Heat treatment and loading orientation effects on some mechanical properties of steamed cashew kernels (*Anacardium occidentale L.*)

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Abstract: The economic interest has made many countries of the world to encourage the cultivation of cashew and it is fast becoming an export produce in many developing countries. The necessary processing operations needed for cashew nut before obtaining the standard exportable quality of edible cashew kernel require lot of time, materials and human resources. This study considers the wholeness of kernels obtainable by varying the drying duration and temperature. The cashew kernels were steamed, peeled and dried. Mechanical properties of the dried samples of the kernels were determined at axial, lateral and longitudinal loading. The breaking force and energy of cashew kernels followed a non-steady pattern with moisture removal at constant temperature and different durations of drying. However, to save energy and time, drying at 80°C for 5 h and drying at 90°C for 3 h are recommended for high quality kernels.

Keywords: steaming, cashew kernel, heat treatment, loading orientation, drying

1 Introduction

The cashew tree Anacardium occidentale L., is generally bushy, low-branched and spreading, may reach 10.6 m in height and width. The true fruit of the tree is the cashew nut resembling a miniature boxing-glove; consisting of a double shell containing a caustic phenolic resin in honeycomb-like cells, enclosing the edible kidney-shaped kernel (ITDG, 2005). The economic interest has made many countries of the world to encourage the cultivation of cashew. Among horticultural crops, it has been known to provide very high economic returns.

The cashew kernel is the main product which has aroused economic interest in the wide spread cultivation of cashew. The kernel is widely consumed as snacks and used as a basic ingredient for confectionaries in most countries of the world because of its good nutritive value. The exportation of cashew as raw nuts has therefore earned much foreign exchange for many developing countries including Nigeria (Ogunsina, 2009). Three main cashew products are traded in the international market: raw nuts, cashew kernels and cashew nut shell liquid (CNSL). The cashew apple is generally processed and consumed locally. The raw cashew are either exported or processed prior to export. The skin of the kernel is also high in tanning for hides.

The cashew nut shell contains a kind of viscous and dark liquid, known as cashew nut shell liquid (CNSL), which is extremely caustic. It is contained in the thin honeycomb structure between the soft outer skin of the nut and the harder inner shell. CNSL is an important and versatile industrial raw material for phenolic resins and friction powders for the automotive industry (brake linings and clutch disks as binders), mouldings, acid-resistance paints, foundry resins, vanishes, enamels and as insecticides and fungicides (Asiru, 2010). After extracting the

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CNSL, the cashew nut shells can be burnt to provide heat for the decorticating operation or can be used in the manufacture of agglomerates. The cashew nut kernel consists of the shell, the kernel and the adhering testa. The primary product of cashew nut is the kernel, the only edible.

The necessary processing operations needed for cashew nut before obtaining edible cashew kernel requires lot of time, material and human resources. This includes: cleaning, roasting/steaming, shelling, drying and packaging. Today, the caustic substance which is a valued by-product of cashew nut production made plant domestication difficult, such as the highly caustic CNSL which causes severe skin irritation on contacting with human body. Roasting nuts would remove the caustic oil, allowing the nut to be cracked and consumed without any ill effects. When nuts are burnt or roasted, contacting with or breathing of the fumes can also cause skin and eye irritation, inflammation or poisoning.

Since the heat applied to the nut cannot be fully regulated, this may completely destroy the CNSL which is a valuable raw material for industrial processes and will also affect the quality of the kernels in the shell causing the kernels to break and having become brittle during shelling. However, kernels when removed wholly and without crack attract more economic value and this must be considered in cashew nut processing.

Considering that most research works by Oloso and Clarke (1993); Ajav (1996); Umesh and Rastogi (2000); Balasubramanian (2002); Akinoso, Asiru and Awoliyi (2004); Umesh and Ramesh (2004) and Ojolo and Ogunsina (2007) are carried out on roasted nuts, alternative method of kernels production must be explored. This informs the use of steam roasting in this research work. The main objective of this study is therefore to use the variation in the mechanical properties of cashew kernel to determine the appropriate temperature and duration of drying shelled cashew kernel, which will give the desirable quality for export. Specifically, the optimum condition being necessary to produce whole kernels, which are of high economic importance, are to be determined. Considering the various economic uses of cashew kernel, research effort should be geared towards maximizing the quality of the consumable kernels through the determination of appropriate drying duration (time) and degree of temperature of the drier to give the best output of kernels with good qualities and to reduce losses through kernel wastage, unnecessary power consumption and time wastage.

2 Materials and methods

2.1 Preparation of samples

Cashew nut sample weighing 20 kg was divided into five batches of 4 kg using a digital weighing balance (Mettler PC 440 Delta Range, Switzerland). Each batch was packed securely in a net and steamed in an autoclave (Dixon Surgical Instrument Ltd, Model 3T 19T) for 15 min. under a pressure of $7.93 \times 10^5 \mathrm{N} \cdot \mathrm{m}^{-2}$ at 121^{o}C (Raman, Pushpalatha and Narayanankutt, 2000). These conditions were obtained from a preliminary experiment. The net ensures that the nuts are suspended in the autoclave chamber and only in contact with steam but not the body of the autoclave which will pass heat by conduction. The steamed cashew nuts were then cooled in an open air for 24 h before shelling to remove the kernels using FIIRO cashew nut cracker. After the careful removal of the kernels from the shells, whole kernels were separated from the broken and cracked ones. The whole-kernels were kept in a polythene bag sealed using a pulse sealing machine and labeled accordingly before storing in a cool environment in a refrigerator. Samples were taken before storage to determine the moisture content using the oven dry method. This involved placing the weighed representative samples in an electric oven (Gallenhamph, Model OV-440, England) set at 103 ± 2 ^{o}C and weighing at intervals until constant weights obtained.

The kernels were dried in a cabinet dryer at temperatures of 70, 80, 90, 100 and 110 ^{o}C for 3, 4, 5, 6, 7, and 8 h. This gives a 5 x 6 factorial combination. The samples obtained were analyzed for Yield Parameters, Failure Forces and Energy at Failure during shelling. The samples were then packed in polyethylene bags and sealed after labeling them to avoid re-absorption of moisture and loss of moisture to the environment since they were not bone dried. The whole samples were then stored in refrigerators to avoid damage by micro-organisms, insects and rodents.

2.2 Test of mechanical properties

The processed cashew kernels were tested for their strength properties under compression when loaded under a Universal Testing Machine (Testometric Machine, Model M500 - 25KN). These properties are the Peak Force, Breaking Force, Stress at Break, Energy at Peak, Energy at Break, Deformation at Peak and Deformation at Break. Loading of the cashew kernels were done axially, laterally and longitudinally.

3 Results and discussion

The moisture content of the cashew kernel dried at 70^{o}C with duration of drying used for the drying studies is presented in Figure 1. The moisture content decreased with time of drying. This trend of drying is a pattern which can be related to the normal drying curve with three stages of drying indicating the loss of capillary water (0–90 min.), bound water (90–150 min.) and adsorbed water (150-210 min.). Hardening or caking did not seem to have occurred, so only moisture was lost.

The equation of the line of fit of moisture content (MC, %) against duration of drying (t, min) is given as equation (1).

$$MC = 1x19^{-11}t^{6} – 7x10^{-9}t^{5} + 2x10^{-6}t^{4} - 0.0003t^{3} + 0.0229t^{2} - 0.9055t + 17.223\ (R^{2} = 0.99) \quad (1)$$

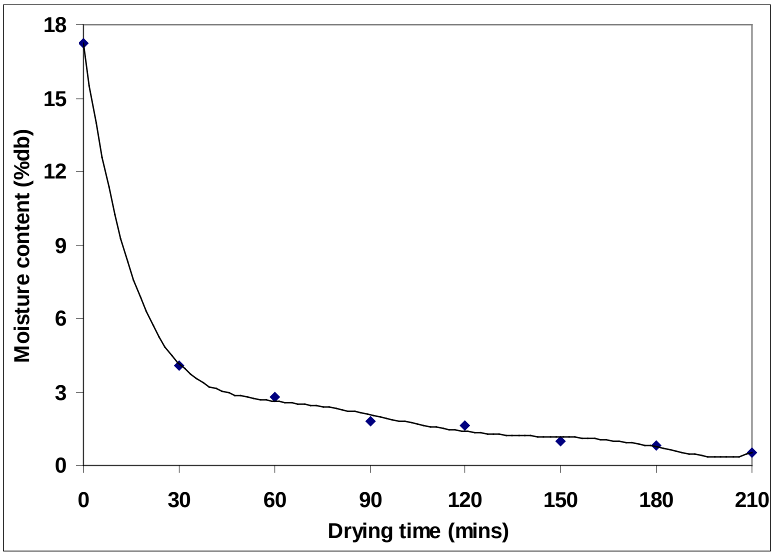


Figure 1 Variation of moisture with duration of drying

3.1 Changes in mechanical properties of cashew kernels at different loading orientations

The results of kernel loading axially, laterally and longitudinally at varying temperatures and duration of drying for cashew kernel are presented in Table 1 - 3 and Figure 2 - 7.

3.2 Mechanical properties for axial loading

3.2.1 Deformation at Peak and Break after 3 h of drying

The deformation of the cashew kernels under axial loading under 3 h of drying and at different temperatures are shown in Figure 2 (a and b). For kernels dried at 70°C the deformation was evident because the kernel was still tender while at 80°C the deformation decreased because more moisture has been lost (compared to 70°C) due to the heat supplied, giving room for high compression of the cashew kernel at low force application. At 90°C, 100°C and 110°C there were reductions in deformation due to the hardening of the surface (caking) of the cashew kernel thereby trapping moisture inside the endocarp. Since liquids are incompressible, the material became difficult to be compressed reducing the deformation at peak with a slight increase in the force applied (Figure 3), the cashew kernel therefore failed resulting in an increase in the deformation at break.

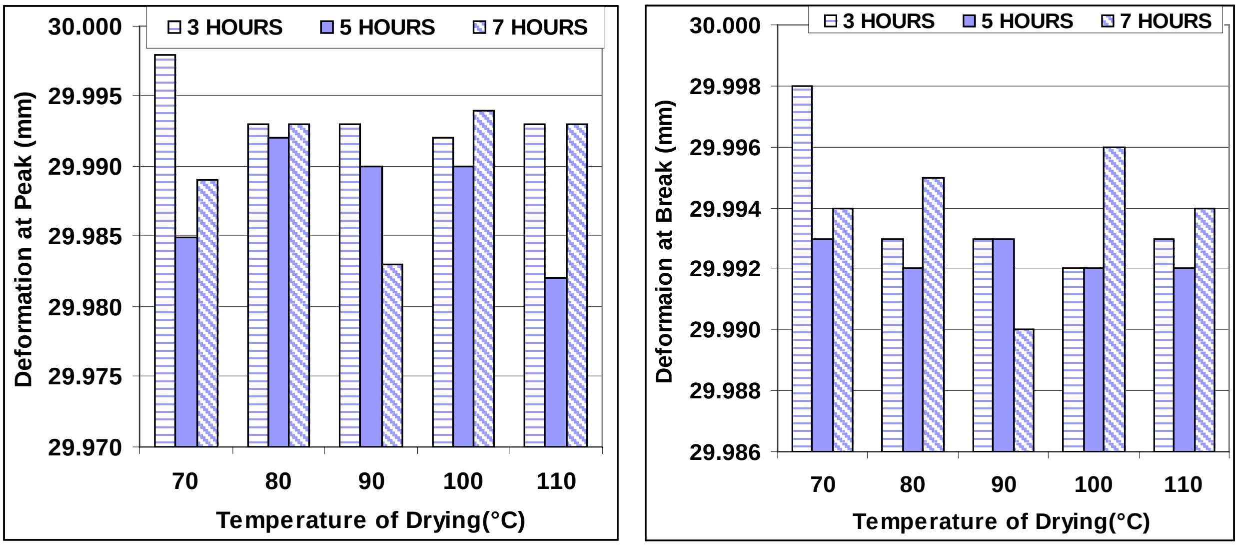
Deformation at break followed a similar pattern as in peak (Figure 2b), and it clearly showed that a lower force was required to cause deformation at 70°C while at 80°C less deformation at break occurred because more moisture has beeng lost and the surface has been hardened leading to high force to cause deformation. Above 80°C the already caked surface kept the level of deformation and forces needed at almost a constant level as caking had already set in.

3.2.2 Deformation at Peak and Break after 5 h of drying

The deformation at peak for the kernels dried for 5 h as shown in Figure 2a increased from 70°C to 80°C due to uniform loss of moisture of the material but for 90°C to 110°C, there was a decrease. This means during drying at these temperatures for 5 h of drying the material has possibly started caking making compression difficult. The decreasing force and higher deformation showed that the materials were adequately dried and became brittle hence deformed and broke easily as a result of lack of moisture and caking. The trend for the deformation at break (Figure 2b) showed a relatively uniform deformation at all the temperatures.

3.2.3 Deformation at Peak and Break after 7 h of drying

These mechanical properties according to Figure 2 (a and b) followed similar pattern for 3 h. At 70°C the moisture was fully removed due to the longer drying time, so there was less deformation. At above 80°C the surface caked before the moisture could be removed fully, so the deformations were high because the hardened surface with tendered inner part has been pressed. At 90°C the material has caked but the fibres and tissues were not yet fully tendered, so the distance of deformation dropped. At 100°C and 110°C the material surface has been hardened and the inner fibres and tissues properly cooked and made tender. The deformation increased and the cashew kernel collapsed completely.



a. b.

Figure 2 Deformation at (a) Peak and (b) Break for axial loading

3.2.4 Peak Force, Breaking Force and stress at Break at 3 h of drying

Figure 3 (a and b) and Table 1 can be interpreted by relating the peak and breaking forces with the deformation at peak and deformation at break respectively. The peak and breaking forces rose from 70^{o}C to 80^{o}C and thereafter dropped sharply for reasons given for the deformation. The Energy at Peak and Break followed the pattern in an inverse manner increasing from 80^{o}C to 100^{o}C in relation to corresponding increase in Peak and Breaking Forces. At 110^{o}C there was a drop in the Energy at Peak and Break corresponding to the increase in the values of the Peak and breaking forces. This can be linked to the decrease in the Deformation at Peak as stated above. Similar trend was observed by Oloso and Clarke (1993) for hot oil roasted cashew nuts and Mamman, Umar and Aviara (2005) for balanites egyptica nuts.

Table 1 Mechanical properties after 3 h, 5 h, and 7 h of drying for axial loading

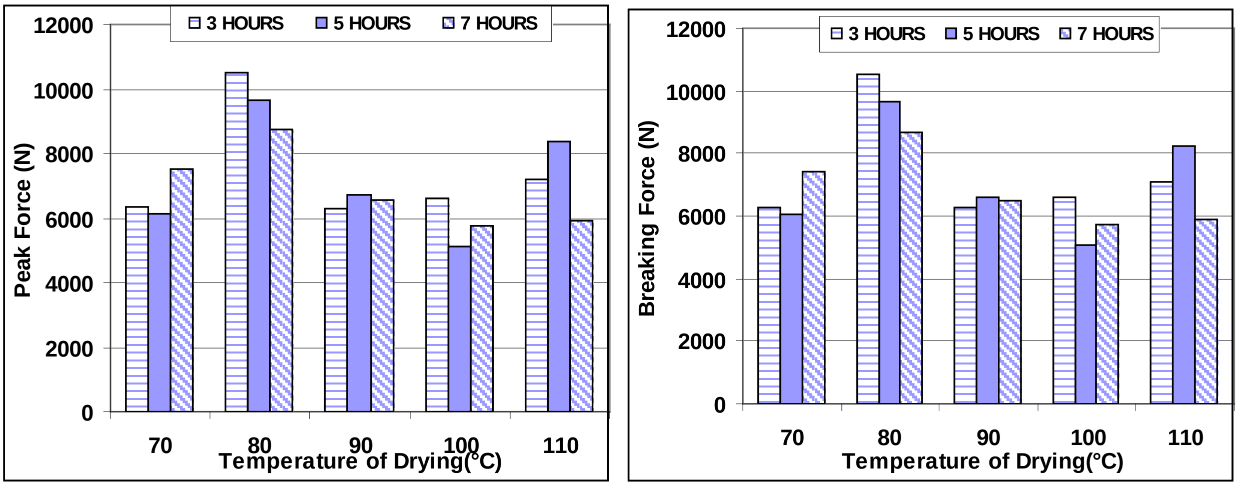
Axial loading	3 h			5 h			7 h		
Temperature of Drying (°C)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)
70	6291.0	7.6037	7.6516	9649.0	20.896	20.942	7431.3	8.1170	8.1490
80	5918.0	6.7185	6.7783	9642.0	20.612	20.612	8686.3	15.1130	15.1340
90	6260.7	7.4103	7.4399	6618.7	7.187	7.203	6485.7	7.5812	7.6219
100	6605.3	12.6110	12.6110	5070.7	8.464	8.471	5717.0	6.5191	6.5325
110	7115.7	11.7780	11.8070	6467.0	8.520	8.620	5890.7	9.2930	9.2970

3.2.5 Peak Force, Breaking Force and stress at Break dried for 5 h

Figure 3 (a and b) and Table 1 show continuous decrease in the values of these mechanical properties from 80^{o}C, 90^{o}C and 100^{o}C. As stated for deformation for increased drying time of 5 h, the moisture loss along the axis decreased gradually without caked surfaces. At 110°C the increase in these values after 5 h meant the high heat application has caused the surface of the cashew kernel to cake thereby trapping moisture which is incompressible and this increased the values slightly. The energy at Peak and energy at Break dried for 5 h decreased with increase in temperature (Table1). This means that there was a gradual loss of moisture when dried for 5 h but at 100°C and 5 h of drying, caking started and increased at 110°C causing an increase in the axial compressive energy at Peak and Break.

3.2.6 Peak Force, Breaking Force and stress at Break at 7 h of drying

Table 1 and Figure 3 (a and b) shows the variation in the mechanical properties after 7 h of drying a sample of cashew kernel. These properties were obtained by applying axial load on the cashew kernels. The undulating variation in the Peak Force, Breaking Forces and stress at Break could be because there was a gradual moisture removal at 70°C even after the 7 h of drying. At 80°C of heating, the surface has been hardened causing moisture to be trapped inside. Since liquids are incompressible, this increased the Peak Force, Breaking Force and stress at Break of the biomaterial. At 90°C and 100°C, heating for 7 h has made the surface to cake but these continuous high temperatures will still force the heat through the hardened surface causing the fibres and tissues of the cashew kernel to cook leading to a chemical reaction and these tender fibres and tissues result in load reduction at 90°C and 100°C. But at 110°C the material had been hardened and this high heat burns the inner fibres and tissues causing the inner particles to be hardened too and this results in a gradual increase in the mechanical properties. Table 1 shows that the energy at Peak and Break follow the same pattern as in 3 and 5 h of drying and these have the same explanation.



a b

Figure 3 (a) Peak Force (b) Breaking Force for axial loading

3.3 Mechanical properties for lateral loading

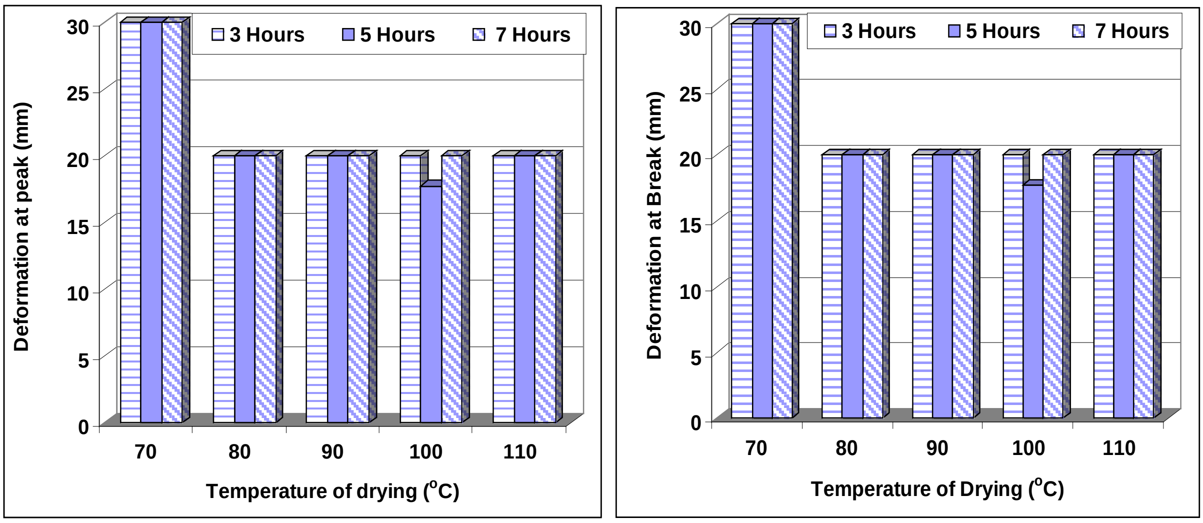
The variation in the mechanical properties after three periods of drying a sample of cashew kernel loaded laterally are presented in Table 2 and Figure 4 and 5.

Table 2 Mechanical properties at 3 h, 5 h and 7 h of drying

Lateral loading	3 h			5 h			7 h		
Temperature of Drying (°C)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)
70	8249.5	10.452	10.497	8389.0	8.729	8.809	6884.7	6.687	6.714
80	8113.0	8.135	8.151	7619.3	7.993	8.037	5321.3	4.621	4.621
90	7306.3	9.894	7.934	6019.7	5.670	5.685	8405.3	11.032	11.061
100	6131.3	6.574	6.609	3145.2	2.489	2.490	6700.7	7.859	7.859
110	4104.3	4.196	4.219	4137.7	4.300	4.324	6554.0	6.136	6.1562

The variations in loading at all the duration of drying under lateral loading follow the same pattern except for 5 h where it showed a slight decrease at 100^{o}C. These are shown in Figures 4 and 5 (a and b). At 70^{o}C there was a great deformation of the cashew because water has not being fully removed. However there were variations created in the particles of the cashew kernels which upon load application got disarranged and the pore spaces filled, thereby causing great deformation. At 80^{o}C more moisture has been removed but less deformation due to the hard nature of the tissues and fibres. At 90^{o}C, 100^{o}C and 110^{o}C the moisture could not be removed because the cashew kernel tissue and fibres were already hardened hence there was no increase in deformation.

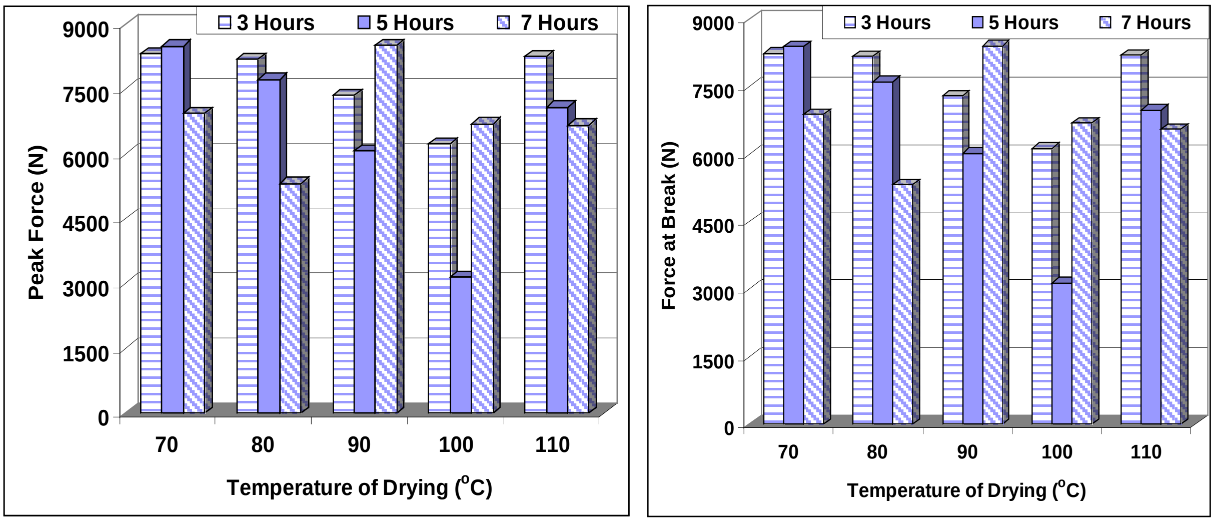
In Figure 4 (a and b), at 5 h of drying and 100^{o}C there was a sudden decrease in the deformation which suggests that the biomaterial has caked, shrank and collapsed under high heat and the duration of heating, giving no room for further deformation. At 110^{o}C, the sudden increase or rise in deformation could be as a result of the fact that after the material has collapsed, some of the particles got burnt leaving the fibres and tissues dried up and creating a vacuum. Deformation for lateral loading ranges between 18.898 to 19.998 for lateral loading. These values is much more higher than reported by Suthar and Das (1997) for Karingda seed and Gupta and Das (2000) for sunflower seed and kernel.



a b

Figure 4 Deformation at (a) Peak and (b) Break for lateral loading

Considering Table 2 and Figure 5 (a and b), all the mechanical properties of the samples loaded laterally at 3 and 5 h follow the same trend with a drop in value as the drying temperature increases except for a sharp increase at 110^{o}C. However the samples dried at 7 h the properties dropped from 70 -80^{o}C, rose at 90^{o}C and the downward trend continued till 110^{o}C. This indicates a uniform emission or loss of moisture without minimal indication of surface hardening. This could be linked to the orientation of the cashew kernels in the drier and the direction of heat supplied alongside circulation of air in the drier. These values were higher than that obtained for karingda seed (Suthar and Das, 1997) and cummin seed (Singh and Goswani, 1998) but followed the same trend as moisture content decreases with horizontal loading.



a. b

Figure 5 (a) Peak Force and (b) Breaking Force for lateral loading

3.4 Mechanical properties for longitudinal loading

The variation in the Mechanical properties after three, five and 7 h of drying a sample of cashew kernel are as presented in Table 3 and Figure 6 and 7. These properties were obtained by applying load on the cashew kernels placed longitudinal on the loading platform.

Table 3 Mechanical properties at 3 h, 5 h and 7 h of drying

Longitudinal loading	3 h			5 h			7 h		
Temperature of Drying (°C)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)	Stress at Break (N/mm^2)	Energy at Peak (J)	Energy at Break (J)
70	7748.5	6.687	10.168	9670	12.771	12.771	9862	12.904	12.904
80	7588.0	4.621	8.065	8612	13.229	13.263	6792	8.274	8.274
90	8897.7	11.032	13.097	8110	13.225	13.250	8060	10.599	10.628
100	7169.3	7.859	9.676	7873	10.243	10.256	9509	12.197	12.283
110	5549.3	6.136	7.236	3533	3.339	3.547	8517	12.017	12.083

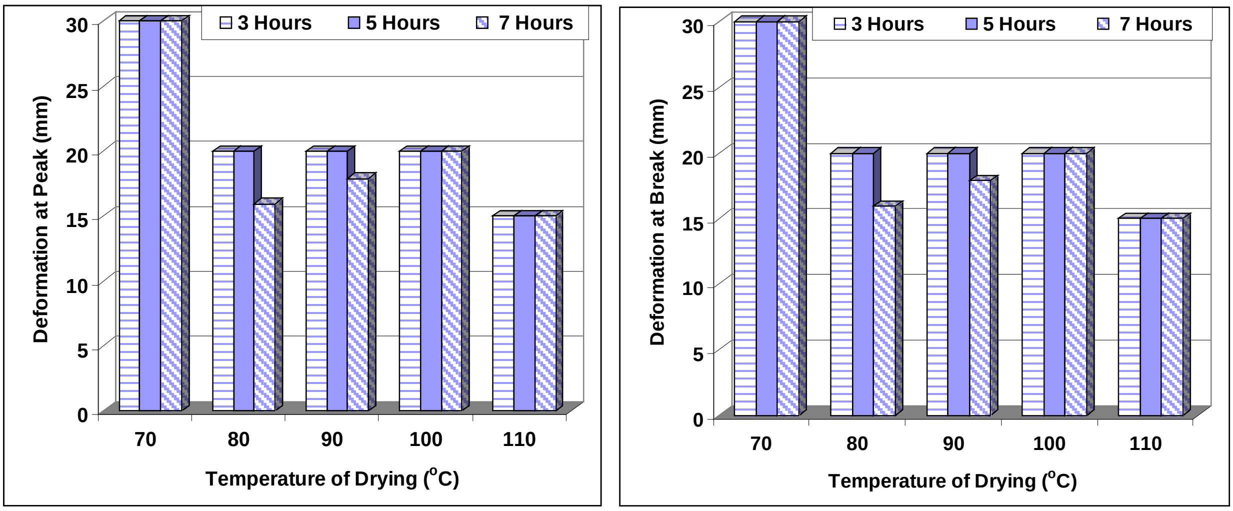


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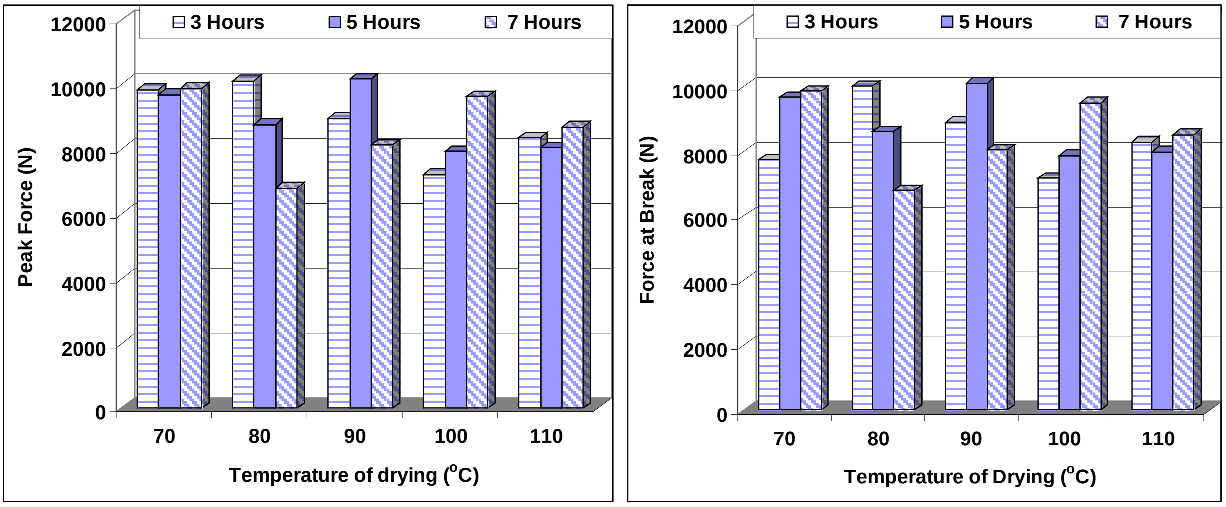
Figure 6 Deformation at (a) Peak (b) Break for longitudinal loading



a b

Figure 7 (a) Peak Force and (b) Breaking Force for longitudinal loading

In Figure 6 and 7 (a and b), for three and 5 h drying, the deformation decreases rapidly from 70^{o}C to 80^{o}C because the moisture has not been adequately removed thereby preventing compressive longitudinal loading. At 90^{o}C and 100^{o}C no considerable deformation was noticed while at 110^{o}C the deformation decreased. This could be as a result of chemical reaction that removes the moisture and allows the kernel to cook causing the tissues to be tender.

At 70^{o}C to 80^{o}C both deformation at peak and break for 7 h of drying decreased but increased up to 100^{o}C due to hardened surface and lack of high heat to penetrate the hardened surface (Figure 6). At 100^{o}C the surface though hardened, the heat was able to penetrate the hard coat and cause the inner component to become soft and tender thereby having an increasing deformation at peak. At 110^{o}C the tendered tissues and fibres become burnt and shrank so when load was applied deformation dropped.

3.4.1 Mechanical properties at 3 h of drying

Carefully observing Figure 7 (a and b) and Table 3, a similar trend and gradual increase in the mechanical properties was noticed, indicating that at 70^{o}C heat was applied to the cashew kernel for 3 h but this did not remove much moisture trapped in the biomaterial thereby causing an increase in the value of the mechanical properties.

At 80^{o}C, heat applied for 3 h removed considerable amount of moisture thereby reducing the values of the mechanical properties. These remained uniform at 90 and 100^{o}C, however at 110^{o}C the increase in the values could be linked to the surface hardening of the biomaterial thereby increasing the values of the mechanical properties obtained by applying longitudinal loading to cashew kernels.

3.4.2 Mechanical properties at 5 h of drying

The Deformation at Peak, Deformation at Break, Peak Force, Breaking Force, Energy at Break and Energy at Peak are as presented in Table 3 and Figure 7 (a and b) all the physical and mechanical properties follow the same pattern at 5 h of drying, the biomaterial becomes caked and this made the fibres to become tender, thereby causing the mechanical properties to decrease with increasing moisture.

3.4.3 Mechanical properties at 7 h of drying

The Peak Force, Breaking Force, Stress at Break, Energy at Break and Energy at Peak as presented in Figure 7 (a and b) and Table 3 showed that all the properties follow the same trend. There is a drop in value from 70^{o}C to 80^{o}C meaning that at 70^{o}C heat was applied gradually and the heat stayed for 7 h but could not totally remove the moisture content or tender the fibres, so the values of the properties were still high. At 80^{o}C, the temperature has increased so it took less time to remove all the moisture and these take less energy and force to fail. At 100^{o}C as the drying time of the hardened material increases more moisture was given off, the fibres and tissues became tender, and this takes a lightly increasing force and energy to break. Heavily caked and burnt material at 110^{o}C required greater force and energy to break.

As observed earlier, in longitudinal loading, the mechanical properties generally decreases with increase in drying time and temperature as expected of biomaterials. This trend was also reported by Oloso and Clarke (1993), Shutra and Das (1997), Singh and Goswani (1998) and Gupta and Das (2000).

Therefore, in general, to obtain good and whole kernel after peeling the best drying conditions under axial loading is 110^{o}C for 3 h, for Lateral loading it is best to dry at 90^{o}C for 3 h and 100^{o}C for 5 h. For longitudinal loading the best conditions of drying was obtained at 80^{o}C for 5 h, 90^{o}C for 3 h and 110^{o}C for 3 h. However, to save energy and time of drying at 80^{o}C for 5 h and 90^{o}C for 3 h are recommended as against the kernels produced from traditional hot oil roasting of cashew nut dried at 70^{o}C for 6 to 8 h.

4 Conclusions

This study established the optimum drying conditions and mechanical properties variation for cashew kernels from pressurized steam pretreated cashew nut. The steam roasting method has shown that the unit processes of soaking and draining of cashew nut, quenching and rapid cooling of the cashew nut associated with hot oil roasting were eliminated and exposure of operators to health hazards was reduced, cracking and breaking of the cashew nuts was easily and fully done. The steam roasting method can therefore be concluded to have the potential of saving time and energy however further study on energy and process optimization will be required to establish these. The stated properties or stages of preparing a good and edible cashew kernel was found to occur at all stages of compressive load application. However, more work needs to be done especially on the quality parameters (colour, proximate analysis and sensory analysis) to obtain optimum condition of drying for the best quality cashew kernels.

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