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SOME PHYSICAL AND MECHANICAL PROPERTIES OF CASHEW NUT AND KERNEL GROWN IN GHANA

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ABSTRACT
Physical and mechanical properties of cashew, other nuts and seeds are often needed for the design of cleaning, de-hulling and sundry grain processing equipment and machinery. These properties were determined for cashew nut and kernel in the moisture content range of 5.0% to 9.0% wet basis. The average length, thickness, width, equivalent diameter, sphericity and volume for cashew nuts were 41.15 mm, 23.92 mm, 32.76 mm, 31.89 mm, 77.37% and 312.54 mm^3 respectively and that for the kernels were 33.16 mm, 15.87 mm, 17.91 mm, 21.23 mm, 64.02% and 101.47 mm^3 respectively. The bulk density of Cashew nut and kernel decreased linearly from 625.62 to 592.68 kgm^{-3} and 559.60 to 505.06 kgm^{-3} respectively. However, true density, surface area, and porosity increased linearly from 1100.16 to 1209 kgm^{-3}, 2754.68 to 2918.18 mm^2, and 43.19 to 51.02% respectively for the nuts while for the kernels the properties increased from 946.23 to 991.29 kgm^{-3}, 1189.98 to 1309.02 mm^2, and 40.86 to 49.05% respectively. The maximum compressive load, maximum displacement, stress, strain, and young's modulus increased linearly from 0.445 to 0.574 kN, 7.760 to 8.008 mm, 2.225 to 2.872 MPa, 0.777 to 0.801 mm/mm and 4.666 to 9.853 MPa respectively for the kernel and increased from 0.146 to 0.213 kN, 3.006 to 4.105mm, 0.214 to 1.214 MPa, 0.355 to 0.472 mm/mm, and 2.446 to 6.416 MPa respectively for the nuts. The relationship between compressive stress properties studied and moisture content were found to be significant at 0.05.

Key words: *Cashew nuts, kernel, bulk density, compressive load, displacement, young's modulus.*

INTRODUCTION

Cashew tree (*Anarcardium Occidentale)* is a native of southern America and was brought to Africa by the Portuguese. The tree produces nuts in a kernel with economic importance. World production and consumption has rapidly increased and according to Ohler (1979) it was estimated to increase over 1260,000 tonnes in the next 20 years. The major producing countries of cashew are Tanzania, India, Mozambique, Sri Lanka, Kenya, Madagascar, Thailand, Malaysia, Indonesia, Nigeria, Senegal, Malawi, and Angola. Cultivation of the cashew in Ghana was recorded recently in the world records starting with 500 tonnes in 1990 and increased to 7500 tonnes in 2000. In Ghana cashew farms are located in the Brong Ahafo, Northern, Ashanti, and Eastern regions.

Cashew nut is very nutritious with high amount of energy as it contains protein, minerals, fats, carbohydrate, vitamins and fibre, all of which contribute enormously to good health from its consumption. Cashew nut kernel can be eaten raw, fried and sometimes pre-treated with salt or sugar (Manay *et al.,* 1987). Other useful products made from cashew are jam, juice, syrup, chutney and beverage (Winterhaler, 1991).

Physical properties of biological materials such as cashew nut and kernels have unique characteristics which set them apart from other engineering materials. The irregular shape of most biological materials complicates the analysis of their behaviour. Physical properties of cashew nut and kernel like other cereals, fruits and vegetables are needed for the design of processing equipment. Also, the study of physical properties plays an important role in developing sensors to control machines and processes. It helps to detect quality differences during harvesting, handling and storage. Various types of cleaning, grading and separation equipment are designed on the basis of their physical properties (Teye & Abano 2012). According to Esref and Halil (2007) the knowledge of physical properties constitutes an important and essential engineering data in the design of machines, storage structures, and processing. Physical properties affect the converting characteristics of solid materials either by air or water, cooling and heating of food products (Sahay & Singh, 1994; Teye & Abano, 2012).

On the other hand, mechanical properties of biological materials are the behaviour of the materials under applied forces. The study of mechanical properties is needed for textural analysis and better understanding of product quality. For example, firmness of horticultural products as measured by instrumental methods is frequently used to determine their maturity and ripeness. These are important in handling, storage and processing procedures. Force-deformation testing of biological materials can also be used to study damage which occurs during harvesting and handling of grains, seeds, fruits, and vegetables. Knowledge

of the behaviour of a particular material from testing or from test data enhances the evaluation of engineering designed equipment used for its handling. One of the most important considerations in engineering design is to ensure that stresses in components do not exceed the strength of the agricultural materials.
The physical and mechanical properties of other biological materials such as grains, seeds, fruits and vegetables have been determined by other researchers; (Baryeh, 2001; Bart-Plange & Baryeh, 2003, Teye & Abano, 2012). The physical and mechanical properties of the cashew nut and kernel grown in Ghana are unknown but essential for the design and construction of structures and equipment for handling, transportation, processing, and harvesting of the nuts and kernels. The objective of this study was to investigate some moisture dependent physical and compressive properties of cashew nut and kernel grown in Ghana.

MATERIALS AND METHODS

The cashew nuts and kernel used in the present study were procured from the local market at Wenchi in the Brong Ahafo region of Ghana during the main harvesting season. The cashew samples were then transported to Nsawkaw, the administrative capital of the Tain district where they were processed at a local cashew processing company. Figure 1 and 2 show cashew nut and kernel.

Figure 1: Cashew nuts

Figure 2: Cashew kernels

The samples were manually cleaned to remove foreign materials, and broken or immature nuts. The moisture content of the samples was determined by using a standard hot air oven method at 105°C for 24hours (Dursun et *al*., 2006). In order to attain the desired moisture levels for the study, samples were conditioned by adding a calculated amount of distilled water based on equation (1) (Solomon and Zewdu, 2008, Coskuner and Karababa 2007).

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad (1)$$

Where;

Q is the mass of water to be added in kg;

W_i is the initial mass of the sample in kg;

M_i is the initial moisture content of the sample in % db and

M_f is the final moisture content in % db.

The samples were sealed in separate polythene bags and kept in a refrigerator at 5°C for five days for moisture to distribute uniformly throughout the sample. Before starting the test, the required quantity of seeds were taken out of the refrigerator and allowed to warm up to room temperature for about two hours (Nimkar and Chattopadhyay, 2001).
The moisture content of cashew nut and kernel were determined at four (4) moisture levels (5.0, 6.5, 8.0, and 9.0% wb). These values are within the range of moisture contents encountered for cashew nut and kernel from harvest to storage. It is recommended that for storage, the moisture content for cashew nut and kernel should be at 5% (Azam-Ali and Judge, 2001).

Experimental Procedures

The average size was determined based on 100 randomly selected seeds. To determine the average size of the seed, a sample of 100 seeds were randomly picked and the three principal dimensions namely, Length *(a),* width *(b)* and thickness *(c)* axes were measured using a micrometer screw gauge with an accuracy of 0.01 mm. The width and thickness were measured perpendicular to the major axis. The geometric mean diameter *(Dg)* or equivalent diameter *(De)* as used by some researchers was calculated using the following relationship (Mohsenin, 1980):

$$D_e = (abc)^{1/3} \quad (2)$$

The Sphericity index (ϕ) of cashew nut and kernel were calculated using the following formula (Mohsenin, 1980).

$$\emptyset = \frac{(abc)^{1/3}}{a} \times 100 \quad (3)$$

Karababa and Coskuner (2007) citing Jain and Bal (1997) have stated that kernel volume, V , and kernel surface area, S , may be given by

$$V = \frac{\pi B a^2}{6(2a - B)} \quad (4)$$

$$S = \frac{\pi B a^2}{2a - B} \quad (5)$$

Where; B= $(bc)^{1/2}$ (6)

The bulk density of nuts and kernels defined as the ratio of the mass of sample of seeds to its total volume was measured by pouring samples into a cylindrical container of known volume, striking excess samples without compacting the nuts and kernels (Zewdu and Solomon, 2008; Karababa and Coskuner, 2007). The bulk density was calculated by dividing the mass of samples filling the cylinder with the volume of the cylinder.

The true density defined as the ratio of the mass of the sample to its kernel volume was determined using the water displacement method (Baryeh, 2001). A nut of known mass was immersed inside a known volume of water in a measuring cylinder. Owing to the short duration of the experiment and considering the nature of the skin of the samples which could easily absorb water, the amount of displacement was quickly recorded from the graduated scale of the cylinder. The experiment was repeated four times and the average values recorded. The ratio of weight of kernels to the volume of displaced water gave the true density (Ogunsina and Bamgboye, 2007; Karababa, 2006).

Porosity is the fraction of the space in the bulk sample which is not occupied by the kernels (Karababa, 2005; Baryeh and Mangope, 2002). The porosity of bulk samples was computed from the values of true (kernel) density and bulk density using the following relationship (Mustafa, 2006; and Pradhan *et al.,* 2008):

$$\varepsilon = \frac{P_t - P_b}{Pt} \times 100 \quad (7)$$

For the determination of mechanical properties, the Instron Universal Testing Machine (UTM) which is one of the most popular destructive test devices was used. The test was based on the force-deformation characteristics of the nut and this was done at four different moisture contents with four replications.

The device has three main components which are stable up and motion bottom of platform, a driving unit, and a data acquisition system. During a compressive test, the cashew sample was placed laterally on the stable up platform and was compressed with a motion probe at a constant speed until the specimen fractured. The rupture force of sample was measured by the dynamometer and data acquisition system, and the mechanical parameters of the test were automatically generated by the machine when programmed to determine the required mechanical properties of the cashew nut and kernel.

RESULTS AND DISCUSSIONS

4.1 Physical Properties

Dimension of Cashew nut and kernel

At the moisture content of 5.0% wb, which is the recommended storage moisture content, the average length, thickness, width, equivalent diameter were 41.15 mm, 23.92 mm, 32.76 mm, 31.89 mm for cashew nuts and the corresponding values for kernel at the same moisture content were 33.16 mm, 15.87 mm, 17.91mm and 21.23 mm respectively.

4.1.1 Sphericity Index (ϕ)

The values of sphericity index of the cashew nut and kernel were calculated individually with Eq. (3) by using the data on geometric mean diameter and the major axis of the cashew nut and kernel. The results obtained are represented in Fig. 3. The sphericity decreased marginally from 64.02 to 63.66% and 77.90 to 77.68% at moisture content range of 5.0% to 9.0% wb for cashew nut and kernel respectively. A similar trend of sphericity has been reported by Aydin et al. (2002) for mahaleb, Özarslan (2002) for cotton and Sacilik *et al.,* (2003) for hemp seed. The relationship between sphericity and moisture content for nut and kernel can be represented by:

ϕ_{n} =0.069mc +77.19

ϕ_{k} = 0.061mc +64.13

The values for coefficient of determination (R^2) for the nut and kernel are 0.872 and 0.880 respectively. The relationship between sphericity and moisture content was found to be significant at a significance level of 0.05.

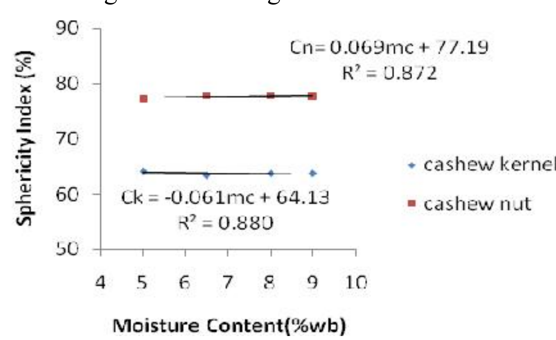


Figure 3. *Effect of moisture content on sphericity index of cashew nut and kernel*

4.1.2 Kernel Volume (V)

The variation of volume with kernel moisture content is shown in Fig. 4. The volume increased linearly with increase in moisture. When the moisture content changed from 5.0% to 9.0% wb, the volume increased from 101.47 to 110.83 mm^3 for cashew kernel. Similarly, the volume of cashew nuts increased with moisture content from 312.54 to 332.94 mm^3. The relationship between the nut and kernel volumes and moisture content are given by the following equations:

$V_n = 4.761mc + 289.30 \quad (R^2 = 0.965)$

$V_K = 2.283mc + 89.64 \quad (R^2 = 0.976)$

The increase in volume is obviously as a result of the increase in moisture. It can be seen from the graph (Fig. 4) that the kernel absorbed more moisture than the nuts and this could be due to the CNSL between the shells and the kernel. A number of food and agricultural products have recorded similar linear results. Some of these products are; Popcorn kernel (Karababa, 2006); Millet (Baryeh, 2002); Moth gram (Nimkar *et al.,* 2005).

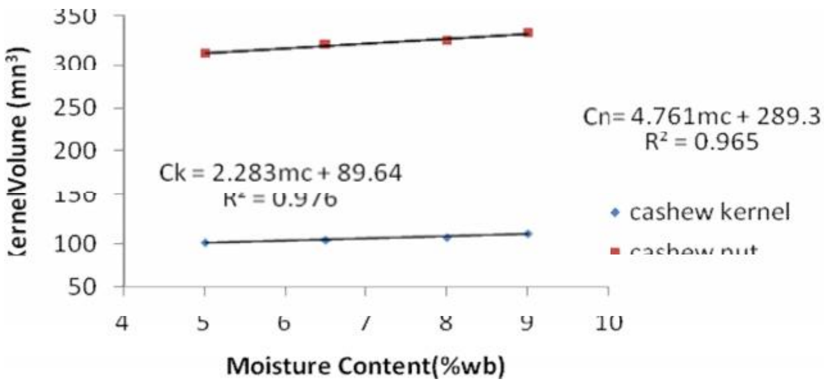


Figure 4. *Effect of moisture content on kernel volume of cashew nut/kernel*

4.1.3 Surface Area (S)

The values for surface area are presented in Fig. 5. The surface area of the cashew nut and kernel increased from 2754.68 to 2918.36m^2 and 1188.98 to 1309.02m^2 respectively with moisture variation ranging from 5.0% to 9.0% wb. The relationship between moisture content and surface area (S) was linear and can be represented by the regression equations:

$S_n = 38.54mc + 2559 \quad (R^2\ 0.957)$

$S_K = 28.54mc + 1046 \quad (R^2\ 0.982)$

Similar results for surface area were reported by Sherpherd and Bhardwaj (1986) for pigeon pea; Baryeh (2001) for bambara groundnuts, Baryeh (2002) for millet and Baryeh and Mangope (2002) for pigeon pea. However, Hsu *et al.*,(1991) found the surface area of pistachios to decrease with increasing grain moisture content.

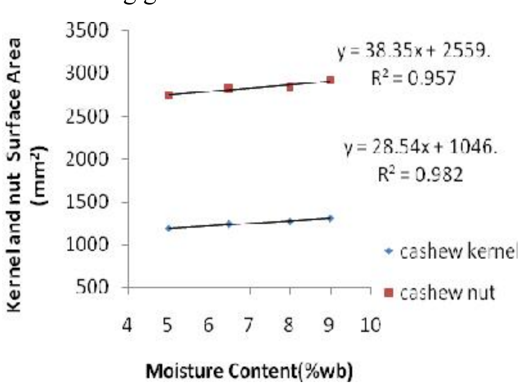


Figure 5. *Moisture content effect on kernel surface area of cashew nut and kernel*

4.1.4 True Density (ρ_t)

The variation of true density with grain moisture content is depicted in Fig. 6. The true density increased linearly from 946.23 to 991.29 kgm^{-3} and 1100.16 to 1209.51 kgm^{-3} for kernel and nut respectively as the moisture content increased from 5.0% to 9.0% wb. The relationship between true density and moisture content was obtained as:

$\rho_{tn} = 24.66mc + 72.1 \quad (R^2 = 0.889)$

$\rho_{tk} = 11.79mc + 889.2 \quad (R^2 = 0.966)$

This increase in true density indicates that there is a higher grain mass increase in comparison to its volume increase as its moisture content increases. This variation of true density with moisture content agrees with the findings of Singh and Goswani (1996) for cumin seed; Gupta and Das (1998) for sunflower seeds; Aviara *et al.* (1999) for guna seeds; Chandrasekar and Viswanthan (1999) for coffee beans. It is however contrary to the results of Baryeh (2001); Esref and Halil (2007); and Dursun *et al.* (2007) who found the true density to decrease with increase in moisture content for bambara groundnuts, red kidney bean and sugar beet respectively. These seeds thus have lower weight increase in comparison to volume increase as their moisture contents increase.

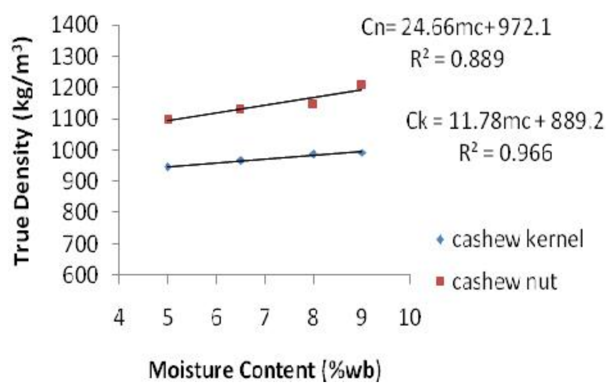


Figure 6. *Effect of moisture content on true density of cashew nut and kernel*

4.1.5 Bulk Density (ρ_b)

The bulk density of cashew nut and kernel as depicted in fig.7 decreased linearly from 625.62 to 592.42 kgm^{-3} and from 559.60 to 505.06 kgm^{-3} respectively as moisture content increased from 5.0% to 9.0% wb. The decrease in bulk density with an increase in moisture content is mainly due to the higher increase in volume than the corresponding increase in mass of the material. The negative linear relationship of bulk density with moisture content was also observed by Aydin (2003) and Gupta and Das (1997) for neem nut and sunflower seed respectively. Bulk density was found to have the following relations with moisture content:

ρ_{bn} = 8.534mc + 666.80 (R^2 = 0.976)

ρ_{bk} =12.10mc +621.10 (R^2 = 0.882)

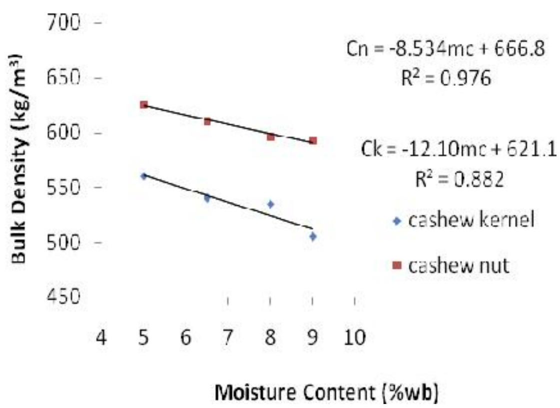


Figure 7. *Effect of moisture content on bulk density of cashew nut and kernel*

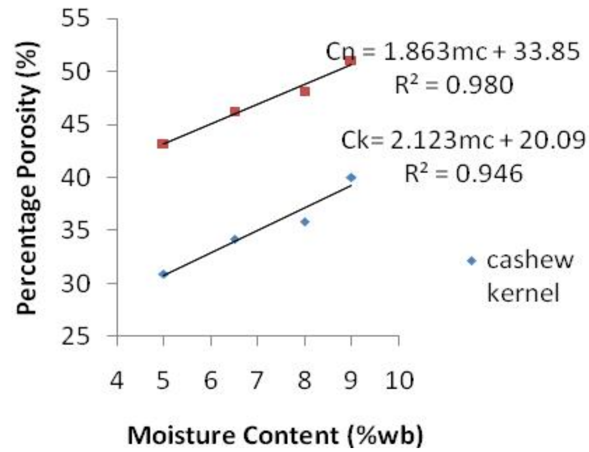
4.1.6 Bulk Porosity (ε)

The porosity of the samples calculated using Eqn.7 at different moisture content is shown in Fig. (8). The porosity increased linearly from 30.86 to 40.05% for kernel and 43.19 to 51.02% for nut with increase in moisture content from 5.0% to 9.0% wb. The increase in moisture content could be attributed to the expansion and swelling of the samples that might have resulted in more void spaces between the samples and hence the increase in bulk volume. The relationship between porosity and moisture content is given by:

ε_k = 2.123mc + 20.09 (R^2 = 0.946)

ε_n = 1.863mc + 33.85 (R^2 = 0.980)

Similar observations were reported for tef seed (Zewdu and Solomon, 2007); Niger seed (Solomon and Zewdu, 2008);



category B cocoa bean (Bart-Plange and Baryeh, 2003); moth gram (Nimkar *et al.,* 2005); amaranth seeds (Abalone *et al*., 2004); peanut and kernel (Aydin, 2006). However, a reverse relationship had been found for okra seed (Sahoo and Srivastava, 2002). This is an indication that porosity of different food and agricultural products could respond differently to changes in moisture contents which could be attributed to their morphological characteristics.

Figure 8. *Effect of moisture content on percentage porosity of cashew nut and kernel*

4.2 Mechanical properties

4.2.1 Maximum compressive load *(L)*

Figure 9 shows the relationship between maximum compressive load and moisture content. The value of the compressive load increased progressively as the moisture content was varied. The load increased from 0.445 to 0.574kN and from 0.146 to 0.213kN for the kernel and nut respectively in the moisture content range of 5.0 to 9.0wb. The relationship between compressive load and moisture content may be expressed by the following regression equations:

C_k = 0.029mc + 0.296 (R^2 = 0.934)
C_n = 0.017mc + 0.059 (R^2 = 0.997)

From the linear relationship, it can be said of the two slopes that the load required to crack the nuts was less than the load required to crush the kernels.

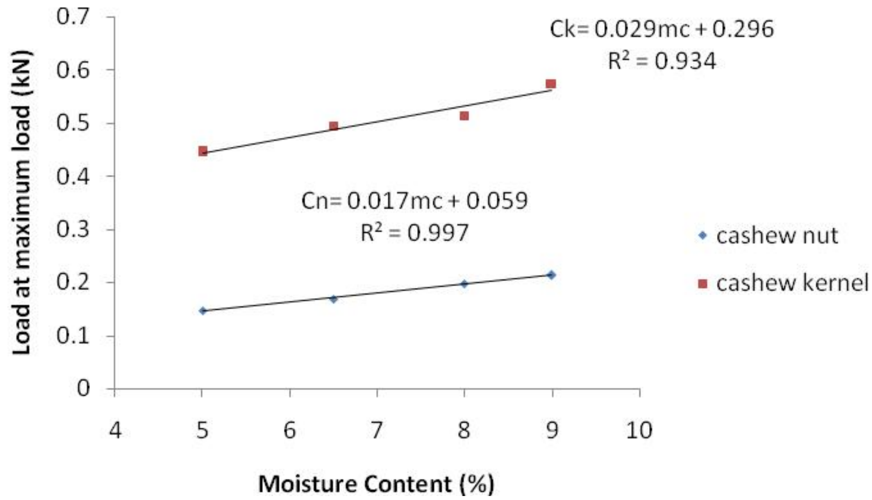


Figure 9. *Relationship between maximum load of cashew nut and kernel and moisture content*

4.2.2 Maximum displacement (d)

The maximum displacement of the cashew nut and kernel obtained from the experiment in the moisture content range of 5.0% to 9.0% wb was found to lie between 3.006-4.105 mm for the nuts and 7.76-8.008 mm for the kernel respectively. The variation of maximum displacement with moisture content is shown in figure10. The average displacement for crushing the cashew kernel was 6.89mm and for cracking the cashew nut was 4.50 mm. The experimental values of the cashew nut and kernel as a function of moisture content were correlated using the regression equations:

$C_k = 0.052mc + 7.472 \quad (R^2 = 0.672)$

$C_n = 0.317mc + 1.292 \quad (R^2 = 0.870)$

The kernel is softer and tougher as compared to the nuts and therefore the kernel required a higher compression depth than the nuts.

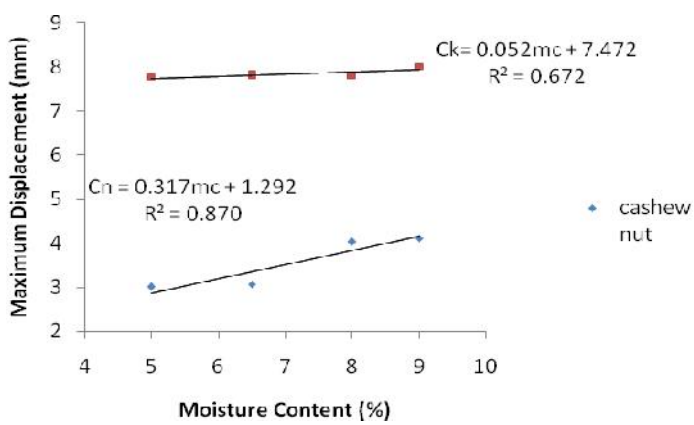


Figure 10. Variation in maximum displacement of cashew nut and kernel with moisture content

4.2.3 Stress at maximum load

The relationship between compressive stress and moisture content is shown in fig. 11. The experimental values of compressive stress increased from 2.225-2.872 MPa and 0.214-1.215 MPa for cashew kernel and nut respectively. The variation of stress with moisture content for the kernel and nut resulted in a linear relation. The regression equations resulting from the relationships are as follows:

$C_k = 0.147mc + 1.479 \quad (R^2 = 0.933)$

$C_n = 0.255mc + 1.076 \quad (R^2 = 0.997)$

The cashew kernel recorded higher values than the cashew nuts. The reason accounting for this is the fact that, during the compression process, it took much force crushing the kernel and this may be due to the oily nature of the kernel.

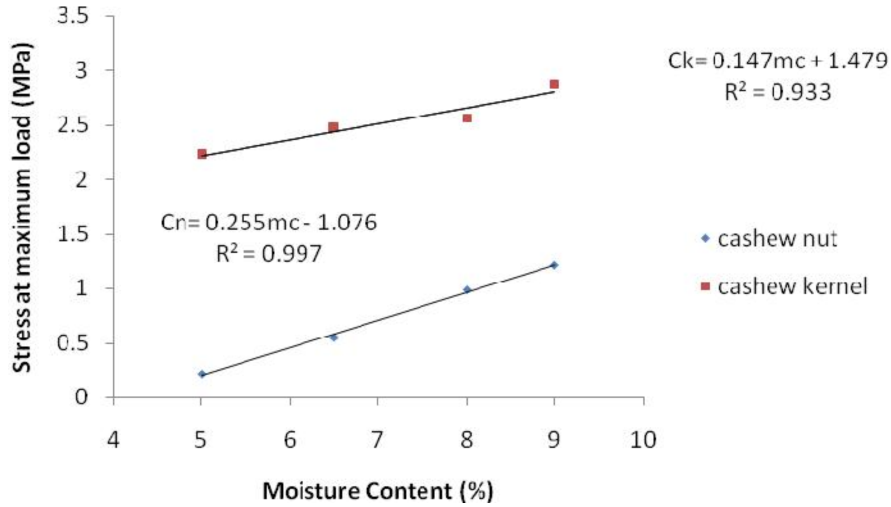


Figure 11. *Variation in compressive stress of cashew nut and kernel with moisture content*

4.2.4 Strain at maximum load

The relationship between compressive strain and moisture content for cashew nut and kernel are shown in fig. 12. The values for cashew nuts and kernels increased as moisture content increased. The compressive strain of the cashew kernel increased from 0.777 mm/mm at a moisture content of 5.0% wb to 0.801 mm/mm at a moisture content of 9.0% wb. Similarly, the compressive strain of the nuts varied from 0.355 mm/mm at 5.0% wb to 0.472 mm/mm at of 9.0% wb. The relationship between the cashew nut and kernel are represented by the regression equations:

$C_k = 0.005mc + 0.746$

$C_n = 0.028mc + 0.200$

with the values of the coefficient of determination R^2 of 0.863 and 0.909 respectively. The strain values of the cashew kernel were higher than that of the nuts. The relationship between compressive strain and moisture content was found to be significant at 0.05.

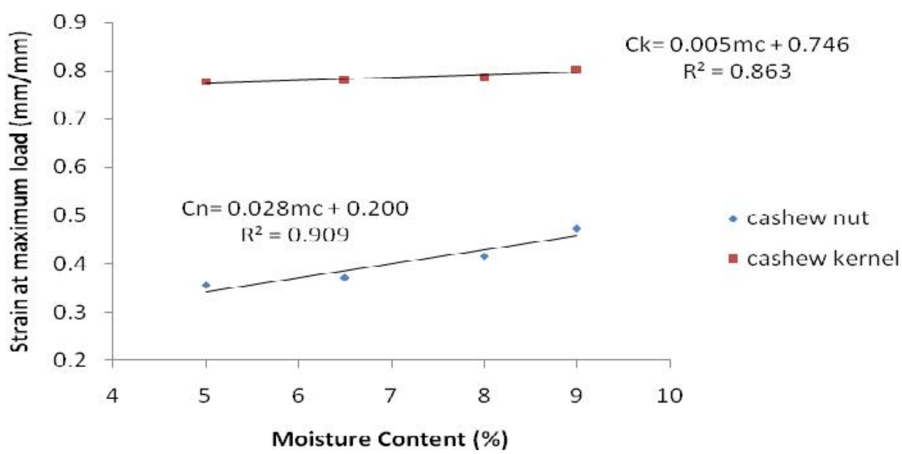


Figure 12. *Variation in compressive strain of cashew nut/kernel with moisture content*

4.2.5 Young's modulus

Figure 13 shows the relationship between young's modulus and moisture content. Young's modulus increased from 4.666-11.139 MPa and from 2.446-6.416 MPa for kernel and nut respectively as moisture content increased from 5.0-9.0% wb. The relationship of young's modulus and moisture content can be represented by the following equations:

$C_k = 1.656mc – 3.640$

$C_n = 0.864mc – 1.982$

With a value for R^2 of 0.996 and 0.843 respectively. Similar linear relationship between young's modulus and moisture content has been reported by Seyed and Maryam (2007) for kiwifruit.

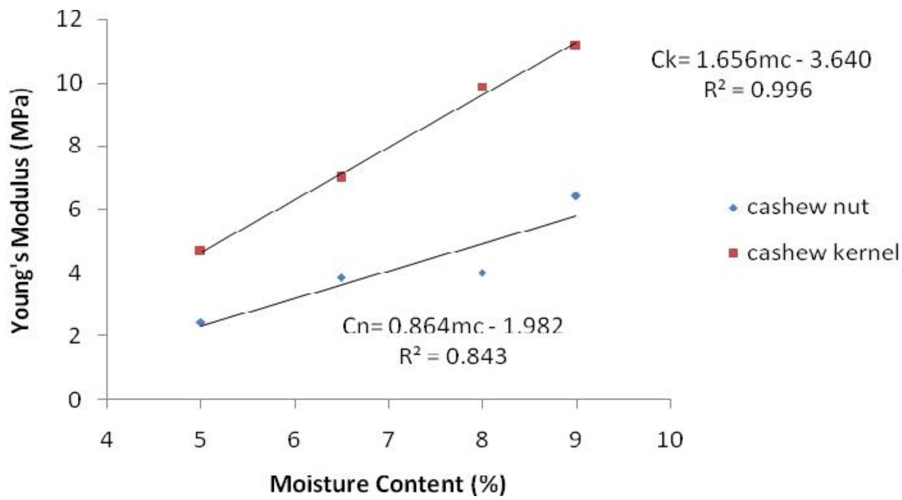


Figure 13. *Variation in young's modulus of cashew nut and kernel with moisture content*

5.0 CONCLUSIONS

For the moisture content range of 5.0% wb and 9.0% wb all the engineering properties of the cashew nut and kernel studied were found to be moisture dependent.

5.1.1 Physical properties

- The average length, thickness, width and equivalent diameter for cashew nuts were 41.15 mm, 23.92 mm, 32.76 mm and 31.89 mm respectively and that of kernels were 33.16 mm, 15.87 mm, 17.91 mm and 21.23 mm respectively.
- The sphericity decreased marginally from 64.02 to 63.66% for kernel and 77.90 to 77.37% for nut as moisture content varied within the predetermined range of 5.0 % to 9.0% wb. Also, the kernel and nut volumes increased linearly from 101.47 to 110.83mm^3 and 312.54 to 332.94 mm^3 respectively. The surface area of the nut and kernel increased from 2754.68 to 2918.36m^2 and 1188.98 to 1309.02m^2 respectively with moisture content ranging from 5.0% and 9.0% wb.
- True density for nut and kernel increased from 1100.16 to 1209.51kgm^{-3} and 946.23 to 991.29 kgm^{-3} respectively but on the other hand bulk density decreased correspondingly from 625.62 to 592.42 kgm^{-3} and 559.60 to 505.06 kgm^{-3} as moisture content was increased from 5.0% to 9.0% wb.
- With increasing moisture content, bulk porosity of the kernel and nut increased linearly from 40.86 to 49.05% and 43.19 to 51.02% respectively.

5.1.2 Mechanical properties

- Maximum compressive load of cashew kernel increased from 0.445 kN at 5.0% wb to 0.574 kN at 9.0% wb whilst that of cashew nuts increased from 0.146 to 0.213 kN at the same moisture content range. Similarly, the maximum displacement for the kernel and nut also increased from 7.760 to 8.008 mm and 3.006 to 4.105 mm respectively.
- The compressive stress at maximum load, increased linearly from 2.225 to 2.872 MPa for cashew kernel and 0.214 to 1.215 MPa for cashew nut at a moisture content range between 5.0% and 9.0% wb. The compressive strain values of the cashew kernel and nut also increased from 0.777 to 0.801 mm/mm and 0.355 to 0.472 mm/mm respectively at a moisture content range of 5.0%9.0% wb.
- As moisture content varied from 5.0% to 9.0% wb, the young's modulus of Cashew kernel and nut increased progressively from 4.666 to 9.853 MPa and 2.446 to 6.416 MPa respectively.

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