

Original Article

Rupture Variations of Cashew Nut to Compressive Loading at Different Drying and Feed Rates

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Abstract - The rupture variations of cashew nuts under uniaxial compression, considering the different methods of loading, drying, and feed rate, were investigated. Cashew nuts were conditioned by sprinkling water on the surface, separated into three parts, and later dried in an oven operating at the temperature of $121 \pm 1^\circ\text{C}$ and relative humidity of 40 % to moisture contents of 7.30% (w.b.), 8.45% (w.b.), and 9.60% (w.b.), respectively. Three loading orientations (longitudinal, lateral, and transverse) and three loading rates (2.5, 3.5, and 4.5mm/min) were considered at three replicates using a universal testing machine. The highest and lowest average values of rupture forces required to crack cashew nut were 322 N and 224.3N, at moisture content of 8.45% and 7.30 % with loading orientations on longitudinal and transverse. It was also shown that the highest and lowest average values of rupture forces required to crack cashew nuts were 514.3 N and 237 N, at loading rates of 4.5mm/min and 2.5mm/min, with loading orientations on longitudinal and transverse. The highest average rupture deformations, rupture energy, and young modulus are 2.62mm, 1.34J, and 159.3N/mm² at moisture content of 8.45 %, 9.60 %, and 9.60% on longitudinal, transverse, and transverse loading, respectively. The highest average rupture deformations, rupture energy, and young modulus are 3.12mm, 1.90J, and 165.3N/mm² at loading rates of 3.5mm/min, 4.5mm/min, and 4.5mm/min on longitudinal loadings. It was discovered that rupture variations of cashew nut were dependent on the level of drying of the nut, which showed that the cashew nut at the lowest moisture content required the highest rupture force to crack the cashew nut, and the best loading pattern for cracking the nut was longitudinal, which showed the lowest rupture force.

Keywords - Rupture, Cashew Nut, Compressive Loading, Drying, Feed rates.

1. Introduction

The nut (in c-shape), which is attached to the lower portion of the cashew apple, contains an edible kernel usually roasted locally in Nigeria. The primary products of cashew nuts are the kernels, which have value as confectionery nuts. Cashew Nut Shell Liquid (CNSL) is an important industrial raw material for resin manufacture, and the shells can be burned to provide heat for the decorticating operation [5]

The cashew nut tree, an evergreen tropical tree, is one of the economic trees that has the potential to generate enormous wealth for farmers across the country, but it has received little attention from farmers. The fast-growing tree can reach a height of 12 meters; it can start producing after three years of planting, and the fruit ripens within eight weeks. It blossoms between November and January. Everything about cashew has a value chain that, if processed, farmers could generate huge income from the product. The average yield of nuts of a mature tree is in the range of 7 to 11 kg per annum. Although the cashew tree is capable of

living for 50 to 60 years, most trees produce nuts for about 15 to 20 years [16]

The cashew nut is composed of three different portions, namely the shell, the kernel, and the adhering testa. The primary product of cashew nuts is the kernel, which is the edible portion of the nut and is consumed in three ways: directly by the consumer, as roasted and salted nuts, in confectionery and bakery products, for example, finely chopped kernels are used in the production of sweets, ice creams, cakes and chocolates, both at home and industrially and as paste to spread on bread [12]

The kidney-shaped edible Nuts are called kernels and are obtained from the fruit or the raw nut after removal of the outer leathery covering, which surrounds it, using different processing methods – drying, steaming, shelling, peeling, grading, roasting, quality inspection, quality control, and packing.

Cashew processing actually includes the various steps, and the processing methodology used varies from region to region. In Brazil, mechanical processing is done, while in



India, processing is highly labor-oriented. Even inside India, there are differences in the processing methods used in different regions [7]

The nut is roasted, which makes the shell brittle and loosens the kernel from the inside of the shell. By soaking the nuts in water, the moisture content of the kernel is raised, reducing the risk of it being scorched during roasting and making it more flexible so it is less likely to crack [4]. Cashew nuts are very nutritious, with a high amount of energy as they contain protein, minerals, fats, carbohydrates, vitamins, and fiber, all of which contribute enormously to good health from their consumption. Cashew nut kernels can be eaten raw, fried, or sometimes pre-treated with salt or sugar. On the other hand, the mechanical properties of biological materials are the behavior of the materials under applied forces [3].

Cashew nuts are a dietary source of copper, which helps to break down the fat in your food. Copper is also needed for brain function, and cashew nuts are a storehouse of all essential nutrients. Cashew nuts have Vitamin E that helps to prevent aging tissue damage, reduce the risk of cancer, and improve immunity [9].

The cashew nut shell contains a 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. The CNSL content of the raw nut varies between 20 and 25 percent [17]

The raw cashew nut is the main commercial product of the cashew tree, though yields of the cashew apple are eight to ten times the weight of the raw nuts. Raw nuts are either exported or processed prior to export. Processing of the raw nuts releases the by-product CNSL that has industrial and medicinal applications. The skin of the nut is high in tannins and can be recovered and used in the tanning of hides. The fruit of the cashew tree that surrounds the kernel can be made into a juice with high vitamin C content and fermented to give a high-proof spirit [10].

It is estimated that 60 percent of cashew kernels are consumed in the form of snacks, while the remaining 40 percent are included in confectionery. The cashew competes in the same market as other edible nuts, including almonds, hazels, walnuts, pecans, macadamias, pistachios, and peanuts. There has recently been a considerable rise in demand for edible nuts by consumers interested in the quality and health aspects of food. The breakfast cereal, health food, salads, and baked goods markets are all expanding markets for cashew nuts [15].

Shelling is a technique that can be relatively easily learned. Strength is not required for the breakage of the shell. Correct positioning of the nut and the ability to hit the nut in

the correct position, so as to allow its breakage, are most important. If the nuts have been properly roasted and are correctly positioned on the striking platform, they will easily break down the natural line of cleavage when struck at the broad end [6]. The convex side of the nut should be placed in contact with the striking platform, with the plane of cleavage at right angles to the surface of the striking post. Occasionally, a nut will require more than one strike in order to open the shell, but this technique comes with practice. An average sheller can open one nut in about six seconds or ten nuts per minute. In an eight-hour working day, this amounts to about 4,800 nuts or about 5 kg of kernels [8]. At an extraction rate of 24 percent, this quantity corresponds to about 21 kg of raw nuts per day or about 7 tonnes per year. Experienced shellers in India can produce around half as much again, with a quality of 90 percent whole kernels. A good sheller will produce a high percentage of clean, unbroken kernels, whereas a poor sheller will produce a larger quantity of dirty, broken kernels [2].

The inner shell of the kernel has to be removed to produce the white nuts. The peeling process is designed to remove this inner soft shell after the kernel is removed from the oven. The kernel is used for peeling after it is left in the open for a period of 12 hours. This cooling helps in the peeling process. Each nut is individually peeled to get white nuts. These white nuts are then sent to the grading department [17]. At this stage, the testa is loosely attached to the kernel, although a small number of kernels may have already lost the testa during the previous operations. Manual peeling is done by gently rubbing with the fingers. Those parts still attached to the kernel are removed by the use of a bamboo knife. One person can peel about 10-12kg of kernels per day. It is important that the kernels are not cut or damaged during the peeling process. The use of knives increases the likelihood of the kernels becoming damaged, but it is also essential that all of the testa be removed [11].

Understanding the force-deformation characteristics of cashew nuts and other kernels helps in identifying the conditions that will favor or facilitate easy removal of the kernel from the shell with little or no mechanical damage. Fracture resistance of Agricultural nuts will give insight into their fracture mechanics and provide a basis for rational design or modification of shelling devices and dehullers [16]. This investigation focuses on the loading orientation, feed rates, and moisture contents on the rupture variations of cashew nuts with a view to minimizing kernel breakage and increasing the quantity of kernel during shelling.

2. Materials and Method

Cashew nut samples were obtained from a local cashew plantation plot at Ihube (NIHORT) in Okigwe Local Government of Imo State, Nigeria. The nuts were cleaned manually to remove foreign and extraneous materials, shriveled apples, immature nuts, and broken nuts. These

samples were representative of the Nigerian cashew nuts market with respect to the varieties and cultural conditions.

2.1. Preparation of Samples

Cashew nuts were conditioned by sprinkling water on the surface, separated into three parts, and later dried in an oven operating at the temperature of $121 \pm 1^\circ\text{C}$ and relative humidity of 40 % to moisture contents of 7.30% (w.b.), 8.45% (w.b.), and 9.60% (w.b.), respectively. The dried nuts were stored at 0°C and at 65%–70% relative humidity in plastic bags (moisture-tight) during the tests. Before the cracking test, nuts were visually inspected, and those with damaged shells were discarded.

2.2. Rupture Resistance Test

Samples of the graded cashew nuts were subjected to uniaxial compression using a universal testing machine (Universal texture analyzer, Lloyd Instruments equipped with 1kN load cell). Each nut was wrapped in a polyethylene bag to protect the spindle of the

Universal texture analyzer from CNSL loaded between two parallel hardened steel plates at a constant rate until the nut ruptured. Three loading orientations (longitudinal, lateral, and transverse) and three loading rates (2.5, 3.5, and 4.5mm/min) were considered at three replicates. A compression load was applied to nuts to about 35% deformation. This deformation was chosen as a criterion for

stopping the tests. The rupture characteristics of cashew nuts were expressed in terms of maximum force required to fracture the shell, energy required to deform the nut shell to rupture, specific deformation, and kernel extraction quality. The energy was determined directly from the formula below or by measuring the area under the force–deformation curves. The specific deformation was obtained through equations 1 and 2.

$$Energy = \frac{1}{2}mv^2 = Load \times deformation \quad [13] \quad (1)$$

$$\epsilon = \frac{L_1 - L_2}{L_1} \times 100 \quad [13] \quad (2)$$

Where m is the Mass (kg), v is the Speed (m/s), L_1 is the undeformed nut dimension (in mm), and L_2 is the deformed nut dimension (in mm) in the direction of the compression axis.

3. Results and Discussion

The rupture variations of cashew nuts to compressive loading at three different moisture contents, loading orientations, and loading rates were determined. Results of rupture forces, deformations, energy, and young modulus of rupture characteristics of cashew nuts are shown in the tables below.

Table 1. Rupture Characteristics of Cashew nuts at different Moisture Contents

Moisture Content (%)	Rupture Force (N)			Deformation (mm)			Rupture Energy (J)			Young Modulus (N/mm ²)		
	1	2	3	1	2	3	1	2	3	1	2	3
7.30	283	262	233	1.91	1.61	1.50	1.28	1.10	0.91	148.9	163.7	148.7
	287	249	219	1.72	1.63	1.42	1.22	1.09	0.81	156.8	152.8	154.2
	282	282	221	1.83	1.81	1.50	1.20	1.30	0.80	154.1	155.8	147.3
Average	284	264.3	224.3	1.82	1.68	1.47	1.23	1.16	0.84	152.6	157.4	150.1
8.45	322	314	298	2.62	2.10	1.90	1.30	1.22	1.29	122.9	149.5	156.8
	321	322	301	2.53	2.52	2.10	1.21	1.32	1.31	126.9	127.8	143.3
	324	319	292	2.70	2.60	1.83	1.40	1.31	1.30	120.0	122.7	154.6
Average	322.3	318.3	297	2.62	2.41	1.94	1.30	1.28	1.30	123.27	133.3	151.57
9.60	304	286	278	2.12	1.82	1.72	1.24	1.20	1.43	145.4	157.1	161.6
	312	292	277	2.42	1.90	1.73	1.40	1.24	1.27	128.9	153.7	160.1
	309	301	281	2.23	2.11	1.80	1.32	1.43	1.32	138.6	142.7	156.1
Average	308.3	293	278.7	2.26	1.94	1.75	1.32	1.29	1.34	137.6	151.2	159.3

1 = Longitudinal, 2 = Lateral, 3 = Transverse

Table 2. Rupture Characteristics of Cashew nuts at different loading Rates

Loading rate (mm/min)	Rupture Force (N)			Deformation (mm)			Rupture Energy (J)			Young Modulus (N/mm ²)		
	1	2	3	1	2	3	1	2	3	1	2	3
2.5	321	304	241	2.62	2.18	1.89	1.14	0.96	0.76	122.5	139.4	127.5
	324	311	232	2.71	2.22	1.78	1.18	0.99	0.71	119.6	140.1	130.3
	322	309	238	2.59	2.19	1.69	1.13	0.98	0.70	124.3	141.1	140.8
Average	322.3	308	237	2.64	2.20	1.79	1.15	0.98	0.72	122.1	140.2	132.9

3.5	489	464	402	3.03	2.93	2.89	1.78	1.66	1.46	161.4	158.4	139.1
	491	459	412	3.22	2.89	3.01	1.88	1.63	1.54	152.5	158.8	136.9
	488	462	409	3.10	2.87	2.91	1.81	1.60	1.49	157.4	161.01	140.5
Average	489.3	461.7	407.7	3.12	2.90	2.94	1.82	1.63	1.50	157.1	159.40	138.83
4.5	512	492	458	3.17	3.03	2.92	1.92	1.79	1.64	161.5	168.5	156.8
	522	501	460	3.19	3.09	2.96	1.97	1.85	1.66	163.6	162.1	155.4
	509	489	459	2.98	3.01	2.88	1.82	1.77	1.62	170.8	162.5	159.4
Average	514.3	494	459	3.11	3.04	2.92	1.90	1.80	1.64	165.3	164.4	157.2

1 = Longitudinal, 2 = Lateral, 3 = Transverse

The effect of moisture content, loading rate, and loading orientation on the rupture characteristics of cashew nuts is shown in the figures below.

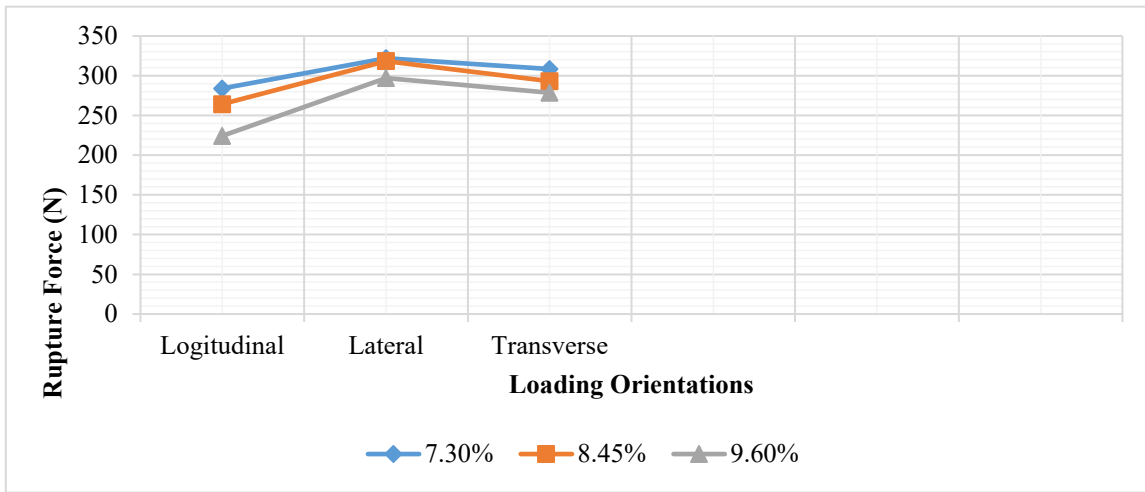


Fig. 1 Effect of moisture content and loading orientations on rupture characteristics of cashew nut

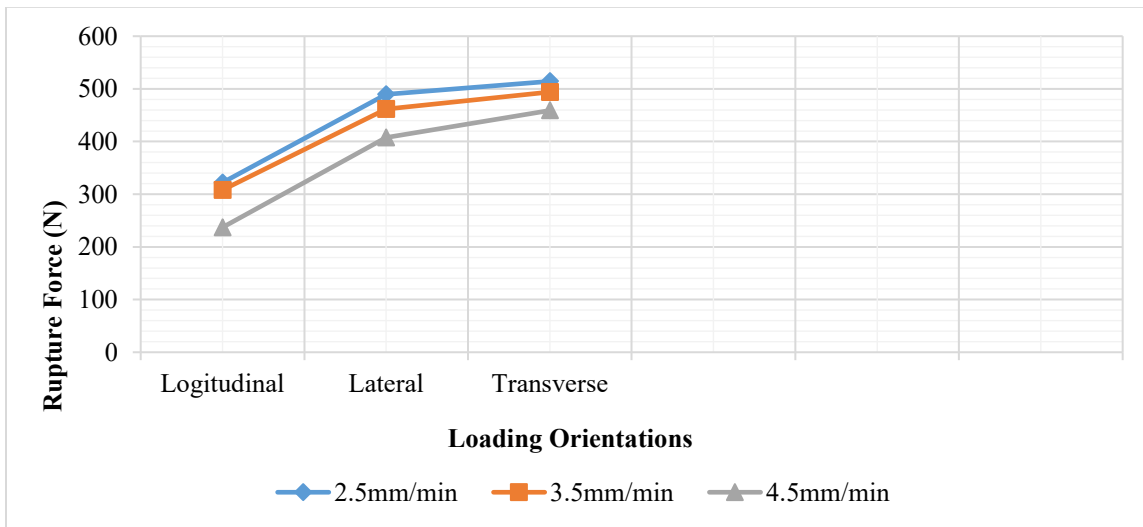


Fig. 2 Effect of loading rates and orientations on rupture characteristics of cashew nut

3.1. Discussion

The rupture characteristics of cashew nuts at different moisture contents with different loading speed rates are shown in Table 1. The average values of rupture forces at longitudinal, lateral, and transverse loading with a moisture content of 7.30 % were 284 N, 264.3 N, and 224.3 N, while

322.3 N, 318.3 N, and 297 N were obtained at 8.45 % moisture content, and 308.3 N, 293 N, and 278.7 N were also obtained at 9.60 % moisture content, respectively. It was also discovered that the average deformations at moisture content of 7.30 % on longitudinal, lateral and transverse loading were 1.82mm, 1.68mm, 1.47mm, rupture energy were 1.23 J,

1.16 J, 0.84 J, and young modulus were 152.6 N/mm², 157.4 N/mm², 150.1 N/mm², while 2.62mm, 2.41mm, 1.94mm deformations, 1.30 J, 1.28 J, 1.30 J rupture energy, 123.27 N/mm², 133.3 N/mm², 151.57 N/mm², young modulus were obtained at 8.45 % moisture contents and 2.26mm, 1.94mm, 1.75mm deformations, 1.32 J, 1.29 J, 1.34 J rupture energy, 137.6 N/mm², 151.2 N/mm², 159.3 N/mm², young modulus were obtained at 9.60 % moisture contents respectively. The results showed that cashew nuts needed more force to rupture, high deformation, rupture energy, and young modulus at a moisture content of 8.5%, and also showed brittleness at low moisture of 7.30%. Loading orientations of the cashew nuts to compression did not affect the rupture pattern [14].

Rupture variations of cashew nuts at different loading speeds with the longitudinal, lateral, and transverse loading orientations are presented in Table 2. The average values of rupture forces at longitudinal, lateral, and transverse loading with a loading rate of 2.5 mm/min were 322.3 N, 308 N, and 237 N, while 489.3 N, 461.7 N, and 407.7 N were obtained at 3.5mm/min, and 514.3 N, 494 N, 459 were also obtained at 4.5mm/min respectively.

It was also shown that the average deformations at loading rate of 2.3mm/min on longitudinal, lateral and transverse loading were 2.64mm, 2.20mm, 1.79mm, rupture energy were 1.15 J, 0.98 J, 0.72 J, and young modulus were 122.1 N/mm², 140.2 N/mm², 132.9 N/mm², while 3.12mm, 2.90mm, 2.94mm deformations, 1.82 J, 1.63 J, 1.50 J rupture energy, 157.1 N/mm², 159.40 N/mm², 138.83 N/mm² young modulus were obtained at loading rate of 3.5mm/min and 3.11mm, 3.04mm, 2.92mm deformations, 1.90 J, 1.80 J, 1.64 J rupture energy, 165.3 N/mm², 164.4 N/mm², 157.2 N/mm² young modulus were obtained at loading rate of 4.5mm/min respectively. It was found from loading orientations and rates that the force required to crack a cashew nut, deformation, rupture energy, and young modulus were highest when the loading rates were increased to the highest. This showed that compression occurred faster in low loading rates than progressively over a high loading period [13].

Figure 1 shows the effect of moisture content and loading orientations on the rupture characteristics of the cashew nut. It was discovered that the rupture characteristics of the cashew nut were dependent on the drying criteria of the nut. The figure also showed that, at the lowest moisture content, the highest rupture force was required to crack the cashew nut, and the best loading pattern for cracking the nut was longitudinal, which showed the lowest rupture force [9]. The effect of loading rates and loading orientations on the rupture characteristics of the cashew nut was shown in Figure 2. The highest rupture force was recorded at 2.5mm/min, as against the lowest rupture force, which was shown at 4.5mm/min. It was presented from the figure that cashew nut rupture characteristics relied on the loading rates

of the nut [1]. The figure also showed that the best loading pattern for cracking the nut was longitudinal, which showed the lowest rupture force.

4. Conclusion

The rupture characteristics of cashew nuts at different moisture contents, with different loading speed rates and orientations, were varied. The highest and lowest average values of rupture forces required to crack cashew nuts were 322 N and 224.3N, which were recorded at moisture content of 8.45% and 7.30 % with loading orientations on longitudinal and transverse. It was discovered that drying of cashew nuts significantly affects their cracking characteristics, which showed that high moisture content required high cracking force. The highest average rupture deformations, rupture energy, and young modulus are 2.62mm, 1.34J, and 159.3N/mm² which were recorded at moisture content of 8.45 %, 9.60 %, and 9.60% on longitudinal, lateral, and transverse loading, respectively. The results showed that moisture content significantly affects the rupture deformation, rupture energy, and Young's modulus of cashew nuts.

It was also shown that the highest and lowest average values of rupture forces required to crack cashew nuts were 514.3 N and 237 N, which were recorded at loading rates of 4.5mm/min and 2.5mm/min with loading orientations on longitudinal and transverse. It was shown that the loading rate of cashew nuts significantly affects their cracking characteristics, which showed that a high loading rate required a high cracking force. The highest average rupture deformations, rupture energy, and young modulus were 3.12mm, 1.90J, and 165.3N/mm² which were recorded at loading rates of 3.5mm/min, 4.5mm/min, and 4.5mm/min on longitudinal loadings, respectively. The results presented that loading rate significantly affects, but loading orientation do not significantly affect the rupture deformation, rupture energy, and young modulus on cracking cashew nuts.

It was discovered that rupture variations of cashew nut were dependent on the level of drying of the nut, which showed that the cashew nut at the lowest moisture content required the highest rupture force to crack the cashew nut, and the best loading pattern for cracking the nut was longitudinal, which showed the lowest rupture force.

It was presented from the figure that cashew nut rupture variations relied on the loading rates of the nut, and the best loading pattern for cracking the nut was longitudinal, which showed the lowest rupture force. It is recommended to determine the effect of different moisture content, loading rates, and loading orientation on the rupture variations of cashew nuts with a view to minimizing kernel breakage during shelling, and policy thrust in the agricultural transformation agenda on cashew nut shelling, with a view to improving cashew nut processing should be implemented.

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