99%) as shown in Table 5.20. The redesigned thresher had a clearance of 26mm at the tip of the spike and 10mm at the knife end.

Fan speed and air velocity: The threshing trials showed that fan peripheral speed of 647 m/min (470 rpm) was adequate for pneumatic separation of chaff and stalk from threshed cowpea grains without noticeable grain loss. Cleaning at this fan speed was so adequate that no mechanical separators were necessary. The grains however contained a fairly high percentage of chaff (3.12%) which could be reduced by insertion of an additional sieve at the grain chute, and use of appropriate sieve size.

As this study was restricted to selected physical and mechanical properties of cowpea, the aerodynamic properties, like the terminal velocity, were not determined. But the suspension and terminal velocities of threshed materials from selected crops displayed in Table 5.24, shows that the air

Table 5.2 Suspension/terminal velocities of threshed materials from selected crops

Material	Crop	Suspension velocity+ ft/min	m/min
Chaff	Wheat, oats & barley	300-500	91-152
Straw	Wheat, oats & barley up to 173 mm long	400-1200	122-366
Grain	Wheat, oats & barley	1000-1900	305-579

Grain	Terminal velocity* ft/min	m/min
Wheat	1140-1800	347-549
Oats	1020-1560	311-475
Corn	1560-2520	475-768
Soyabean	1800-3600	549-1097

+Source: Cooper, 1966

*Source: Mohsenin, 1970

velocity of 486m/min calculated from the chosen fan speed (470 rpm) was well above the terminal velocities of threshed stalk and chaff, which did not exceed 366m/min. The knives introduced in the modification of the thresher would further reduce the stalks to easily air-borne pieces. Moreover the calculated air velocity (486m/min) was lower than the highest terminal velocity range 549 - 1097 m/min recorded for soyabean. It was therefore not advisable to increase the fan speed further to avoid exceeding the terminal velocity of cowpea grain, which would result in grain loss since the terminal velocity of cowpea was not precisely known.

The calculated air flow rate for cleaning threshed cowpea by pneumatic separation only was $16m^3$/min. Singh et al (1978) had recommended an air flow rate of $12m^3$/min for cleaning decorticated groundnut but their design included a mechanical eccentric and separating screen in addition to pneumatic cleaning.

Expected performance: The modified cowpea thresher would be expected to thresh whole shoot cowpea without clogging and stoppage which were the case with the pod thresher. With the increase in machine dimension, power, cylinder speed and the installation of knives in the cylinder, the machine would be expected to accommodate more material, thresh faster, and reduce the stalks to smaller pieces that could be more easily blown out. The machine residue would be reduced when necessary through the evacuating chute to give room to fresh material. The additional sieve at the grain chute would result in cleaner seeds..

While the five grades of sieves and the two grades of concave grate would enable the machine to thresh efficiently all common varieties of cowpea. With the installation of the knives, it would be possible to thresh whole shoot cowpea efficiently at moisture contents higher than 8% wb which was the moisture level at which the cowpea stalk became very brittle. The modified thresher would be expected to thresh whole shoot cowpea efficiently at 12 to 10% MC, wb. But it should be noted that the higher the stalk moisture content, the greater the cutting action, and the more the power requirement. Ghaly (1985) has observed that stalk cutting greatly increased the power requirement in threshing wheat.

Based on the threshing trials and subsequent calculations, the new thresher would be expected to have a capacity of about 114kg/h and grain output of 32kg/h at threshing efficiency of about 98% with less than 1% chaff in grain and 1% grain damage. At higher cylinder speed (450 m/min) the machine capacity would be expected to rise to about 188kg/h with 40kg/h grain output and with grain damage within 2%.

Chapter 6

SUMMARY AND CONCLUSIONS

Harvesting is one of the greatest bottlenecks in cowpea production. Hand picking of pods is a very tedious, time-consuming and costly operation. Since the pods are produced all over the shoot, mechanical harvesting of cowpea will entail the cutting of the entire plant shoot which on drying will be threshed to extract the grains. This suggests that the present machine for threshing cowpea pods has to be redesigned to handle the entire crop shoot.

This project was set out to study the selected physical and mechanical properties of cowpea that are related to the mechanical threshing of the entire cowpea shoot and redesign the pod thresher to handle the entire shoot.

The physical properties studied were limited to grain size and pod pericarp thickness, moisture content and the stalk dimensions which were necessary for the determination of the mechanical properties. The mechanical properties of the stalk in radial compression and simple bending and grain in uniaxial compression were studied and the minimum cracking force of the pods was measured.

From these studies it was found that the real problem did not lie on the pods which required very small force to break; nor on the grain which were strong enough to resist any secondary impact.

But the problem was on the stalk which formed the bulk of the threshing material. It was however observed that the woody stalks easily broke on bending. This finding encouraged the decision to embark upon whole shoot threshing trials using an existing pod thresher. The result of the trials was very encouraging. The thresher successfully extracted the grains, and threw out most of the materials from the chaff chute. However, the thresher suffered from clogging caused mostly by crushed small stalk which were too fluffy to break in the threshing chamber.

Finally a redesign of the pod thresher was embarked upon. The size of the machine was increased since more materials were now to be handled. The threshing cylinder was redesigned to include eight knives set at 60° knife angle to ensure optimum cutting of the stalk. An additional sieve was inserted at the grain chute to delay the falling grains for better cleaning. Five sizes of sieve, and two sizes of concave grate were recommended for different sizes of cowpea grains. A matching driving power of 3hp was suggested and two cylinder speeds of 350m/min and 450m/min were put forward for seeds for planting and general purpose grains respectively, at a concave clearance of 26mm.

The following conclusions were drawn from the study:

1. Cowpea kernel size is significantly different in different varieties. Of the seven varieties studied, five have grains that are significantly different in size. The mean grain size ranged from 6.35 to 9.18mm in length, 5.24 to 7.44mm in width, and 4.0 to 5.82mm in thickness. Different sizes

of sieve are therefore necessary for cowpea threshing.

2. The thickness of the pod pericarp is significantly different in different varieties of cowpea and is found to be related to the grain size. Small grain cowpeas have thin pericarp while large grain varieties have thick pericarp. The mean pericarp thickness ranged from 0.346 to 0.824mm at 0.158 to 0.265 standard deviation.

3. The minimum force required to crack the pod is significantly different in different varieties of cowpea studied. The mean force ranged from 7.25N for small grain, to 29N for large grain cowpea variety and the force is highly sensitive to small changes in the pod moisture content.

4. The minimum cracking force of pod and field shatter losses are closely related to the pod pericarp thickness. Cowpeas with thick pericarp have large grains and higher cracking force, and do not shatter in the field. The cowpea variety with pericarp thickness of 0.824mm and minimum cracking force of 29N did not shatter in the field.

5. Regression analyses show that the moisture content has linear relationship with pod minimum cracking force and stalk mechanical properties in different varieties of cowpea studied. The simple regression models for predicting the mechanical properties from moisture content are as follows: For mechanical properties of stalk in radial compression

$$\varepsilon_c = 0.09457 - 0.0002337MC \quad (5.1)$$

$$E = 34.5236 - 0.2704MC \quad (5.2)$$

$$\sigma_c = 5.4377 - 0.0465MC \quad (5.3)$$

$$7.6\% \leq MC \leq 61.2\% \text{ wb}$$

For stalk in simple bending,

$$E = 3614.6846 - 49.2434MC \quad (5.4)$$

$$\sigma_b = 36.5492 - 0.4562\ MC \quad (5.5)$$

$$7.88 \leq MC \leq 70\% \text{ wb}$$

And for the minimum cracking force of pods

$$F = 2.0285\ MC - 9.538 \quad (5.6)$$

$$F = 3.7905\ MC - 16.7689 \quad (5.7)$$

$$F = 3.3722\ MC + 1.6621 \quad (5.8)$$

For TVX 3236, Ife brown and IT 985 respectively.

$$6.9 \leq MC \leq 9.3\% \text{ wb}$$

6. Hertz elastic theory of contact stresses has been found to be useful in calculating the elastic modulus of cowpea grain in uniaxial compression assuming the grain to be ellipsoidal in shape. It was also applied to calculate the contact width and the crushing strength of stalk in radial compression.

7. Basic flexure formulae of a hollow cylinder simply supported on both ends and loaded at the mid-span, has been found applicable for calculating the elastic modulus and the bending strength of cowpea stalk in simple bending.

8. The elastic modulus of cowpea grain in uniaxial compression is not significantly affected by the cowpea variety or the rate of loading. The mean elastic modulus of grain was

found to be 454 MPa (SD. 94) and mean crushing force of grain, 69.3N (S.D. 24.7), at 7.5% MC, wb.

9. Cowpea stalk is a viscoelastic material since its mechanical properties in radial compression are significantly influenced by the moisture content and the rate of loading.

10. The mechanical properties of cowpea stalk in simple bending is significantly influenced by moisture content. The effect of the rate of loading is not statistically significant. The mean properties at different moisture content were as follows: at 70% MC, wb, elastic modulus was 458 MPa, bending strength 6.35 MPa; at 22.5%, elastic modulus was 1273 MPa, bending strength 18.9 MPa; and at 7.88%, 4170MPa and bending strength 38.6MPa.

11. The mechanical properties of cowpea stalk are found to increase with the decrease in moisture content and increase in the rate of loading. The mean properties of stalk at different moisture content and rate of loading were as follows: The crushing strain, elastic modulus and crushing strength of stalk in radial compression at 25mm/min loading rate were 0.082, 17.4MPa and 2.59MPa respectively, at 61.2% MC, wb; 0.091, 23.2MPa and 3.67MPa respectively, at 19.9% MC; and 0.099, 30.4MPa and 5.10MPa respectively, at 7.9% MC. The mean properties in radial compression at 7.9% MC, wb at different rates of loading were 0.104, 21.0MPa and 3.59MPa respectively at 12.5mm/min rate of loading; 0.099, 30.4MPa and 5.10MPa respectively at 25mm/min; and 0.082, 54.5MPa and 8.02MPa respectively

at 50mm/min rate of loading. While the mean elastic modulus in simple bending and the bending strength of stalk at different rates of loading were 1311 MPa and 19.1 MPa respectively at 12.5mm/min rate of loading; 1346 MPa and 23.2 MPa respectively at 25mm/min; and 3244MPa and 22.4 MPa respectively at 50mm/min.

12. The influence of variety on the mechanical properties of cowpea is mostly insignificant. Variety has only a significant effect on the crushing strain of stalk in radial compression.

13. The examination of force-deformation/deflection curves from the tests show that cowpea stalk has no bioyield point. For stalk in radial compression, failure occurs at pith cracking. In simple bending the cowpea stalk breaks at the maximum bending force.

14. Force-deflection curves of cowpea stalk in simple bending at different moisture contents show that wet stalks (70% wb) do not break on bending but the deflection continues to increase at a constant force. At intermediate moisture (20% wb) the deflection increases at a constant force for sometime before breaking. But when dry (about 8% wb) the stalk breaks instantly at maximum bending force.

15. The stalk moisture content for threshing should be about 8% wb and below. That is the moisture content at which the stalk can break instantly at the maximum bending force.

A farmer can detect this when the stalk of his cowpea can break instantly on bending with hand.

16. Whole shoot of some varieties of cowpea can be threshed in the conventional pod thresher at the stalk moisture content of (5.5 - 6% wb) but the process has to be slow to avoid clogging and machine stoppage.

17. Different varieties of cowpea stalk behave differently in the threshing machine concave, large grain varieties with woody stalk will break, small grain type with numerous small stalk will be crushed into spongy mass. This results in clogging. A successful design will take into account the different behaviour of the varieties. Any design based on few/similar varieties will not be versatile.

18. Examination of the threshing process and the contents of the threshing chamber at different stages of threshing portrays that failure of the stalks was mainly by bending and crushing. The crushing was found to be initially radial before pulping followed. This confirms the failure theory of agriculutral products in the machine concave put forward by Anazodo (1980).

19. The energy required for crushing and breaking of single main stalk of cowpea at 8% moisture content, wet basis and 25mm/min loading rate, were 0.00393 and 0.109 J respectively; while the threshing energy requirement of the whole shoot thresher was estimated as 139 J at 450m/min cylinder speed and 8% stalk moisture content.

20. An air flow rate of 16m^3/min has been found to be adequate for pneumatic cleaning of threshed whole shoot cowpea.

21. Pod thresher is defective in handling the entire shoot of cowpea because of clogging caused by crushed stalks, its small size for handling much bulkier material, non-evacuation of the accumulated residues and poor cleaning of the grains.

22. And finally, a design of cowpea thresher to handle the entire plant shoot was proposed.

Chapter 7

RECOMMENDATIONS FOR FURTHER RESEARCH

The following areas for further research were recommended:

1. The Poisson's ratio for cowpea should be accurately determined using proper instrumentation. In this study Poisson's ratios of 0.39 for the stalk in radial compression and 0.35 for the grain in uniaxial compression were adopted by studying the literature on Poisson's ratios of similar materials.
2. Dynamic tests on cowpea stalk, pod and grain should be carried out to compare their viscoelastic behaviour in the high range of strain frequency with that under quasi-static loading.
3. Studies are necessary to investigate the effect of temperature and other environmental conditions on the viscoelastic behaviour of cowpea using instrument with adequate environmental chamber.
4. Work is required on the aerodynamic properties of threshed cowpea grain, pod shells and stalk in order to determine precisely their terminal velocities which are necessary for pneumatic separation.

5. There is a great need for the crop breeders to come up with high yielding varieties of cowpea adequate for mechanization. The necessary characteristics of such variety have been discussed in Chapter 5.

6. Construction and test of the proposed design of whole shoot thresher is necessary to determine accurately the machine parameters and confirm the expected performance of the machine.

7. Further work is required to incorporate a straw pick-up mechanism in a tractor-operated cowpea whole shoot thresher, The machine can then pick up dry cowpea shoots from the field swath and thresh them along.

8. In line with the above, research has to be undertaken on adequate mowing machine for cowpea stalks.

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APPENDICES

APPENDIX A

SOME PHYSICAL PROPERTIES OF COWPEA GRAIN

Table A1: Mean grain densities and thousand kernel weight (TKW) of three varieties of cowpea

Variety	MC, % wb		Bulk density, gcm^{-3}		Solid density gcm^{-3}		T K W, g		No. of cases
	Pod	Grain	Mean	S.D			Mean	S.D.	
TVX 3236	6.95	7.19	0.813	0.011	1.23	0.020	97.2	1.76	3
Ife brown	7.27	7.25	0.772	0.009	1.23	0.010	159	3.81	3
IT 985	6.89	7.31	0.780	0.007	1.24	0.017	210	1.81	3
Entire pop.	7.04	7.25	0.789	0.20	1.23	0.015	155	48.8	9

APPENDIX B

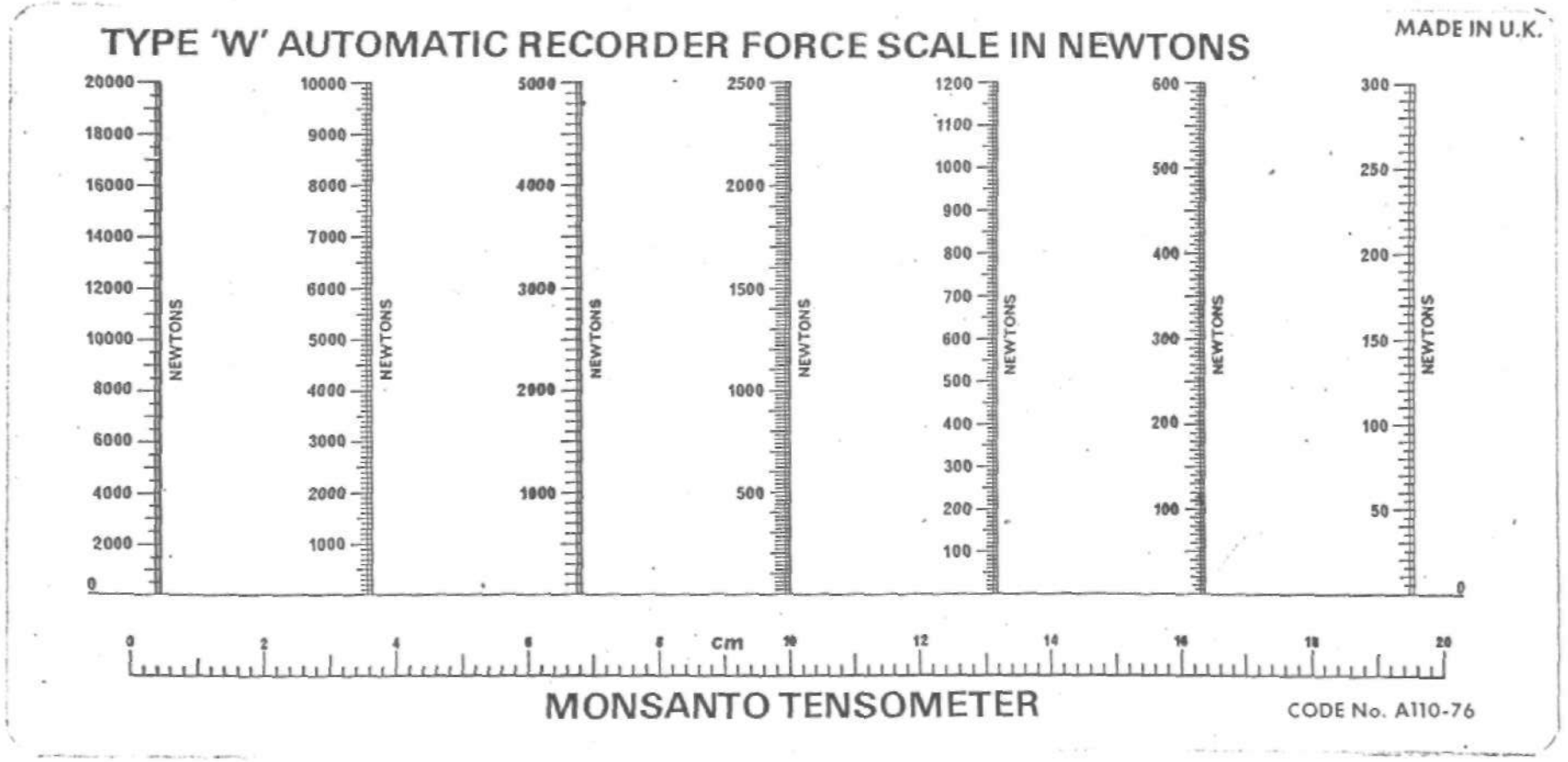
CHARACTERISTICS OF THE SOIL USED FOR THE PRODUCTION OF (COMPEA) TEST SAMPLES

Table B1: Soil analysis

Soil classification	Sandy loam
% clay	8.0
% fine silt	4.1
% coarse silt	33.9
% coarse sand	16.5
Lower plastic limit	16.15
Upper plastic limit	41.34
Plasticity number	25.07
Bulk density	1.53gcm^{-3}

APPENDIX C

COPY OF PLASTIC SCALE FOR MOSANTO TENSOMETER W



APPENDIX D

THE TERM Z AS USED IN DETERMINATION OF ELASTIC MODULUS AND CRUSHING STRENGTH OF STALK IN RADIAL COMPRESSION

Theory: The term Z defined as

$$Z = R/b \quad (3.8)$$

was used by Sherif et al (1976) to simplify the Timoshenko and Goodier (1970) equation for calculating the elastic modulus of cylindrical biomaterial of length l from Poisson's ratio, μ, radius of curvature, R, and half contact width, b.

E is estimated from the equation

$$\varepsilon_c = (\ln(2Z) + \tfrac{1}{2})/2Z^2 \quad (3.12)$$

Z obtained is used directly in Sherif's equation

$$E = 4FZ^2(1 - \mu^2)/\pi Rl \quad (3.7)$$

to obtain the elastic modulus. While b obtained from the definition (equation 3.8) is used to calculate the crushing strength from Hertz equation

$$\sigma_c = q_o = 2F_c/\pi lb \quad (3.13).$$

Table D1: Values of Z at different values of ε_c

ε_c	Z	ε_c	Z	ε_c	Z
o.010	13.80	0.031	7.20	0.052	5.23
0.011	13.08	0.032	7.00	0.053	5.17
0.012	12.44	0.033	6.89	0.054	5.11
0.013	11.88	0.034	6.80	0.055	5.06
0.014	11.38	0.035	6.60	0.056	5.00
0.015	10.92	0.036	6.52	0.057	4.95
0.016	10.52	0.037	6.45	0.058	4.90
0.017	10.15	0.038	6.35	0.059	4.85
0.018	9.83	0.039	6.20	0.060	4.80
0.019	9.52	0.040	6.10	0.061	4.75
0.020	9.24	0.041	6.03	0.062	4.70
0.021	8.96	0.042	5.95	0.063	4.66
0.022	8.75	0.043	5.90	0.064	4.60
0.023	8.45	0.044	5.75	0.065	4.57
0.024	8.30	0.045	5.70	0.066	4.52
0.025	8.11	0.046	5.60	0.067	4.48
0.026	7.85	0.047	5.55	0.068	4.44
0.027	7.85	0.048	5.49	0.069	4.40
0.028	7.65	0.049	5.45	0.070	4.35
0.029	7.40	0.050	5.36	0.071	4.33
0.030	7.29	0.051	5.29	0.072	4.29

Table D. 1 Contd.

ε_c	z	ε_c	z	ε_c	z
0.73	4.25	0.094	3.63	0.115	3.20
0.074	4.22	0.095	3.61	0.116	3.18
0.075	4.18	0.096	3.59	0.117	3.17
0.076	4.15	0.097	3.56	0.118	3.15
0.077	4.11	0.098	3.54	0.119	3.13
0.078	4.08	0.099	3.52	0.120	3.12
0.079	4.05	0.100	3.50	0.121	3.10
0.080	4.02	0.101	3.48	0.122	3.08
0.081	3.99	0.102	3.45	0.123	3.07
0.082	3.95	0.103	3.43	0.124	3.05
0.083	3.93	0.104	3.41	0.125	3.04
0.084	3.90	0.105	3.39	0.126	3.02
0.085	3.87	0.106	3.37	0.127	3.00
0.086	3.84	0.107	3.35	0.128	2.99
0.087	3.81	0.108	3.33	0.129	2.97
0.088	3.79	0.109	3.31	0.130	2.96
0.089	3.76	0.110	3.29	0.131	2.95
0.090	3.73	0.111	3.27	0.132	2.93
0.091	3.71	0.112	3.25	0.133	2.92
0.092	3.68	0.113	3.24	0.134	2.90
0.093	3.65	0.114	3.22	0.135	2.89

APPENDIX E

TRADITIONAL THRESHING OF COWPEA



Plate E1: Traditional method of theshing cowpea by beating the pods with stick



Plate E2: Traditional winnowing of cowpea using the wind current

APPENDIX F

DESCRIPTION OF COWPEA

The cowpea (Vigna unguiculata (L.) Walp) probably originated from Central Africa where many native wild varieties exist (Piper 1913, Vavilor 1950, Bellschop 1962, Faris 1964). Today it is widely grown in many parts of the world. There are many varieties of cowpea. The main features that distinguish one variety from another are the colour of the seed coat, wrinkled or smooth seed-coat, the size and shape of pods, and determinate and indeterminate growth of the stem (Onwueme, 1979).

Cowpea is grown for food and the haulms are important as fodder. In Nigeria the major cowpea growing areas lie north of latitude 10^{o}N (Steele, 1972). However the production of cowpea is fast increasing, and in recent years cowpea production in southern Nigeria as a late crop, is gaining ground.

Cowpea is a leguminous annual plant requiring 12 - 15 weeks from planting to harvesting. Although there is now a variety (IT 82S - 60) that matures in 60 days, most varieties mature in about 12 weeks. Cowpea has a tap root system which can penetrate the soil to the depth of three metres or more. The stem of cowpea is weak and at times creeps on the ground. The growth of the stem help to identify the cowpea varieties. In some, the stem grows to full size and stops. In these the growth is determinate. While in others where the stem continues to grow throughout the life of the plant, the stem is said to be indeterminate. The leaf is trifoliate, dark-green and hairy.

Each leaf is borne on a long petiole. There is a leaf-like appendage, known as stipule, at the point of attachment of each leaf petiole to the stem.

The inflorescence is borne on long peduncle developing from the leaf axil. The flower resembles a typical legume flower except that nine stamens are fused together out of 10. The flower is self-pollinated (Onwueme, 1979).

Cowpea has a typical legume fruit. The dehiscent pod is long and narrow. It consists of the pericarp and seeds. The pericarp forms protective cover for the seeds. It is made up of three layers of cells namely (from the outside to inside): the exocarp, the mesocarp and the endocarp (Fig F1). The exocarp consists of the outer epidermis and hypodermis, both with thickened cell walls. The mesocarp is made up of loosely packed parenchyma. While the endocarp comprises the thick-walled sclerenchyma and the inner epidermis. Both the hypodermis and sclerenchyma are elongated cells but their axis of elongation are in opposite planes. They shrink in opposite directions when they lose moisture, the stresses developed aid the opening of the mature dry pod. The pod splits on both sides when dry (Esau, 1977).

Cowpea seeds have smooth or wrinkled seed coat. The colour varies in different varieties. The most common are white, brown, black and mottled varieties. The cowpea seed is a nonendospermous kidney - shaped seed with two basic parts: the seed coat and the embryo. The embryo is made up of two fleshy cotyledons which make up the bulk of the seed. The cotyledons supply food to the

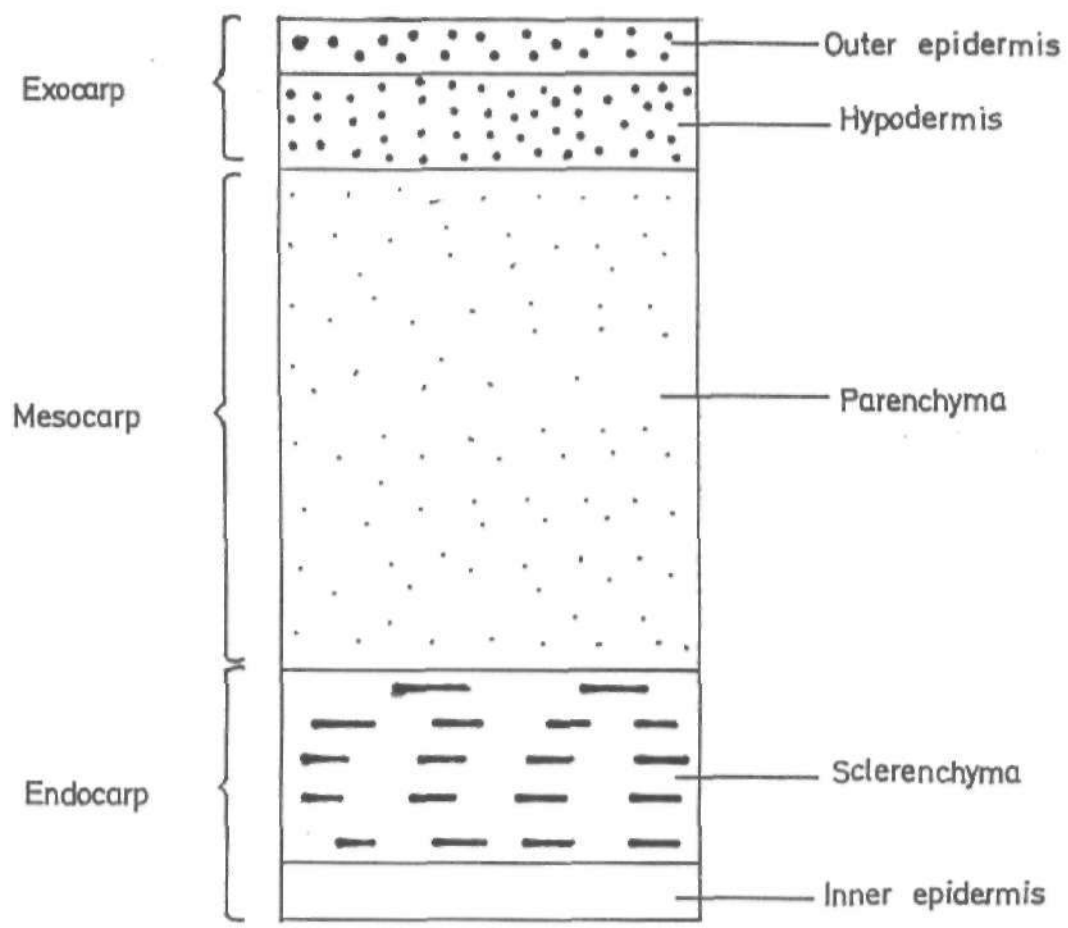
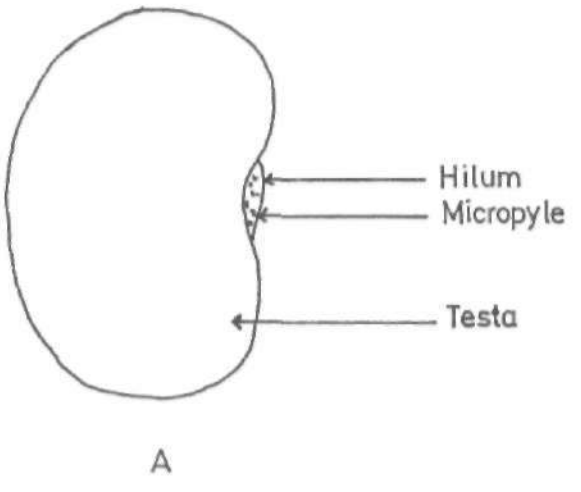


Fig. F.1. Simplified structure of cowpea pod pericarp in cross-section.

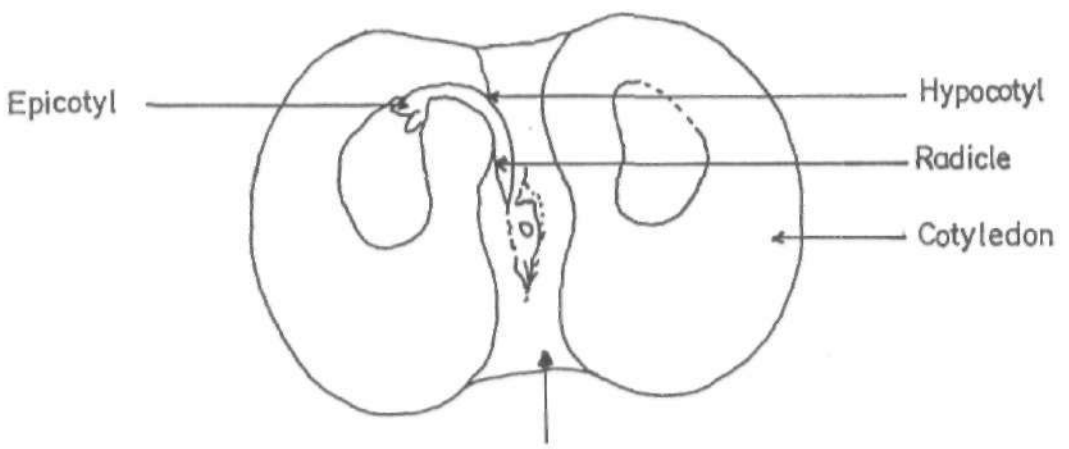
young seedling during the early growth. The relatively thin seed coat protects the embryo from fungi and bacteria before and after planting. The seed will have little chance of developing into a healthy seedling if the protective coat is cracked during threshing and other handling.

The embryo is made up of two parts: the radicle (primary root) and the plumule (the shoot). The plumule is made up of the hypocotyl and the epicotyl located under the seed coat at one end of the hilum which is the point of attachment of the seed to the pod. The hypocotyl lifts the cotyledons out of the soil during germination while the epicotyl forms the shoot. The colour of the cowpea hilum is typical as it is usually white surrounded by a dark (brown or black) ring. A tiny opening in the testa known as the micropyle occurs at the centre of hilum. The micropyle is quite visible when the testa is removed (Fig F2, Onwueme 1979).

The living cell is the basic unit of the cowpea. The cell consists of protoplasm enclosed by a cell wall which is made up of cellulose microfibrils embedded in an amorphous matrix. The rheological properties of the cell wall are responsible for the elasticity, strength and rigidity of the biomaterial. The protoplasm inside the cell wall consists of the cytoplasm, nucleus and vacuoles. The vacuoles consist of droplets of solution called cell sap. While the major factor responsible for the elasticity of the biomaterial is the elastic cell wall, the cell sap is responsible for exerting hydrostatic pressure (tungor pressure) on the cell walls. The cytoplasm exhibits both elastic and viscous properties. The cell wall and the protoplasm are responsible for the viscoelastic properties (Mohsenin, 1970).



A



B

Fig. F.2. Cowpea seed structure (A) An external view (B) Cotyledons spread apart

APPENDIX G.

Calculation of Mechanical Properties from Observed Readings

Stalk mechanical properties in radial compression:

Consider the following readings obtained from radial compression test of a stalk sample (TVX 3236) at 7.6% moisture content, wet basis:

Rate of loading = 12.5mm/min

Stalk diameter, 2R = 6.4mm

Stalk sample length, l = 20.1mm

Force at pith cracking, F_c (from f - d curve)

= 131.5N

Recorded deformation, D (from f - d curve)

= 1.01mm

Estimated degree of elasticity, β = 78.2%

(see Fig 5.1)

Crushing strain, ε_c :

From Equation (3.10), elastic component of deformation at pith cracking

$D_c = \beta D/100$

$D_c = 0.782 \times 1.01\text{mm} = 0.7898\text{mm}$

The crushing strain, ε_c, is given as

$\varepsilon_c = D_c/2R = 0.7898/6.40 = \underline{0.1234}$

Elastic modulus, E

Using Equation (3.12), Z is estimated by trial and error as follows:

$$\varepsilon_c = (\ln(2Z) + \tfrac{1}{2})/2Z^2$$

$$0.123 \simeq \left[\ln(2 \times 3.07) + 0.5\right] / 2 \times (3.07)^2$$

$$\therefore Z = 3.07$$

The elastic modulus is calculated from Equation (3.7)

$E = 4F_c Z^2(1 - \mu^2)/ \pi Rl$

The Poisson's ratio, μ = 0.39 (See Section 5.3.2).

$\therefore$ $E = 2.159F_c Z^2/2Rl$

$E = 2.159 \times 131.5N \times (3.07)^2/6.4mm \times 20.1mm$

$= \underline{20.8008 N/mm^2 \text{ or } MPa}$

Half contact width, b, at pith cracking:

From Equation (3.8)

$Z = R/b$

$\therefore$ $b = R/Z$

$= (6.4 mm/2)/3.07$

$b = \underline{1.0423mm}$

Crushing strength, σ_c :

From Equation (3.13)

$\sigma_c = q_o = 2F_c/ \pi lb$

$= 0.63662 F_c/lb$

$= (0.63662 \times 131.5N)/(20.1 \times 1.0423mm)$

$= \underline{3.9959N/mm^2 \text{ or } MPa}$

Stalk mechanical properties in Simple bending:

Consider the following readings obtained in a simple bending test of a cowpea stalk sample (Ife brown) at 7.88% moisture content, wet basis:

Rate of loading - 25mm/min

Stalk diameter, d = 6.6mm

Hollow pith diameter, d_o = 1.73mm

Max. breaking force, F_b = 85N

Max. deflection, ν = 2.5mm

Degree of elasticity, β = 62%

The elastic component of deflection, ν_e is calculated from Equation (3.28)

$$\nu_e = \nu\beta/100$$

$$\nu_e = 2.5\text{mm} \times 0.62$$

$$= \underline{1.55\text{mm}}$$

Then <u>the elastic modulus, E</u> is calculated from equation (3.29)

$$E = 4F_b l^3/3\nu_e \pi(d^4-d_o^4)$$

But the bending span, l = 50mm, is constant

$$\therefore E = 53051.65F_b/\nu_e(d^4-d_o^4)$$

$$E = 53051.65 \times 85/1.55((6.6)^4 - (1.73)^4)\text{N/mm}^2$$

$$= 4509390.25/2927.20\text{N/mm}^2$$

$$E = \underline{1540.5132\text{MPa}}$$

The <u>bending strength, σ_b</u> is calculated from Equation (3.23)

$$\sigma_b = 8F_b ld/\pi(d^4-d_o^4)$$

$$l = 50\text{mm}$$

$$\therefore \sigma_b = 127.324F_b d/(d^4 - d_o^4)$$

$$= 127.324 \times 85 \times 6.6/1888.5162\text{N/mm}^2$$

$$\sigma_b = \underline{37.8227\text{MPa}}$$

Elastic modulus of cowpea grain in unaxial compression :

Consider the following readings obtained from a uniaxial compression test of a cowpea grain sample (IT 81D - 985) at 6.5% moisture content, wet basis:

Rate of loading - 12.5mm/min

Grain dimensions: length = 8.09mm

Width = 7.01mm Thickness = 4.67mm

Crushing force, F = 59.9N

Deformation, D = 0.55mm

Degree of elasticity, β = 50%

Poisson's ratio, μ = 0.35

Assuming the cowpea grain to be ellipsoidal in shape, the major and minor radii of curvature R_1 and R_1' are calculated using the measurements of length, l, width, w and thickness, t, and substituting these values in Equations (3.17) and (3.18) respectively.

$$R_1 = (l^2 + t^2)/4t$$

$$R_1' = (w^2 + t^2)/4t$$

Thus,

$$R_1 = ((8.09)^2 + (4.67)^2)/4 \times 4.67$$

$$R_1 = \underline{4.6711mm}$$

$$R_1' = ((7.01)^2 + (4.67)^2)/4 \times 4.67$$

$$R_1' = \underline{3.7981mm}$$

The elastic component of deformation, D_e, is determined from Equation (3.10) as:

$D_e = \beta D/100$

$D_e = 0.50 \times 0.55mm$

$= 0.275mm$

Then using Equation (3.16), the elastic modulus, E, of the cowpea grain is determined as

$$E = 1.502 F(1 - \mu^2) \left[\left(\frac{1}{R_1} + \frac{1}{R_1'} \right) / D_e^3 \right]^{\frac{1}{2}}$$

The Poisson's ratio $\mu = 0.35$

$$\therefore E = 1.318 F\left(\left(\frac{1}{R_1} + \frac{1}{R_1'} \right) / D_e^3 \right)^{\frac{1}{2}}$$

$E = 1.318 \times 59.9(0.477/(0.275)^3)^{\frac{1}{2}} N/mm^2$

$= \underline{378.0963 MPa}$

APPENDIX H

Calculation of Some Thresher Parameters from Measured Data.

Total Kinetic Energy of IAR Thresher

The total kinetic energy, K.E., generated by the IAR thresher at a given angular speed, ω, is given by:

$$K.E. = \tfrac{1}{2}\,\omega^2 (I_s + I_c + I_p) \quad (3.45)$$

where I_s, I_c and I_p are the polar moments of inertia of the shaft, threshing cylinder and the pulley respectively.

$$I_s = \tfrac{1}{2}\, m_s R_s^2 \quad (3.46)$$

where m_s = mass of shaft = 1.87kg

R_s = radius of shaft = 0.012m

$$I_s = \tfrac{1}{2} \times 1.87 \times (0.012)^2 \text{ kg - m}^2$$

$$= \underline{0.000134 \text{ kg-m}^2}$$

The moment of inertia of cylinder:

$$I_c = I_b + I_d \quad (3.47).$$

where I_b, I_d = moments of inertia of the cylinder bars and support discs, respectively.

$$I_d = \tfrac{1}{2} m_d R_d^2 = \tfrac{1}{2} \times 6.27 \times (0.128)^2$$
$$= \underline{0.05136} \text{ kg-m}^2$$

$$\therefore I_c = I_b + I_d = \underline{0.25336 \text{ kg-m}^2}$$

The polar moment of inertia of the pulley, I_p, is given by:

$$I_p = \tfrac{1}{2} m_p R_p^2 = \tfrac{1}{2} 3.15 \times (0.15)^2$$
$$= \underline{0.03544 \text{ kg-m}^2}$$

At 475 rpm

$$\omega_o = \frac{2\pi \times 475}{60} \text{ rad/s.}$$

Therefore the kinetic energy of the whole shoot thresher is obtained as:

$$K.E. = \tfrac{1}{2} \times \left(\frac{2\pi \times 475}{60}\right)^2 (0.289) \text{ J}$$
$$= \underline{357.53} \text{ J}$$