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Effect of Moisture Content and Loading Orientation on Some Strength Properties of Conophor (*Tetracarpidium conophorum*) Nut

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Abstract: The effect of moisture content and loading orientation on some mechanical properties of *conophor* nut relevant in the development of its cracking machine was determined using a Testometric Universal Testing Machine (UTM). In the moisture range of 14.9% - 50.3% d.b. under both lateral and longitudinal loading orientations, the bioyield, yield and rupture points; bioyield, compressive and rupture strengths; modulus of stiffness, modulus of resilience and modulus of toughness decreased parabolically with increase in moisture content down to a minimum value and thereafter increased with further increase in moisture content. Under lateral loading, modulus of elasticity decreased with increase in moisture content to a minimum value and increased with further increase in moisture content, but it increased continually with increase in moisture content on longitudinal loading.

Key words: Conophor % (*tetracarpidium conophorum*) % Walnut % Mechanical properties % Compressive tests

INTRODUCTION

African walnut - *Conophor* (*Tetracarpidium conophorum*) - is a woody perennial climber that belongs to the family Euphorbiacaea [1]. It is widely distributed in the Southern part of Nigeria, where it is called “ukpa” by the Igbo, “awusa” or “asala” by the Yoruba and “eporo” by the Efik and Ibibio people [2]. The nut (Fig. 1a) is spherical in shape [3] and has a black shell inside which is embedded a milky kernel (Fig. 1b).

The plant is cultivated principally for it nuts which are cooked and consumed as snacks with boiled corn. Enujiugha [1] noted that freshly harvested mature *conophor* nut on a dry weight basis, contained 29.09% protein, 6.34% fibre, 48.9% oil, 3.09% ash and 12.58% carbohydrates. It is rich in valuable minerals like phosphorus, potassium, sodium, magnesium and zinc [4]. Its oil is edible and commands high price. Walnut oil is not used for high temperature cooking because its heating normally removed the flavor and produced slight bitterness and as a result, it is used primarily as an ingredient in cold dishes such as salad dressings, where its flavor more easily comes through. The oil could be used in the manufacture of paints and vanishes. The cake obtained after oil expression can be used as source of protein for livestock or as source of nitrogen fertilizer. The nut shell could be used as fuel on the farm for low cost drier [3]. The health benefits of walnut include lowering of cholesterol, reducing inflammation and improving arterial function [5, 6].

Fig. 1: *Tetracarpidium conophorum* (a) Nuts and (b) Kernels

Despite the economic importance of *conophor* nut, no commercial production and industrial utilization of the crop takes place in Nigeria. Akani *et al*. [7] noted that research has been concentrated only on the agronomics, while work on the processing of indigenous crops appears to have been neglected. The unavailability of such engineering data as rupture force, cracking energy and deformation energy of indigenous crops has greatly

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retarded the development of indigenous technologies for the processing of the crops. When these data are available, the design and development of machines for processing the crops will receive the needed boost and large scale production of the crops (including *conophor* nut) by farmers will be encouraged.

Makanjuola [8] developed a machine for cracking *conophor* nut but it was not reported that the design was based on the physical or mechanical properties of the nut. In order to design the equipment for processing, storing and extracting oil from *conophor* nut, there is need to have data on its physical and mechanical properties. Asoegwu [3] studied some physical properties of *conophor* nut, but no information appears to have been reported on the mechanical properties of the nut and their relationship with moisture content. The objective of this study was therefore to investigate the mechanical properties of *conophor* nut relevant in the design of post harvest handling and processing equipment for the nut and determine their variation with moisture content and loading orientation. The mechanical properties include bioyield, yield and rupture points; bioyield, compressive and rupture strengths; modulus of elasticity, modulus of resilience, modulus of stiffness and modulus of toughness.

MATERIALS AND METHODS

Bulk quantity of freshly harvested fruits of African walnut (*conophor* nut) was obtained from Aramoko market in Ekiti State, Nigeria. The nuts were manually extracted from the pods and cleaned by washing in clean water. The cleaning involved the removal of the black thick coat on the surface of the nut that remained on it after it was retrieved from the pod. Nuts noticed to have germinated or cracked were removed. After cleaning in water, the nuts were spread out in a thin layer to dry in natural air for about 6 hours. The nuts were then sealed in a polythene bag and stored in that condition for a further 24 hours. This enabled stable and uniform moisture content of the nuts to be achieved in the bag [9]. Samples of the nut at different moisture level were prepared using the method described by Asoegwu [3]. This method involved the reduction of the moisture content by sun-drying the nuts for different periods of time. During sun-drying and after every 24 hours, a sample of the nut was taken and stored in a polythene bag for 12 hours for it to attain uniform moisture content [9, 10]. The sun-drying exercise proceeded for 96 hours and four samples at different moisture levels were obtained. In addition to the four samples obtained as a result of sun-drying, there was the initial moisture level, which was the highest and at which the nut was purchased.

The moisture contents of the conditioned nut samples were determined using the method described by Asoegwu [3]. This involved oven-drying nut samples at 103°C for 24 hours. The mass of the samples were measured and recorded before and after oven-drying and the moisture content was calculated on dry basis. The experiment was replicated three times for each sample and the average value of the moisture content was determined.

Compression tests were conducted on the nut at five moisture levels using a Testometric Universal Testing Machine (UTM) controlled by a micro-computer. Nut compression was carried out at cross head speed of 10mm/min. As compression began and progressed, a force-deformation curve was plotted automatically by the machine in relation to the response of the nut. The results, statistical data and the force-deformation curves obtained at each loading orientation and moisture level were analyzed for:

- Bioyield point
- Yield point
- Rupture point
- Bioyield strength
- Compressive strength
- Rupture strength
- Modulus of elasticity
- Modulus of stiffness
- Modulus of resilience and;
- Modulus of toughness

The bioyield point was taken as the point on the force - deformation curve at which the compressed nut shell weakened and failed internally without cracking outwardly. At this point, an increase in deformation resulted from either a decrease or no change in force, [11] and the nut could be said to have failed in its internal cellular structure [12]. The yield point was the point on the force-deformation curve at which the visible failure of nut shell became initiated and the shell just began to tear [13]. Rupture point was the point on the force deformation curve at which the nut shell completely became broken and torn with the kernel exposed [11, 12]. The bioyield strength was taken as the stress at which the nut shell failed in its internal cellular structure. The compressive strength was the stress at which the visible failure of the nut shell was initiated so that it began to tear. The rupture strength was taken as the stress at which the nut shell got completely broken. Modulus of elasticity was taken as the ratio of the stress to the strain up to bioyield. Modulus of stiffness was the ratio of the average maximum force to the average maximum deformation of the nut at failure [14]. It was calculated from the force-deformation data of the nut following the method employed by Mamman *et al*. [15] and Aviara *et al.* [13]. Modulus of resilience was taken as area under the force-deformation curve up to bioyield [16, 17] and was determined from the force-deformation curve of the nut using the method that which was followed by Haque *et al*. [18]. Modulus of toughness was taken as area under the force-deformation curve up to failure [16, 17] and was determined from the force-deformation curve using the method that was followed by Haque *et al*. [18].

The test was replicated ten times at each moisture level and the mean of each property under lateral and longitudinal loading orientations was obtained. The relationship existing between the mechanical properties of *conophor* nut and moisture content was established and expressed using regression equations. The variations of these properties with moisture content were also plotted.

RESULTS AND DISCUSSION

The average dry basis (d.b) moisture contents of the five samples of *conophor* nut were found to be 14.9%, 23.1%, 31.9%, 38.6% and 50.3%. The highest moisture level of 50.3% (d.b) was the harvest moisture content as against the 68.6% (d.b) and 60% (w.b) at harvest reported by Asoegwu [3] and Makanjuola [8], respectively. This could be due to differences in the period of the year at which the nuts were obtained. The nuts that were used in this study were procured in November, when the nut was almost out of season and the rainfall was low.

The values of the mechanical properties of *conophor* nut were found to be a function of moisture content. The relationships existing between the properties and moisture content at both lateral and longitudinal loading orientation were best expressed using polynomial equations of the second order. The equations had very high coefficients of determination ($R^2 > 0.9$), which indicated that they described the relationships reasonably.

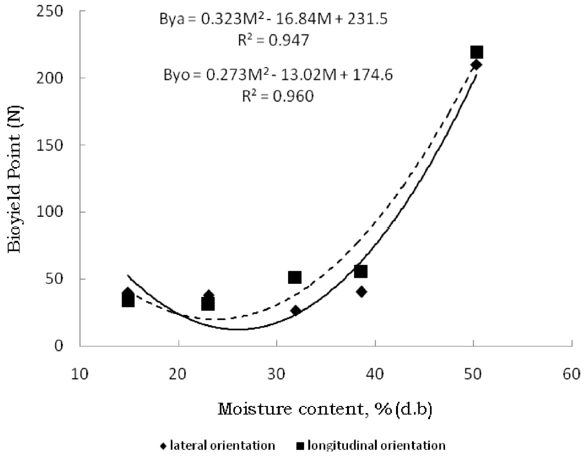

Fig. 2: Effect of moisture content on bioyield point of *T. conophorum* nut under compression on the lateral and longitudinal loading orientations: Bya = bioyield point at lateral loading, Byo = bioyield point at longitudinal loading and M = moisture content, % (d.b)

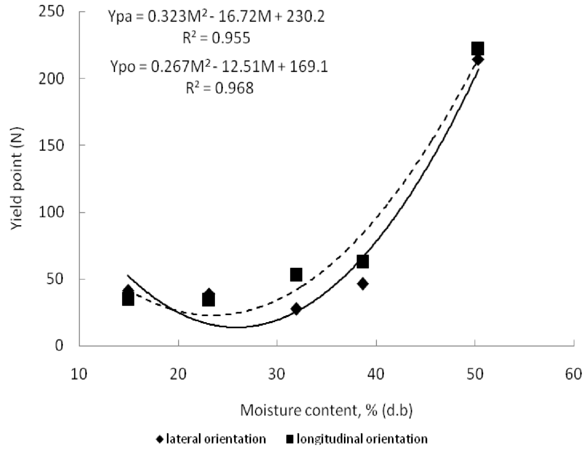

Fig. 3: Effect of moisture content on yield point of *T. conophorum* nut under compression on the lateral and longitudinal loading orientations: Ypa = yield point at lateral loading, Ypo = yield point at longitudinal loading and M = moisture content, % (d.b)

The variation of the bioyield point of *conophor* nut with moisture content under lateral and longitudinal orientation is respectively presented in Fig. 2. The Figure shows that the bioyield point decreased from 40.12N to a minimum of 11.3N as the moisture content increased from 14.9 to 26% (d.b) and thereafter increased with further increase in moisture content under lateral loading orientation. It shows that the bioyield point under longitudinal orientation decreased from 33.78N to a minimum of 20N as the moisture content increased from 14.9 to 24% (d.b) and increased with further increase in moisture content. Similar trend with moisture content was reported for the bioyield point of the two *balanites aegyptiaca* accessions investigated by Mamman *et al*. [15]. The minimum bioyield point of *conophor* nut was

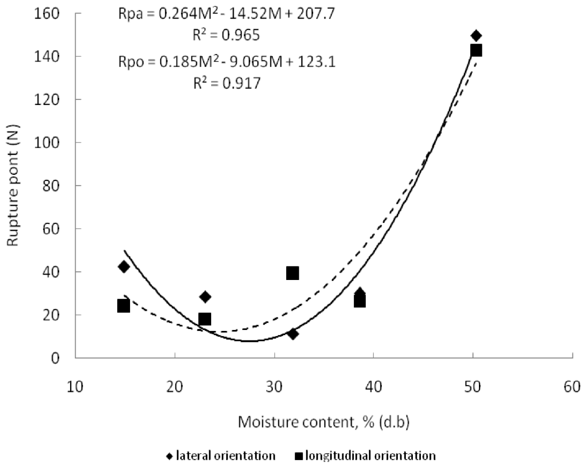

Fig. 4: Effect of moisture content on rupture point of *T. conophorum* nut under compression in the lateral and longitudinal loading orientations: Rpa = rupture point at lateral loading, Rpo = rupture point at longitudinal loading and M = moisture content, % (d.b)

higher at the longitudinal loading and occurred at a lower moisture level than that obtained under lateral loading. At moisture levels above that at which the minimum occurred, the bioyield point was higher under longitudinal orientation than at the lateral orientation but lower at moisture levels below that at which the minimum occurred. The implication of the above result is that the force needed in the compressive cracking of *conophor* nut to initiate the failure of the shell at the microscopic level is moisture and loading orientation dependent. The minimum force needed would be lower at the lateral loading orientation but would require a higher moisture level than that needed at the longitudinal orientation.

The variation of the yield point of *conophor* nut with moisture content when subjected to compression on the lateral and longitudinal orientation respectively is presented in Fig. 3. This shows that the yield point decreased from 41.2N to a minimum of 12.5N as the moisture content increased from 14.9 to 26% (d.b) moisture content and thereafter increased with further increase in moisture content when the nut was compressed on the lateral orientation. It decreased from 34.76N to a minimum of 22N as the moisture content increased from 14.9 to 24% (d.b) and then increased with further increase in moisture content when compression was on the longitudinal orientation. Minimum yield point of *conophor* nut was higher at the longitudinal loading orientation than at lateral orientation. At moisture levels above that at which the minimum occurred, the yield point is higher under longitudinal orientation than at the lateral orientation, but lower at moisture levels below that at which the minimum occurred. This indicates that the minimum force needed in the compressive cracking of *conophor* nut to initiate the failure of the shell at the macroscopic level is moisture and loading orientation dependent. Like the force needed to initiate failure of the shell at the microscopic level, this force would be lower at lateral loading but would require higher moisture level than that needed at the longitudinal loading orientation.

The variation of the rupture point of *conophor* nuts with moisture content in compression under lateral and longitudinal loading orientations is respectively presented in Fig. 4. This Figure shows that when the nut was compressed on the lateral orientation, the rupture point decreased from 42.47N to a minimum of 8N as the moisture content increased from 14.9 to 26% (d.b) and thereafter increased with further increase in moisture content. Likewise, it decreased from 24.05N to a minimum of 12N as moisture content increased from 14.9 to 24% (d.b) and increased with further increase in moisture content when compression was on the longitudinal orientation. The decrease in rupture force with increase in moisture content was unexpected as the shell of the nut was expected to become less brittle as the moisture content increased. The decrease in rupture force may be due to the effect of moisture on the intercellular structure of the nut shell. Similar trend with moisture content was reported by Tavakoli *et al*. [19] and Olaniyan and Oje [20] for the rupture point of soybean and sheanut respectively. Minimum rupture point of *conophor* nut was higher at the longitudinal orientation than at the lateral orientation, but occurred at lower moisture content. At moisture levels above that at which the minimum occurred, rupture point was higher under longitudinal loading than at the lateral orientation but lower at moisture levels below that at which minimum rupture point occurred.

The variation of bioyield strength of *conophor* nut with moisture content is presented in Fig. 5 for loading on both lateral and longitudinal orientation. The Figure shows that the bioyield strength decreased from 0.046N/mm^2 to a minimum of 0.017N/mm^2 as the moisture content increased from 14.9 to 26% (d.b) and thereafter increased with further increase in moisture content when he nut was compressed on the lateral orientation. It also shows that the bioyield strength under loading in the longitudinal orientation decreased from 0.054N/mm^2 to a minimum of 0.023N/mm^2 as the moisture content increase from 14.9 to 24% (d.b) and increased with further increase in moisture content. Similar relationship with

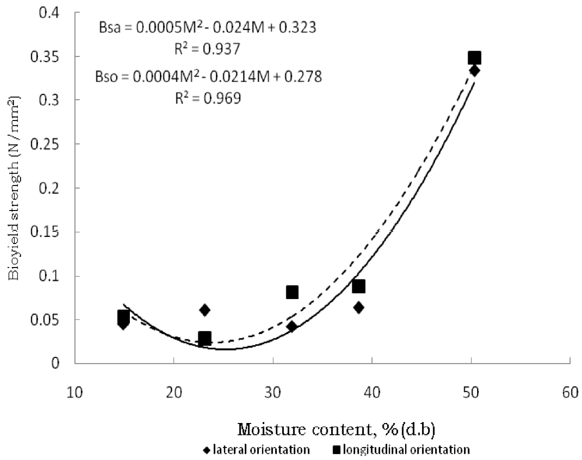

Fig. 5: Variation of bioyield strength of *T. conophorum* nut with moisture content under lateral and longitudinal compressive loadings: Bsa = bioyield strength at lateral loading, Bso = bioyield strength at longitudinal loading and M = moisture content, % (d.b)

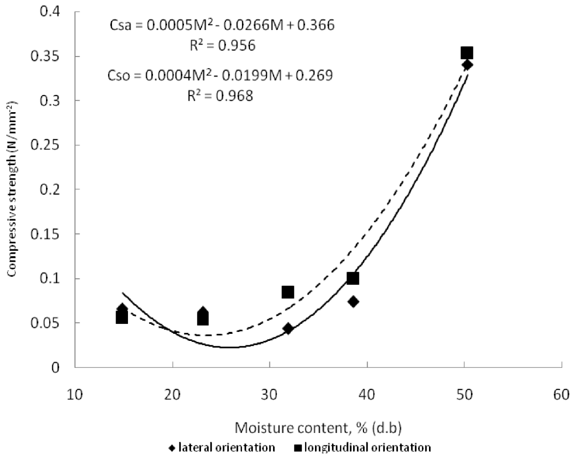

Fig. 6: Variation of compressive strength of *T. conophorum* nut with moisture content under lateral and longitudinal compressive loading: Csa = compressive strength at lateral loading, Cso = compressive strength at longitudinal loading and M = moisture content, % (d.b)

moisture content was obtained for the bioyield strength of the two *balanites aegyptiaca* accessions investigated by Mamman *et al*. [15]. Minimum bioyield strength of conophor nut was higher at the longitudinal loading orientation than at lateral loading, but occurred at lower moisture content. At moisture levels above that at the minimum occurred, the bioyield strength is higher at the longitudinal orientation than at the lateral orientation but lower at moisture levels below that at which the minimum occurred.

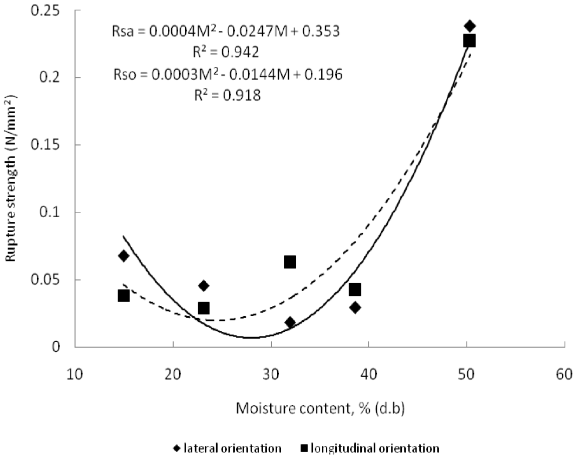

Fig. 7: Variation of rupture strength of *T. conophorum* nut with moisture content under lateral and longitudinal compressive loading: Rsa = rupture strength at lateral loading, Rso = rupture strength at longitudinal loading and M = moisture content, % (d.b)

The variation of *conophor* nut compressive strength with moisture content on compression in the lateral and longitudinal orientations is respectively presented in Fig. 6. This shows that the compressive strength decreased from 0.0655N/mm^2 to a minimum of 0.02N/mm^2 as the moisture content increased from 14.9 to 26% (d.b) moisture content and thereafter increased with further increase in moisture content when the nut was compressed on the lateral orientation. Likewise, it decreased from 0.055N/mm^2 to a minimum of 0.046N/mm^2 as the moisture content increased from 14.9 to 24% (d.b) and then increased with further increase in moisture content when compressed on the longitudinal orientation. The polynomial relationship existing between the compressive strength and moisture content of *conophor* nut at both loading orientations was unlike to the linear relationship existing between that of two accessions of *balanites aegyptiaca* nut investigated by Mamman *et al*. [15].

The variation of rupture strength of *conophor* nut with moisture content under compressive loading in the lateral and longitudinal orientations is respectively presented in Fig. 7. The Figure shows that the rupture strength decreased from 0.068N/mm^2 to a minimum of 0.007N/mm^2 as the moisture content increased from 14.9 to 28% (d.b) and thereafter increased with further increase in moisture content when conophor nut was compressed on the lateral orientation. Likewise, it decreased from 0.038N/mm^2 to a minimum of 0.02N/mm^2 as moisture content increased from 14.9 to 24% (d.b) and increased

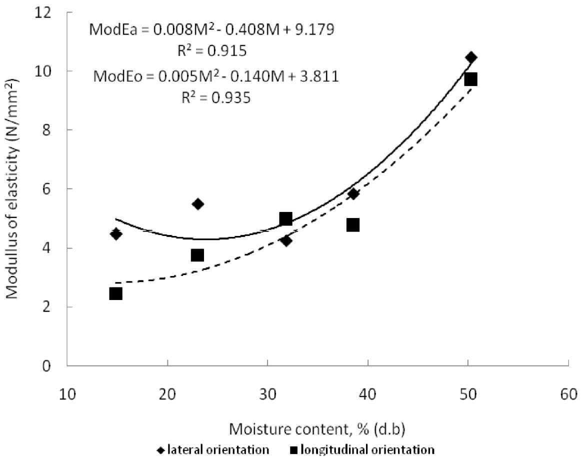

Fig. 8: Variation of modulus of elasticity of *T. conophorum* nut with moisture content under lateral and longitudinal compressive loading: ModEa = modulus of elasticity at lateral loading, ModEo = modulus of elasticity at longitudinal loading and M = moisture content, % (d.b)

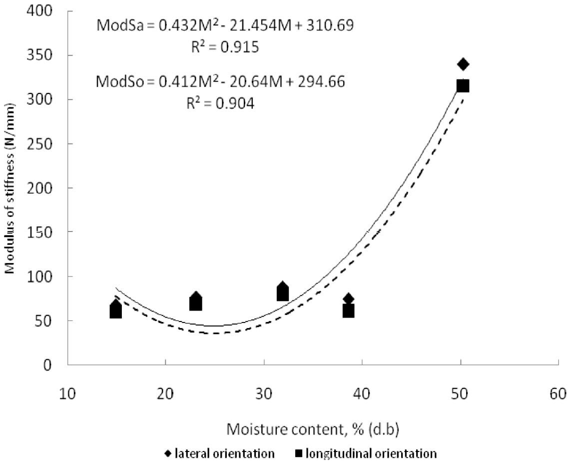

Fig. 9: Variation of modulus of stiffness of *T. conophorum* nut with moisture content under lateral and longitudinal compressive loading: ModSa = modulus of stiffness at lateral loading, ModSo = modulus of stiffness at longitudinal loading and M = moisture content, % (d.b)

with further increase in moisture content when the compression was on the longitudinal orientation. Similar trend wit moisture content was reported by Mamman *et al*. [15] for the rupture strength of the oblong accession of *balanites aegyptiaca* nuts.

The variation of modulus of elasticity of *conophor* nut with moisture content when subjected to compressive loading under lateral and longitudinal orientation is respectively presented in Fig. 8. The Figure shows that the modulus of elasticity of the nut decreased from 4.48N/mm^2 to a minimum of 4.25N/mm^2 as the moisture content increased from 14.9 to 24% (d.b) and thereafter increased with further increase in moisture content under lateral loading orientation. Under the longitudinal loading orientation, the modulus of elasticity increased 2.47N/mm^2 to 9.7N/mm^2 as the moisture content increased from 14.9% to 50.3% (d.b). The modulus of elasticity at each moisture level was higher on the lateral orientation than that at the longitudinal loading. This implies that the nut has a higher ability to return to its original shape after compressive loading on its lateral orientation than on longitudinal orientation.

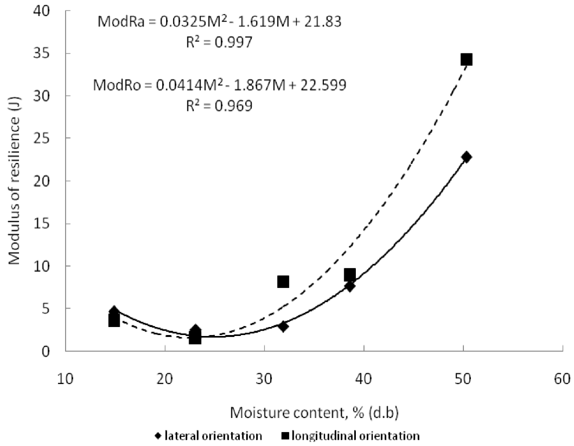

Fig. 10: Variation of modulus of resilience of *T. conophorum* nut with moisture content under lateral and longitudinal compressive loading: ModRa = modulus of resilience at lateral loading, ModRo = modulus of resilience at longitudinal loading and M = moisture content, % (d.b)

The variation of *conophor* nut modulus of stiffness with moisture content when it was subjected to compressive loading on lateral and longitudinal orientations is respectively presented in Fig. 9. The Figure shows that the modulus of stiffness decreased from 67.79N/mm to a minimum of 43.5N/mm as the moisture content increased from 14.9 to 25% (d.b) and thereafter increased with further increase in moisture content when the nut was compressed on the lateral orientation. It decreased from 59.69N/mm to a minimum of 37N/mm as moisture content increased from 14.9 to 25% (d.b) and increased with further increase in moisture content when the compression was on the longitudinal orientation. At similar moisture level, the minimum modulus of stiffness was higher at lateral loading than at the longitudinal loading orientation. At each moisture level, lateral loading gave higher modulus of stiffness than longitudinal loading.

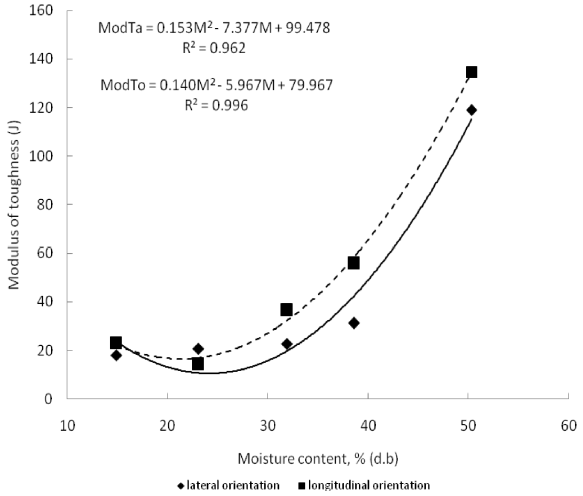

Fig. 11: Variation of modulus of toughness of *T. conophorum* nut with moisture content under lateral and longitudinal compressive loading: ModTa = modulus of toughness at lateral loading, ModTo = modulus of toughness at longitudinal loading and M = moisture content, % (d.b)

The variation of modulus of resilience of *conophor* nut with moisture content in compression under lateral and longitudinal orientations is respectively presented in Fig. 10. The Figure shows that the modulus of resilience of the nut decreased from 4.46J to a minimum of 1.85J as the moisture content increase from 14.9 to 26% (d.b) and thereafter increased with further increase in moisture content under lateral loading orientation. It also shows that modulus of resilience under longitudinal orientation decreased from 3.56J to a minimum of 1.75J as moisture content increase from 14.9 to 24% (d.b) and increase with further increase in moisture content. Minimum modulus of resilience was higher at lateral loading than at longitudinal loading but at higher moisture content. At moisture levels above 26% d.b the modulus of resilience is higher at longitudinal orientation than at lateral orientation but lower at moisture levels below the above moisture content.

The variation of modulus of toughness of *conophor* nut with moisture content under compressive loading in the lateral and longitudinal orientations is respectively presented in Fig. 11. The Figure shows that the modulus of toughness of the nut decreased from 18.03J to a minimum of 12.5J as the moisture content increase from 14.9 to 24% (d.b) and thereafter increased with further increase in moisture content under lateral loading orientation. Likewise it decreased from 22.85J to a minimum of 18J as moisture content increased from 14.9 to 22% (d.b) and increased with further increase in moisture content under longitudinal loading orientation. Minimum modulus of toughness was higher at longitudinal loading orientation than on the lateral orientation at the same moisture content. At moisture levels above that at which the minimum occurred, the modulus of toughness is higher at longitudinal orientation than at lateral orientation but lower at moisture levels below the one at which the minimum occurred.

CONCLUSIONS

- The bioyield, yield and rupture points of *conophor* nut decreased with increase in moisture content to minimum values and increased with further increase in moisture content. At moisture levels above that at which the minimum values occurred, these properties were higher under longitudinal loading than at lateral loading but lower at moisture levels below the ones at which the minimum occurred.
- The bioyield, compressive and rupture strengths of the nut decreased with increase in moisture content to minimum values and increased with further increase in moisture content. The minimum values of these properties were higher under longitudinal loading orientation than at lateral loading.
- The modulus of stiffness, modulus of resilience and modulus of toughness of the nut decreased with increase in moisture content to minimum values and increased with further increase in moisture content under both lateral and longitudinal loading orientation.
- The modulus of elasticity decreased with increase in moisture content to minimum value and increased with further increase in moisture content under lateral loading orientation, but under longitudinal loading, it increased linearly with moisture content.

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