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EFFECT OF MOISTURE CONTENT AND LOADING ORIENTATION ON STRENGTH PROPERTIES OF CORN COBS

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Abstract: This study investigated the effect of moisture content and loading orientation on strength properties of corn cobs using the Testometric Universal Testing Machine at crosshead speed of 10 mm/min. The strength properties investigated were bio yield point, yield point, rupture point, bio yield strength, compressive strength, rupture strength, modulus of stiffness, modulus of toughness, modulus of resilience and modulus of elasticity. Results show that all the properties decreased with increase in moisture content with values being higher at lateral loading than longitudinal loading, except for the Modulus of resilience that gave higher values on longitudinal loading orientation.

In the moisture range of 5.87 to 28.4%, bio yield point decreased from 685 to 220 N and 570 to 150 N at the lateral and longitudinal loading orientation, respectively.

Yield point decreased from 2223.6 to 800 N and from 1200 to 600 N, while rupture point decreased from 2130 to 1120 N and from 1280.7 to 576 N on lateral and longitudinal loading, respectively.

Biofield strength decreased from 9.5 to 2.9 N/mm^2 and 5.5 to 2.6 N/mm^2, compressive strength from 3010 to 800 N/mm^2 and 2550 to 650 N/mm2, and rupture strength from 2500 to 600 N/mm^2 and 2000 to 300 N/mm^2 in the above moisture range and loading orientations.

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Modulus of elasticity decreased from 2500 to 320 N/mm^2 and 2200 to 150 N/mm^2, Modulus of stiffness from 2600 to 420 N/mm and 2300 to 120 N/mm, Modulus of toughness from 240 J to 100 J and 210 J to 80 J, while Modulus of resilience decreased from 440 to 100 J and 500 to 150 J, for lateral and longitudinal loading respectively, in the above moisture range. Regression equations that could be used to express the relationship existing between the strength properties and cob moisture content were established and these yielded very high coefficients of determination.

***Key words**: Bio yield point, moisture content, loading orientation, corn cobs, strength properties, compressive strength, modulus of elasticity*

INTRODUCTION

Corn with the scientific name of *Zea mays* L. is a valuable grain crop that forms the major component of the staple food of many people groups across all the geopolitical zones of Nigeria. Corn has been an important food crop for the people for up to 4500 years now [2]. It is one of the most notable crops and a great means of capturing and storing energy and nutrient for human consumption. The grains therefore, the primary sources of food for mankind. The grains are attached to cobs which at maturity and plucked from the stalks, dehusked and shelled. During the shelling operation, forces are applied to detach the grains from the cobs. The system that is employed must be designed to function with minimum grain damage. A considerable amount of damage to the grains during shelling operations can lead to reduction in quality and economic value. This constitutes such a major bottleneck that has made the reduction of pre and post-harvest losses to now be a common food strategy throughout the world [3]. In some cases, the grains are stored on cobs in silos and cribs. The loading orientation of the material normally determines the behavior it will exhibit in storage. The response of a material to the action of forces on it during the operation of technological processes is governed by its mechanical properties. Mechanical properties can be defined as those characteristics that have bearing with the behaviour of the material under applied forces [4]. Mechanical properties that are time dependent are considered as rheological [4]. Aviara et al. [5] noted that the moisture content of the product being handled has effect on the adjustment and performance of the handling equipment and that a range of moisture content normally exists within which optimum performance is usually achieved. Therefore, in order to design and develop the equipment for handling, conveying, separating, drying, storing and processing the corn crop, the understanding of the mechanical properties of the cobs as affected by moisture content and loading orientation is necessary.

Several studies have been conducted on the physical and mechanical properties of agricultural materials.

Examples are [6] and [7] Tiger nut, [8] and [9] *Balanites aegyptiaca* nut, [10] *Conophor* nut, [11] *Mucuna flagellipes* nut, [12] *Brachystegia eurycoma* seed, [13] Sweet corn plant, [14] Millet stem, [15] Corn grains and [16] Bell pepper fruit. In the study of the mechanical properties of biological materials, it is normally assumed that the techniques employed in evaluating the behavior of conventional engineering materials will be applicable.

Linear elastic theory is normally assumed although agricultural materials being composed of solid and fluids do not act in a purely elastic manner, rather, their resistance to applied load is a combination of elastic, plastic and viscous behaviours [4]. The aim of this study is to determine the mechanical (strength) properties of corn cob as a function of moisture content and loading orientation using the Universal Testing Machine (UTM).

MATERIAL AND METHODS

Sample Procurement and Preparation

The bulk sample of corn cob used in the study was obtained from the main market in Biu town, Biu LGA of Borno State, Nigeria. The cobs were already dehusked and dried. Whole and unshelled cobs were selected and used for the experiments. Broken and shelled or partially shelled cobs were discarded. The useable samples were divided into four portions each packaged in a hessian bag, and transported to the Processing Laboratory of the Department of Agricultural and Bioenvironmental Engineering, Federal Polytechnic Bida, Bida LGA, Niger State, Nigeria, for the experiments.

Samples at different moisture levels were produced by conditioning different packaged portions of cobs using the method of soaking the product in clean water for given periods of time. The first sample (A) was left at the market storage condition and the moisture content was determined without soaking in water. A specified mass of the second sample (B) was soaked in clean water for the period of forty-five minutes (45min), the third sample (C) was soaked for a period of one-hour thirty minutes (1h 30min) and the fourth sample (D) was allowed to soak for a period of two hours (2h). The samples were removed and spread on different platforms at room temperature with no fan blowing to allow the water drain for 20min. Each sample was packaged in a polythene bag and stored in a desiccator for a period of 24 hours to enable uniform moisture content to be attained throughout the sample. By this exercise, four samples at different moisture conditions were obtained. Sample moisture content was determined using oven drying method as described by [17] with modifications. This involved breaking cobs down to uniform particle size and placing a known mass of sample in weighed sample can, and oven drying at 105ºC to constant weight. Weight loss was monitored using an electronic weighing balance on hourly basis to give an idea of the time at which weight loss began to remain constant. Constant weight was taken to have been attained when three consecutive weighing gave identical readings. The moisture content was determined using the formula

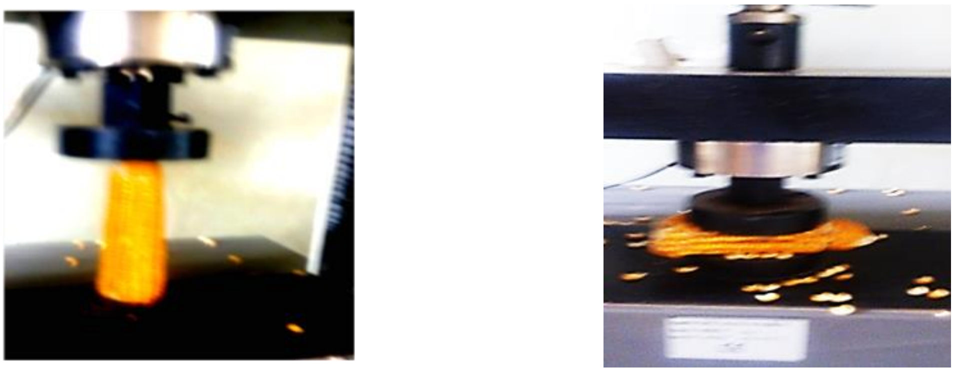
$$MC = \frac{W1 - W_2}{W_1} \times 100\% \qquad (1)$$

Where:
MC = Moisture content (%),
W_1 = Initial mass of the sample before oven drying (g) and
W_2 = Final mass of the sample after oven drying (g).

The experiment was replicated thrice on each of the four samples and their average moisture contents were recorded.

Compression Tests on Corn Cobs using Universal Testing Machine (UTM)

Samples of corn cob at specified moisture content were compressed using the Universal Testing Machine (UTM) running at crosshead speed of 10mm/min. Each sample was loaded either in the vertical (longitudinal) orientation (Figure 1A) or in the horizontal (Lateral) orientation (Figure 1B). As the compression operation began and progressed, a load – deformation curve was plotted automatically in relation to the response of each sample. Compression tests were replicated ten times at each moisture content and loading orientation. A typical force-deformation curve obtained during the compression operation is pr–sented in Figure 2. The force-deformation curves obtained were analyzed for different mechanical properties at each moisture content using the ten replicates and the average values were recorded.



(A) (B)

Figure 1. Loading orientations of corn cob in the UTM, (A) Longitudinal loading and (B) Lateral loading

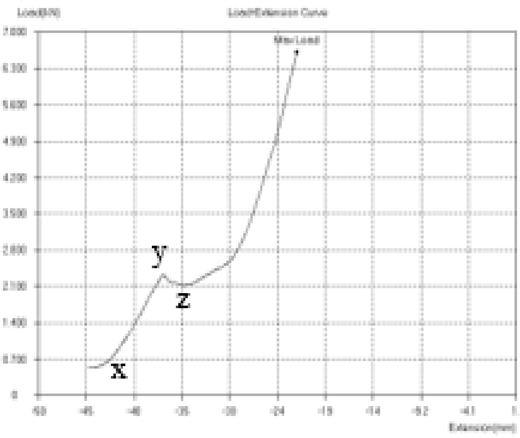


Figure 2. Typical force-deformation curve of corn cob during compression in Universal Testing Machine (UTM)

Evaluation of Strength Properties of Corn Cobs from Force-Deformation Curves
Bioyield point was taken as the point (x) on the force-deformation curve (Figure 2) at which the compressed corn cob weakened and failed internally without cracking outwardly [9]. At this point, an increase in deformation resulted from either a decrease or no change in force [4], and the cob could be said to have failed in its internal cellular structure [18]. Yield point was the point (y) on the force-deformation curve at which the visible failure of the cob became initiated and it just began to tear [19]. Rupture point was the point (z) on the force deformation curve at which the cob completely became broken and torn with the internal structure exposed [4, 18]. Bioyield strength was taken as the stress at which the cob failed in its internal cellular structure and is given by x/A, where x is the bioyield point (N) and A is the cross-sectional area (m^2) of the sample during loading. Compressive strength was the stress given by y/A at which the visible failure of the cob was initiated so that it began to tear. Rupture strength was taken as the stress given by z/A at which the cob got completely broken. Modulus of elasticity was taken as the ratio of stress to strain up to bioyield point in the force-deformation curve. Modulus of resilience was taken as area under the force-deformation curve up to bioyield [19] and was determined from the force-deformation curve of the cob using the method that was followed by [20]. Modulus of stiffness was taken as the ratio of the average maximum force to the average maximum deformation of the cob at failure [21, 10]. It was calculated from the force-deformation data of the cob following the method employed by [8, 19]. Modulus of toughness was taken as area under the force-deformation curve up to failure [11] and was determined from the force-deformation curve using the method that was followed by [20].
Data obtained from the computations of the mechanical properties were regressed against moisture content and their trends and the mathematical expressions relating them to moisture content, with the coefficients of determination were established at the lateral and longitudinal loading orientations.

RESULTS AND DISCUSSION

The average moisture content of corn cob at market storage and varied conditionings were found to be 5.87, 9.8, 18.26 and 28.4%, respectively. The strength properties in the above moisture range under lateral and longitudinal loading orientations are presented as follows.

Bioyield Point
The variation of the bioyield point of corn cobs with moisture content when subjected to compression under lateral and longitudinal loading orientations is presented in Figure 3A. From the Figure, it can be seen that on the lateral and longitudinal loading orientations, the bioyield point decreased from 685 to 220 N and from 570 to 150 N, respectively, as the moisture content of the cob increased from 5.87 to 28.40%. Bioyield point was higher on lateral than longitudinal loading, showing that the cob more readily fails in its internal cellular structure during longitudinal loading than at lateral loading. The relationship existing between the bioyield point of the cobs with moisture content for lateral and longitudinal loading orientations can be expressed with equations (2) and (3), respectively.

$BYP(Lat) = 2221.3M^{-0.708}$, $R^2 = 0.9712$ (2)

$BYP\ (Long) = 2235.9M^{-0.824}$, $R^2 = 0.968$ (3)

Where:
BYP (Lat) is bioyield point on lateral loading (N),
BYP (Long) is bioyield point on longitudinal loading (N) and
M is moisture content of cob (% wb).

Equations (2) and (3) show that the bioyield point of corn cob decreased as a power law function of moisture content when it is compressed at both lateral and longitudinal orientations.

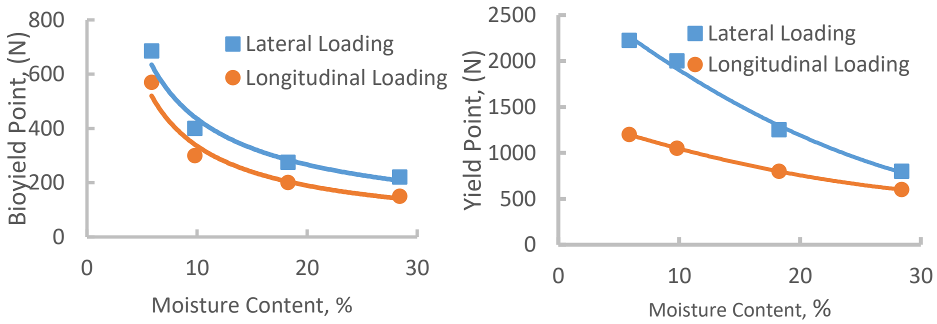
Yield Point

Figure 3B shows the effect of moisture content on yield point of corn cobs under compression in lateral and longitudinal loading orientations. It can also be seen from the Figure, that yield point decreased with increase in moisture at both lateral and longitudinal orientations. In the moisture range of 5.87 – 28.4%, yield point decreased from 2223.6 to 800 N for lateral loading, and from 1200 to 600 N under longitudinal loading showing that yield point is higher on lateral loading than at longitudinal loading.
This indicates that the force at which the visible failure of the cob becomes initiated and it just begins to tear, would occur earlier under load in the longitudinal orientation than in lateral loading. The relationship between yield point and moisture content at both lateral and longitudinal loading, expressed using equations (4) and (5) show that yield point decreased as a quadratic function of moisture content in both loading orientations.

$YP\ (Lat) = 1.2552M^2 - 108.75M + 2864.3$, $R^2 = 0.9916$ (4)

$YP\ (Long) = 0.5664M^2 - 45.955M + 1448.7$, $R^2 = 0.9999$ (5)

Where:
YP (Lat) is yield point on the lateral loading (N),
YP (Long) is yield point on longitudinal loading (N) and
M is moisture content of cob (% wb).



(A) (B)

Figure 3: Variation of bioyield point (A) and yield point (B) of corn cob with moisture content and loading orientation

Rupture Point

The variation of the rupture point of corn cobs with moisture content when subjected to compression under lateral and longitudinal loading orientations is presented in Figure 4A. From the Figure, it can be seen that on lateral and longitudinal loading orientations, the rupture point decreased from 2130 to 1120 N and from 1280.7 to 576 N, respectively, as the moisture content of the cob increased from 5.87 to 28.40%. Rupture point was higher on lateral than longitudinal loading, showing that the cob more readily breaks up during longitudinal loading than at lateral loading. The relationship existing between the rupture point of the cobs with moisture content for lateral and longitudinal loading orientations can be expressed with equations (6) and (7), respectively. While rupture point varied as polynomial of second order with moisture content at lateral loading, it varied as an exponential function with moisture content on longitudinal loading.

$$RP\ (Lat) = 1.0522M^2 - 80.3M + 2554.6, \qquad R^2 = 0.999 \qquad (6)$$
$$RP\ (Long) = 1560.7EXP(0.035M), \qquad R^2 = 0.9985 \qquad (7)$$

Where:

RP (Lat) is rupture point on the lateral loading (N),
RP (Long) is rupture point on longitudinal loading (N).

Bioyield Strength

Figure 4B shows the variation of bioyield strength of corn cob with moisture content for lateral and longitudinal compressive loading. Bioyield strength decreased from 9.5 to 2.9 N/mm^2 and from 6 to 2.6 N/mm^2 as the moisture content of the cob increased from 5.87 to 28.4% under lateral and longitudinal loading orientation, respectively. From the Figure, it can be seen that bioyield strength was higher on lateral loading than at the longitudinal orientation indicating that the failure of the cob in its intercellular structure will occur under lesser pressure in the longitudinal loading orientation than at lateral loading. The relationship existing between bioyield strength and moisture content at both loading orientations could be expressed by equations of the logarithmic form presented as equations (8) and (9).

$$BYS\ (Lat) = -4.23Ln(M) + 16.995, \qquad R^2 = 0.9993 \qquad (8)$$

$$BYS\ (Long) = -2.129Ln(M) + 9.6837, \qquad R^2 = 0.9963 \qquad (9)$$

Where:

BYS (Lat) is bioyield strength on the lateral loading (N/mm^2), and
BYS (Long) is bioyield strength on longitudinal loading (N/mm^2).

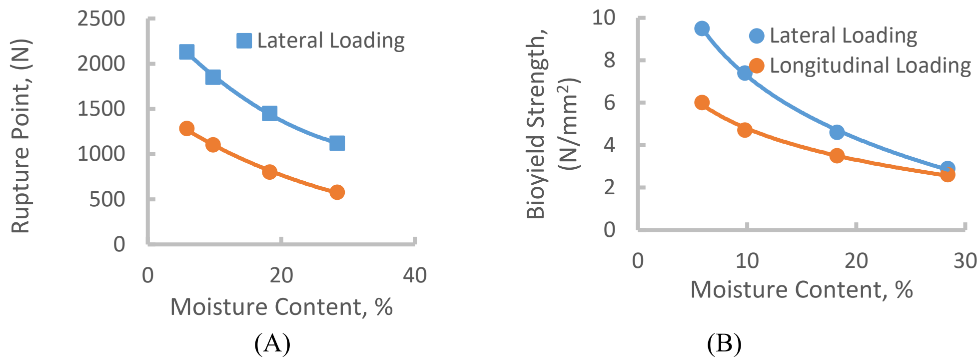


Figure 4: Effect of moisture content and loading orientation on (A): rupture point and (B): bioyield strength of corn cob

Compressive Strength

The variation of compressive strength of corn cob with moisture content when subjected to compression under lateral and longitudinal loading orientations is presented in Figure 5A. Compressive strength of the cob decreased from 3010 to 800 N/mm^2 and from 2550 to 650 N/mm^2 as the moisture content increased from 5.87 to 28.4% in the lateral and longitudinal loading orientation, respectively. In the above moisture range, it can be seen that the compressive strength of the cob is higher on lateral loading than on the longitudinal orientation. This shows that the corn cob will fail more readily under longitudinal loading than at lateral loading, and will be of important consideration in the design of the shelling mechanism and compartment of a corn shelling machine. The relationship existing between compressive strength and cob moisture content was found to be logarithmic and can be expressed using equations (10) and (11).

$$CS\ (Lat) = -1363Ln(M) + 5342.1, \qquad R^2 = 0.9906 \qquad (10)$$

$$CS\ (Long) = -1195Ln(M) + 4604.9, \qquad R^2 = 0.9941 \qquad (11)$$

Where: CS (Lat) is compressive strength on the lateral loading (N/mm^2), and

CS (Long) is compressive strength on longitudinal loading (N/mm^2).

Rupture Strength

Figure 5B shows the variation of rupture strength of corn cob with moisture content on both lateral and longitudinal loading orientations. The Figure shows that the rupture strength decreased with increase in moisture content in the moisture range of 5.87 - 28.4% (wb).

In the lateral loading orientation, rupture strength decreased from 2500 to 600 N/mm^2, while on the longitudinal loading orientation, it decreased from 2000 to 300 N/mm^2, in the above moisture range.

This shows that rupture strength on the lateral orientation is higher than it is on the longitudinal orientation, indicating that the cob will easily break into pieces on longitudinal loading. The relationship existing between rupture strength and cob moisture content on both lateral and longitudinal loading orientations was found to be polynomial of the second order and can be represented by equations (12) and (13).

$$RS\ (Lat) = 0.9958M^2 - 116.15M + 3106.1, \qquad R^2 = 0.9955 \qquad (12)$$

$$RS\ (Long) = 0.9869M^2 - 108.59M + 2591.2, \qquad R^2 = 0.9995 \qquad (13)$$

Where: RS (Lat) is rupture strength on the lateral loading (N/mm^2), and
RS (Long) is rupture strength on longitudinal loading (N/mm^2).

(A) (B)

Figure 4. Effect of moisture content and loading orientation on (A): compressive strength and (B) rupture strength of corn cob

Modulus of Elasticity

The variation of modulus of elasticity of corn cob with moisture content and loading orientation is presented in Figure 6A. Modulus of elasticity decreased from 2500 to 320N/mm^2 on the lateral loading orientation, and from 2200 to 150 N/mm2 on the longitudinal loading orientation as cob moisture content increased from 5.87% to 28.4%. This indicates that the modulus of elasticity of the cob is higher on lateral orientation than on longitudinal orientation, implying that the cob has higher capacity to recover strain due to the application of forces during loading and transportation when it is loaded in the lateral orientation. The relationship existing between modulus of elasticity and moisture content for both lateral and longitudinal loading orientations was found to be logarithmic and can best be described by equations (14) and (15), respectively.

$$E\ (Lat) = -1364Ln(M) + 4885.5, \qquad R^2 = 0.9984 \qquad (14)$$

$$E\ (Long) = -1276Ln(M) + 4449.7. \qquad R^2 = 0.9976 \qquad (15)$$

Where: E (Lat) is modulus of elasticity on the lateral loading (N/mm^2), and
E (Long) is modulus of elasticity on longitudinal loading (N/mm^2).

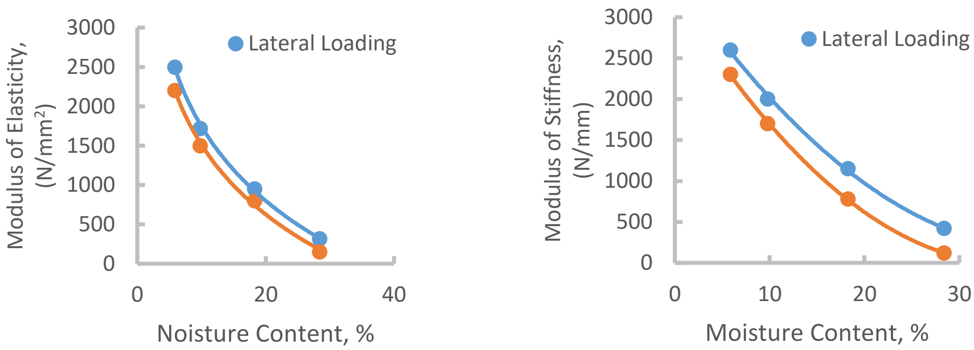
Modulus of Stiffness

Figure 6B shows the variation of modulus of stiffness of corn cob with moisture content at lateral and longitudinal compressive loading orientations. From the Figure, it can be seen that the modulus stiffness decreased with increase in moisture content, from 2600 to 420 N/mm, and from 2300 to 120 N/mm on lateral and longitudinal loading orientation, respectively, in the moisture range of 5.87 - 28.4%. This shows that the modulus of stiffness of the cob is higher on lateral loading than on longitudinal loading orientation, indicating that the cob exhibits more resistance to bending and buckling under the impingement of force when loaded laterally, and implies that in the lateral loading orientation, the cob will resist breakage better than it would do under longitudinal loading. The relationship existing between modulus of stiffness and cob moisture content was found to be polynomial of the second order for both lateral and longitudinal loading orientations. The relationship can be adequately represented by equations (16) and (17), respectively.

$$MS\ (Lat) = 2.1416M^2 - 168.77M + 3492.2, \quad R^2 = 0.9988 \quad (16)$$

$$MS\ (Long) = 2.6199M^2 - 185.93M + 3290.1, \quad R^2 = 0.9998 \quad (17)$$

Where: MS (Lat) is modulus of stiffness on the lateral loading (N/mm),
MS (Long) is modulus of stiffness on longitudinal loading (N/mm).



(A) (B)

Figure 6: Effect of moisture content and loading orientation on (A) modulus of elasticity and (B) modulus of stiffness of corn cob

Modulus of Toughness

Figure 7A shows the variation of modulus of toughness of corn cob with moisture content and loading orientation. On the lateral loading orientation, modulus of toughness decreased from 240 to 100 J as the cob moisture content increased from 5.87 to 28.4%, and in the above moisture range under longitudinal loading, the modulus of toughness decreased from 210 to 80 J, showing that the modulus of toughness of the cob was higher for lateral loading than for longitudinal loading.

The implication of the above finding is that under lateral loading orientation, the cob will exhibit higher capability to resist impact and absorb or dissipate deformation energy, hence it will be able to absorb more impact and deformation energy before fracturing and this could make the lateral loading orientation as the one to be considered when the cobs are being stored in a crib.

During shelling operation, loading on the lateral orientation will require more force and energy to release the grains from the cob, so the longitudinal loading orientation which gave lower modulus of toughness stands the better chance of rendering better performance when employed during shelling operation.

The relationship existing between modulus of toughness and cob moisture content at each loading orientation was found to be polynomial of the second order and it can be adequately expressed with equations (18) and (19), respectively.

$$MT\ (Lat) = 0.1094M^2 - 9.9058M + 293.37, \qquad R^2 = 0.9995 \qquad (18)$$

$$MT\ (Long) = 0.0723M^2 - 8.204M + 254.87, \qquad R^2 = 0.9997 \qquad (19)$$

Where:
MT (Lat) is modulus of toughness on the lateral loading (J), and
MT (Long) is modulus of stiffness on longitudinal loading (J).

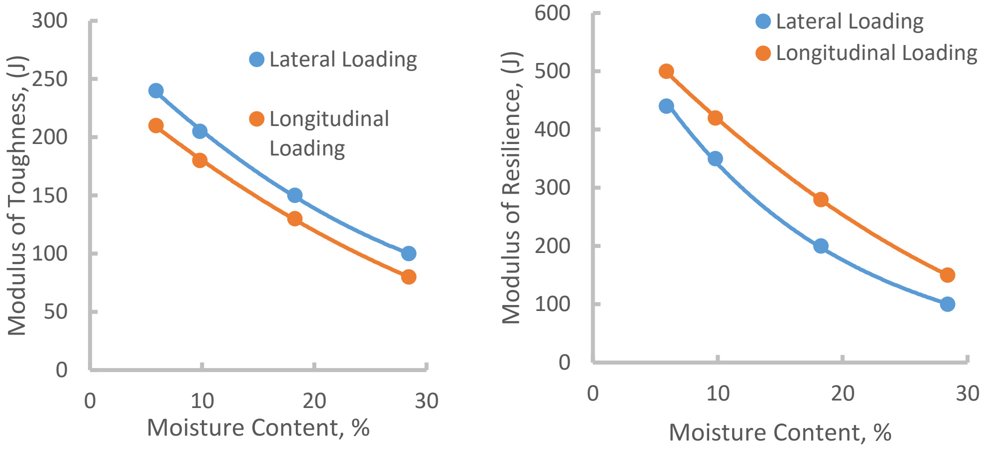
Modulus of Resilience

The variation of modulus of resilience of corn cob with moisture content on lateral and longitudinal loading orientations is presented in Figure 7B. From the Figure, it can be seen that the modulus of resilience decreased from 440 to 100 J in the lateral loading orientation, and from 500 to 150 J in the longitudinal orientation, as the cob moisture content increased from 5.87 to 28.4%. This indicates that modulus of resilience was higher on the longitudinal orientation than on the lateral, implying that the maximum amount of energy that the cob can absorb per unit volume without permanent deformation, and therefore, its ability to store strain energy in the elastic range, is higher when it is loaded on the longitudinal orientation. Higher modulus of resilience also indicates that the longitudinal loading orientation may be the one at which the cob could withstand mechanical hysteresis under static loading in bin or crib during storage. As a result, the quality of the cob could be better preserved when it is stored in the longitudinal loading orientation. The modulus of resilience was found to be a power function of cob moisture content at lateral loading orientation, and on longitudinal loading, it was found to relate with moisture content as a polynomial of the second order. The relationship existing between modulus of resilience and cob moisture content can be described using equations (20) and (21) for the lateral and longitudinal loading orientation, respectively.

$$MR\ (Lat) = 659.85\exp(-0.066M), \qquad R^2 = 0.9989 \qquad (20)$$

$$MR\ (Long) = 0.2248M^2 - 23.182M + 627.35, \qquad R^2 = 0.9999 \qquad (21)$$

Where:
MR (Lat) is modulus of toughness on the lateral loading (J), and
MR (Long) is modulus of stiffness on longitudinal loading (J).



(A) (B)

Figure 7. Effect of moisture content and loading orientation on modulus of resilience of corn cob

CONCLUSIONS

The investigation of the strength properties of corn cob at different moisture contents and loading orientations using the UTM showed that all the properties (bioyield, yield and rupture points, bioyield, compressive and rupture strengths, modulus of elasticity, modulus of stiffness, modulus of toughness and modulus of resilience) decreased with increase in moisture content and varied with loading orientation.

The strength properties with the exception of modulus of resilience were higher on the lateral loading orientation than at the longitudinal orientation.

The relationship between the properties and cob moisture content was mainly nonlinear and could be described by regression models that range from polynomials of the second order through logarithmic functions to expressions of the power form.

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UTICAJ SADRŽAJA VODE I PRAVCA OPTEREĆENJA NA MEHANIČKE OSOBINE KLIPA KUKURUZA

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Abstract: U ovom radu ispitivan je uticaj sadržaja (%) vlage i pravca opterećenja na mehaničke osobine klipova kukuruza korišćenjem uređaja *Testometric Universal Testing Machine (UTM)*, pri brzini pomeranja glave uređaja od 10 mm/min.

Analizirane su osobine: biološka tačka popuštanja materjala, granica tečenja, tačka loma, biološka čvrstoća, pritisna čvrstoća, čvrstoća pri lomu, modul krutosti, modul elstičnosti, modul elastične energije.

Rezultati su pokazali da sva analizirana svojstva opadaju sa povećanjem sadržaja vlage. Uopšteno, vrednosti su bile veće pri bočnom (lateralnom) opterećenju nego pri uzdužnom (longitudinalnom), osim kod modula elastičnosti, koji je imao više vrednosti u uzdužnom pravcu opterećenja.

U opsegu vlage od 5,87 do 28,4 %, biološka tačka čvrstoće materijala se smanjila sa 685 na 220 N i sa 570 na 150 N za bočno i uzdužno opterećenje, redom. Granica tečenja se smanjila sa 2223,6 na 800 N (bočno) i sa 1200 na 600 N (uzdužno), dok se tačka loma smanjila sa 2130 na 1120 N i sa 1280,7 na 576 N za odgovarajuće pravce opterećenja.

Biološka tačka čvrstoće je opala sa 9,5 na 2,9 N/mm² (bočno) i sa 5,5 na 2,6 N/mm² (uzdužno), pritisna čvrstoća sa 3010 na 800 N/mm² i sa 2550 na 650 N/mm², dok je čvrstoća pri lomu biološkog materijala smanjena sa 2500 na 600 N/mm² i sa 2000 na 300 N/ mm², respektivno.

Modul elastičnosti je smanjen sa 2500 na 320 N/mm² i sa 2200 na 150 N/mm²; modul krutosti sa 2600 na 420 N/mm i sa 2300 na 120 N/mm; modul žilavosti sa 240 J na 100 J i sa 210 J na 80 J. Modul elastične otpornosti je opao sa 440 J na 100J i sa 500 J na 150 J za bočno i uzdužno opterećenje, respektivno.

Empirijske regresione jednačine razvijene su za opis odnos između sadržaja vlage u klipu i njegovih mehaničkih osobina.
Dobijeni modeli su pokazali visoke koeficijente determinacije (R^2), što ukazuje na dobru prilagodljivost i visoku prediktivnu tačnost (predviđanje) ishoda testa.

Ključne reči: *Biološka tačka čvrstoće; sadržaj vlage; pravac opterećenja; kukuruzni klip; mehanička svojstva; pritisna čvrstoća; modul elastičnosti.*

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