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Moisture related mechanical properties of drum-roasted cashew nut under compression loading

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ABSTRACT

Quasi-static compression tests were conducted to study the mechanical behavior of roasted cashew nuts at various moisture contents within the range of 6.75 percent to 13.52 percent and at varying loading rates of 5, 10 and 20 mm min^{-1}. The direction of loading in all experiments under the present investigation was perpendicular to the concave and convex edges i.e. on its longitudinal axis along the natural line of cleavage, which is similar to the orientation followed for shelling in conventional manual hand beating method. The results have shown that under the three rates of loading and four levels of moisture contents the mechanical properties such as force for initial rupture, deformation, energy for rupture and modulus of elasticity followed quadratic relationship with moisture content. The results indicated that the force for rupture, deformation and energy for rupture increased up to the moisture content of 10.20 percent under the three rates of loading but the modulus of elasticity decreased under the similar conditions.

***Keywords*:** Compression loading, deformation, energy for rupture, elasticity, roasted cashew nut

Conventional method of shelling roasted cashew nuts by manual hand beating is prevalent in two-third of the processing units in India. The efficiency of shelling operation also depends mostly on human skill because of the irregular shape of the nut and brittleness of the kernel. Several methods of shelling cashew nut have been invented and patented; but at present none of them is in commercial use because of complicacy for commercial application. Thus there remains a need for developing a new technique for cashew nut shelling where the important mechanical properties of roasted cashew nut need to be examined. Studies conducted earlier on other seeds indicate that the moisture content plays a major role in the loading, deformation and toughness of the product under quasi-static compression loading (Paulson, 1978; Kang *et al*., 1993). Orientation (*i.e.* positioning of cashew nut in different axis during shelling) has also considerable effects on the rupture force, deformation at rupture and toughness (Paulson, 1978; Maduako and Faborade, 1994). Oloso and Clarke (1993) conducted quasi-static compression test of oil-bath roasted cashew nuts and reported about the effect of moisture content and direction of loading on failure force, failure deformation and energy absorbed to the point of failure. The present study is aimed to investigate the effect of moisture content and rate of loading on the initial rupture force, deformation, energy for rupture, and modulus of elasticity of drum roasted cashew nuts under quasi-static compression test.

MATERIALS AND METHODS

Raw cashew nuts of variety NRCC-1 were collected from the orchard of AICRP on Cashew nut (OUAT), Bhubaneswar and were roasted at a Cashew Nut Processing Unit, near by Bhubaneswar. During roasting the feed rate, rotational speed of the drum and sprinkling rate were allowed to vary to obtain samples of varying moisture content. The samples were allowed to equilibrate at room temperature for about 48 hours. The moisture contents of these samples were found out from the initial weights and final weights after keeping them in a hot air oven at 105^{0}C for 24 hours. The moisture contents were 6.75, 8.84, 10.20 and 13.52 percent. The cashew nuts, having the length within 30-35mm were sorted out to be treated as sample. Quasi-static compression test of drum-roasted cashew nuts were carried out with Lloyd Materials Testing System (Model: LR100k) equipped with a 100 kN load cell and data analysis software programmer at Central Institute of Plastic Engineering and Technology, Bhubaneswar (an ISO 9001 and NABL accredited institute for testing). This system features an automatic results screen showing all relevant parameters from International Standards, which includes the force-deformation curve and the basic parameters under the present investigation like force for rupture, deformation, energy and modulus of elasticity. Each individual nut was subjected to uni-axial compression and loaded perpendicular to the planes_of concave and convex edges i.e. along the natural line of cleavage. This direction of loading was selected because of the irregular geometry of cashew nut and the structure of the kernel and nut, which are nearly similar and symmetrical about the longitudinal

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axis. The selected direction of loading is rather imperative to be considered for shelling to achieve a whole kernel form the nut. A rigid platform was prepared to allow the nut to sit for the desired direction of loading and was placed on the lower compression plate. Each individual nut was loaded between the plunger and the platform and compressed at prior set loading rates *i.e.* 5, 10 and 20 mm min^{-1} to study the effect of rate of loading on the selected parameters. Compression test of roasted cashew nuts were carried out at four moisture levels and three rates of loading until rupture. Ten nuts were compressed at each combination. Thus a total of 120 nuts were compressed. The force-deformation curves along with the selected parameters were directly recorded in the system.

RESULTS AND DISCUSSION

The results of compression test of roasted cashew nuts have been presented in Table1 which illustrates the average values of the initial force for rupture, deformation at rupture, rupture energy and modulus of elasticity with three rates of loading *i.e.* 5, 10 and 20 mm/min at four levels of moisture contents *i.e*. 6.75, 8.84, 10.20 and 13.52 percent.

Force-deformation characteristics

An examination of a typical force-deformation curve (Fig. 1) shows that the curve is concaved towards the force axis. Further the compressive force increases gradually with increase of the deformation until rupture; beyond which the curve looses its smoothness and becomes much undulated. Similar observations were reported by Oloso *et al*. (1993) for oil-bath roasted cashew nuts. This may be due to the fact that the presence of moisture in biomaterials offers little resistance to shear stress causing relatively large deformations in response to small initial stresses.

Table 1: Effect of moisture content on mechanical properties of cashew nut under various loading rate

Mechanical properties	Rate of loading (mm min^{-1})	Moisture content (%)			
		6.75	8.84	10.20	13.52
Rupture force (N)	5	631.30	634.30	670.00	498.80
	10	573.00	618.80	864.90	692.80
	20	621.30	550.90	453.30	543.80
Deformation (mm)	5	4.05	7.45	4.88	4.96
	10	6.05	6.36	6.48	4.71
	20	6.01	6.26	5.37	6.04
Energy for rupture (N mm)	5	155.88	85.18	137.18	100.50
	10	94.77	97.22	133.51	147.15
	20	103.33	88.03	75.02	90.00
Modulus of elasticity (N mm^{-2})	5	2352	3243	3352	1834
	10	2693	2901	3944	3015
	20	2563	2832	2835	2497

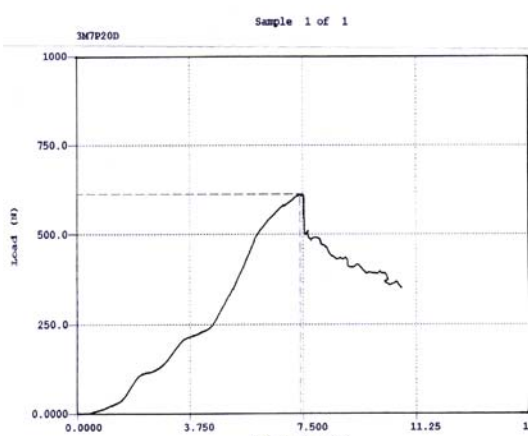

Fig. 1: Force- deformation curve under quasi-static compression loading

Under larger strain, however, the force-deformation curves assume a sigmoidal shape with slope of the curve first increasing and then decreasing. In case of roasted cashew nut the said curve follows similar trend irrespective of moisture level and rate of loading.

Effect of moisture content and rate of loading on selected parameters

The results indicated that the selected parameters *i.e*. rupture force, rupture deformation, rupture energy and modulus of elasticity followed quadratic relationships with moisture content at all the rates of loading under the present investigation. The initial rupture force decreased with the increase in moisture content up to 10.20 percent but later increased with further increase in moisture content at higher rate of loading of 20 mm min^{-1}. Similar results were reported by Oloso *et al*. (1993) with the rate of loading as 50 mm min^{-1}. However, at lower rate of loadings of 5 and 10 mm min^{-1} opposite trends of rupture force with respect to moisture content were observed. This may be due to the resistance to applied force up to rupture, developed in the typical cashew nut shell at lower rate of loading which is further evident in the findings on modulous of elasticity. Highest and lowest rupture force of 864.9 and 453.3 N were recorded at 10.20 percent moisture content with 10 and 20 mm min^{-1} rate of loadings respectively. The rupture forces for roasted cashew nuts at the three different rates of loading are related to moisture content as per the equation 1, 2 and 3.

$$F(5) = -7.5084M^2 + 134.16M + 60.789 \quad \text{---} \quad (1)$$

$$F(10) = -14.126M^3 + 410.33M^2 - 3784.7M + 11769 \quad \text{---} \quad (2)$$

$$F(20) = 4.7443M^3 + 1.33.37M^2 + 1175.5M - 2695.9 \quad \text{---} \quad (3)$$

Where,
F = Initial rupture force, N
M =Moisture content (%)

The deformation of roasted cashew nuts at rupture increased initially with increase of moisture content at all the three rates of loading; but decreased later with further increase of moisture content. Oloso *et al.* (1993) and Das *et al*. (2004) reported similar nature of relationship between deformation at rupture and moisture content. Highest and lowest deformation of 7.447 and 4.05 mm at rupture were recorded at 5 mm min^{-1} rate of loading with 6.75 and 8.84 percent moisture content respectively. The deformation at rupture was found related to moisture at three rates of loading as per the equation 4, 5 and 6.

$$\Delta\ell(5) = 0.2101M^3 - 6.4356M^2 + 63.423M - 195.46 \quad \text{---} \quad (4)$$

$$\Delta\ell(10) = 0.0165M^3 + 0.4041M^2 - 3.1309M + 13826 \quad \text{---} \quad (5)$$

$$\Delta\ell(20) = 0.0595M^3 - 1.7572M^2 + 16.595M - 44.251 \quad \text{---} \quad (6)$$

Where,
$\Delta\ell$ = Deformation (mm)

The failure energy of the roasted cashew nuts were found increasing with increase of moisture content up to 10.20 percent in all the three different rates of loading; but decreased with further increase of moisture content. Das *et al.* (2004) reported similar results on groundnut while Oloso *et al.* (1993) reported that the failure energy increased with increase of moisture content within the range of 7.3 to 15.4 percent. This may be due to the fact that in the later case experiment included oil-bath roasted cashew nuts and the rate of loading was 50 mm min^{-1} while under the present investigation the cashew nuts were drum roasted and the rate of loading were 5, 10 and 20 mm min^{-1}. In oil-bath roasting the temperature of CNSL medium is usually maintained at around 200^{0}C while in case of drum roasting the temperature of roasting drum is maintained at about 450^{0}C. Thus the mechanical properties of the cashew nut in the two roasting methods differ due to the change in the heat treatment to the cashew nut shell. Highest and lowest rupture energy of 3944 and 1834 N mm were recorded with 10.20 percent moisture content at 10 mm min^{-1} and 6.75 percent moisture content at 5 mm min^{-1} respectively. The energy for rupture was found related to moisture content at the three rates of loading as per the equation 7, 8 and 9.

$$\mathrm{Re}(5) = -2.1316M^3 - 45.337M^2 + 1524M - 5213.8 \quad \text{---} \quad (7)$$

$$\mathrm{Re}(10) = -61.479M^3 + 1778.7M^2 - 16356M + 50963 \quad \text{---} \quad (8)$$

$$\mathrm{Re}(20) = 2.1312M^3 - 91.614M^2 + 1166.2M - 1789.9 \quad \text{---} \quad (9)$$

Where,
Re = Rupture energy (N mm)

The moduli of elasticity of the roasted cashew nuts were found decreasing with increase in moisture content at lower rate of loading of 5 mm min^{-1}. Kang *et al*. (1993) reported similar trends of modulus of elasticity of wheat under quasi-static compression with rate of loading at 1 mm min^{-1}. But with higher rates of loading (10 and 20 mm min^{-1}) the modulus of elasticity decreased initially up to moisture content of 8.84 percent and increased thereafter with increase of moisture content. Highest and lowest values of modulus of elasticity of 11.22 and 6.729 N mm^{-2} were recorded with 8.84 percent moisture content at 5 mm min^{-1} rate of loading and with 13.52 percent moisture content at 20 mm min^{-1} rate of loading respectively. The modulus of elasticity was found related to moisture content at the three rates of loading as per the equation 10, 11 and 12.

$$E(5) = -0.069M^3 + 2.0792M^2 - 21.0M + 82.05 \quad \text{---} \quad (10)$$

$$E(10) = -0.047M^3 + 1.687M^2 - 18.916M + 199.25 \quad \text{---} \quad (11)$$

$$E(20) = -0.2287M^3 + 6.7024M^2 - 63.066M + 199.25 \quad \text{---} \quad (12)$$

Where,
E = Modulus of elasticity (N mm^{-2})

The present investigation indicated that the mechanical properties of drum-roasted cashew nut such as rupture force, rupture deformation, rupture energy and modulus of elasticity follows quadratic relationship with moisture content within the range from 6.75 to 13.52 % at three rates of loading within the range from 5 to 20 mm min^{-1}. The force for rupture and deformation at rupture varies with moisture content quite irregularly. The energy for rupture increased up to 10.20 percent moisture content and then decreased irrespective of the rate of loading. The modulus of elasticity of the roasted cashew nut varies with moisture content and rate of loading. However, for development of a sheller for roasted cashew nut, the highest values of rupture force, rupture energy should be taken into account i.e. 864 N and 133.51 N mm, respectively which were recorded at 10.20 percent moisture content and 10 mm min^{-1} rate of loading. The design of a cashew nut sheller, based on the compression mechanism should take the highest values of rupture force for a particular variety and size of the cashew nuts in to consideration.

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