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Moisture dependent physico-mechanical properties of processed cashew kernels

D. Balasubramanian and R.L.K. Joycy

ICAR - Directorate of Cashew Research, Puttur-574 202, Dakshina Kannada, Karnataka, India

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Cashew kernels processed from India irrespective of origin is highly preferred by other countries and therefore, it stands in the first position as far as the export of cashew kernel is concerned. Around 1.31 lakh MT of cashew kernels were exported during the year 2011-12 earning a foreign exchange to the tune of 4390 crores (DCCD, 2012). Cashewnut (*Anacardium occidentale* L.) is an important tree nut and the kernels extracted has protein (21.2%), carbohydrate (22.3%), fat (46.9%), fibre (1.3%), minerals (2.4%) and vitamins, together supplying total calorific value of 570 kcal kg^{-1} (Saroj and Balasubramanian, 2013). Various unit operations *viz.,* nut conditioning (roasting or steaming), shelling, unpeeled kernels drying, peeling, grading and packaging are employed while processing cashewnut. Kernels are graded on the basis of specification prescribed by Govt. of India under the Export (quality control and inspection) Act 1963, which recognizes 23 different export grades of cashew kernels (CEPCI, 2013). Economy of cashew processing depends on quantity of whole kernels extracted during processing which fetches premium price at consumer level. Adopting good manufacturing practice during cashew processing can yield 75-80 per cent of whole kernels. Cashew kernels are sorted out based on size wholesomeness and surface colour. Based on wholesomeness, cashew kernels are sorted into white wholes (WW) as primary grades which are classified into 180, 210, 240, 320, 450 and 520 indicating count per pound *i. e.,* 0.455 g and scorched wholes (SW), scorched wholes seconds (SWS) and dessert wholes (DW) as secondary grades (Balasubramanian, 1998). Profitability of cashew processing depends on obtaining primary grades of higher counts. Physio-mechanical properties of processed cashew kernels play a vital role in the design of processing machinery involved in conveyance, size or colour based grading, packaging and while preparing value added products *viz.,* coating, roasting, size reduction and mixing.

According to Aviara *et al.* (1999), knowledge on moisture dependent physical properties of agricultural commodities assists in the design of suitable processing machines or helps to enhance the performance of existing machines. A range of moisture content usually exists for a particular crop, within which optimum performance is achieved. Therefore, it is essential to investigate the effect of moisture content on relevant physical and mechanical properties. Mohsenin (1980) indicated that shape, size, spericity, bulk density, porosity, angle of repose and coefficient of internal friction were the major moisture dependent physical properties of biological material.

Spatial dimensions of biological material are important for sizing, sorting, sieving and other separation procedures; bulk density determines the capacity of storage and transport systems; true density is useful for separation equipments and porosity determines the degree of resistance to airflow during aeration and drying process (Vilche *et al.*, 2003). Angle of repose is used for designing conveyor and storage system. Frictional forces provide an idea for the selection of conveyor

*Corresponding Author: bavika13@email.com

material and energy required for conveyance process. Data pertains to mechanical behavior under quasi-static compression loading helps during packaging of products and secondary level processing.

Research on physical and engineering properties has been reported for different types of agricultural materials *viz.,* soybean (Deshpande *et al.,* 1993) oil bean (Oje and Ugbor, 1991), sunflower (Guptha and Das, 1997), corn (Mohammed and Reza, 2010), raw cashewnut (Balasubramanian, 2001), walnut (Koyuncu *et al*., 2004), faba bean (Mohammed and Mohammed, 2009), karingda seeds (Suthar and Das, 1996), bean seeds (Sayeed *et al.,* 2012), pistachio (Heidarbeigi *et al.,* 2008) and shea kernel (Manuwa and Muhammed, 2011). Published work on the geometric, gravimetric, frictional properties and mechanical behavior under different compression loading of processed cashew kernels are very few. This manuscript deals about investigation carried out on the moisture dependence of physical and mechanical properties of cashew kernels processed by steaming mode.

Commercially processed cashew kernels grades *viz*., WW 180, WW 210, WW 240, WW 320, WW 400, WW 450, SW, SWS and DW were procured from a cashewnut processing industry, following steaming method of processing located in Mangalore, Karnataka. Cashew kernels were graded according to the standards laid down by the Cashew Export Promotion Council of India (CEPC, 2012). Initial moisture content was determined using the toluene distillation method (Yashajahu and Mclon, 1987). The samples with desired moisture content *viz.,* 3, 5 and 7 per cent on dry basis (d.b) were prepared by spraying calculated quantity of distilled water using mist fan as followed by Coskun *et al.,* (2005).

$$Q = \frac{W(M_f - M_i)}{(100 - M_f)} \qquad \text{.............................. (1)}$$

Where, Q is the mass of water added,

W is the initial mass of sample in g, M_i is the initial moisture content in per cent d.b and M_f is the final moisture content in per cent d.b

Moistened cashew kernels with desired moisture levels were sealed in a polythene bag and transferred to refrigerator maintained at 5 °C for 24 h in order to enable the moisture to distribute throughout the sample. Thereafter, samples were allowed to warm up to room temperature for short period and used for the subsequent investigations.

In order to confirm homogeneity of sample based on surface colour, the energy of the reflected light from the samples across the entire spectrum was measured for various grades of cashew kernels using spectro-colorimeter CM 2500 C (Minolta, Japan). The colour was measured using CIELAB scale at 10° observer and D65 illuminant and the whiteness index was calculated as followed by Maskan (2001).

$$WI = 100 - \sqrt{\left((100 - L)^2 + a^2 + b^2\right)} \qquad \text{...................... (2)}$$

Where, WI is the whiteness index; L, a and b are colour values

Whiteness index of primary grades selected for the investigation *i. e.,* WW 180 to WW 450 ranged from 63.2 to 65.2 and secondary grades *viz.,* SWS from 51.5 to 53.8, SW from 54.2 to 54.9 and DW from 58.5 to 60.2 confirming homogeneity of cashew kernels of particular grade.

Randomly selected cashew kernels of selected grades (50 nos.) were used to determine the size along three principal dimensions *viz.,* length (L), width (W), and thickness (T) using an electronic micrometer (Mitutoyo, Japan). Effective width of cashew kernels (Fig. 1) was also measured taking into account the irregular shape of the kernel and application in designing sieve grader.

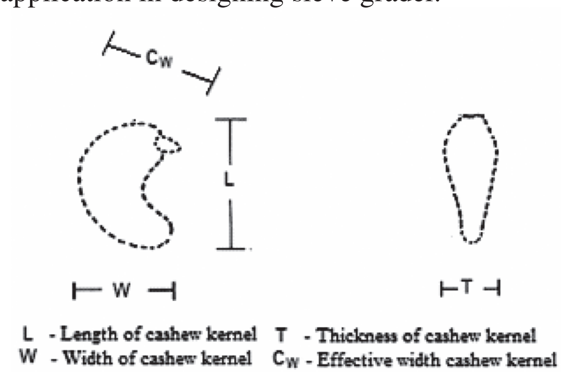

Fig. 1. Geometry of cashew kernel

Geometric mean diameter and sphericity were calculated using the relation referred by Aydin (2003), Mohsenin (1980) and Gupta and Das (1977).

$$D_g = \sqrt[3]{LWT} \quad .... (3)$$

$$\varnothing = \frac{\sqrt[3]{LWT}}{L} x100 \quad .... (4)$$

Where D_g is the geometric mean diameter in mm; ∅ is the sphericity; L is the length of kernel in mm; W is the width of kernel in mm and T is the thickness of the kernel in mm.

The true volume was determined using liquid displacement method (Pliestic *et al.*, 2006). Toluene was used instead of water to minimize moisture absorption by the kernel samples. True density (ρ_t) was computed as the ratio of unit mass of each kernel by the volume of water displaced. Bulk density (ρ_b) was found out by filling a circular top and bottomless cylinder of known volume with cashew kernels up to its brim. Excess kernels were sliced off and the quantity of filled cashew kernels was weighed work out the ratio of weight by volume as bulk density (Balasubramanian, 2001). Porosity was evaluated using mean values of bulk density and true density using the relation expressed by Mohsenin (1980).

$$E = \left(1 - \frac{\rho_b}{\rho_t}\right) x\,100 \quad .... (5)$$

Where, E is the porosity in per cent; ρ_b is the bulk density in kg m^{-3}; ρ_t is the true density in kg m^{-3}

The experiment was performed at different moisture content of cashew kernels using test surfaces of cardboard, glass, mild steel, and galvanized iron as described by Balasubramanian (2001). Angle of repose was determined using a funnel like apparatus at height of 0.15 m above the ground level. Cashew kernels filled within the apparatus was gradually released to form a heap on the flat surface. Height and diameter of the heap was measured and angle of repose was calculated using the relationship (Ozguven and Vursarus, 2004).

$$\phi = Tan^{-1}\left(\frac{2H}{D}\right) \quad .... (6)$$

Where, ϕ is the angle of repose; H is height of the heap (mm) and D is the diameter of the heap in mm.

The experimental apparatus used in friction studies consisted of a frictionless pulley fitted on a frame, a bottomless cylindrical container, a loading pan and test surfaces. The cylinder was filled with cashew kernels and placed on horizontal test surface. Weights were then added to the pan until the cylinder began to slide along the test surface. Based on the values of the normal force (N_f) corresponding to the weight of the kernels in the cylinder and frictional force (F) corresponding to the weights added to the pan, coefficient of internal friction was calculated as

$$\mu = \frac{F}{N_t} \quad .... (7)$$

Where, μ is the coefficient of internal friction; F is the frictional force in kg and N_t is the normal force in kg.

The compression plate was used to evaluate the rupture force of cashew kernels under quasi static compression loading (Faruk and Kubilay, 2004). Compression test was performed using TA-XT2 texture analyser equipped with the compression load of 100 kg capacity. Cashew kernels of various grades at selected moisture level of 3, 5 and 7 per cent d.b were subjected to quasi-static compression loading applied vertically on flat surface of cashew kernels as per the test settings given below (Table.1).

Table 1. Test settings to determine the rupture force

Type of probe used	Compression plate (P6)
Test module	Measure force in compression
Test option	Return to start
Pre test speed	1.0 mm s^{-1}
Test speed	0.1 mm s^{-1}
Post-test speed	2.0 mm s^{-1}
Distance	4 mm
Trigger force	25 g
Load cell	100 kg

Initial moisture content of untreated cashew kernels samples of various grades ranged from 2.3 per cent to 2.9 per cent d.b. Average values of principal dimensions *viz.,* length, width, thickness, effective width, geometric mean diameter, and sphericity for various grades of cashew kernels were determined in the moisture range of 3 per cent to

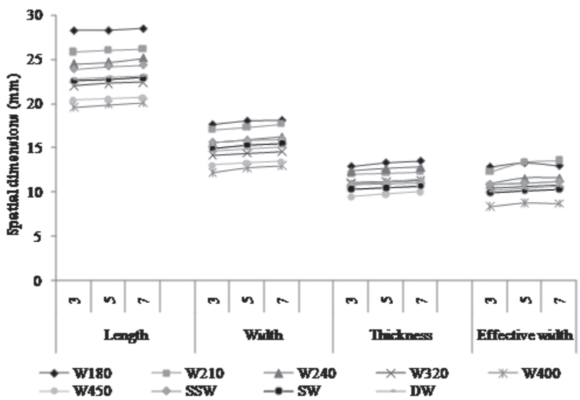

Fig. 2. Changes in the spatial dimension of cashew kernels influenced by moisture content

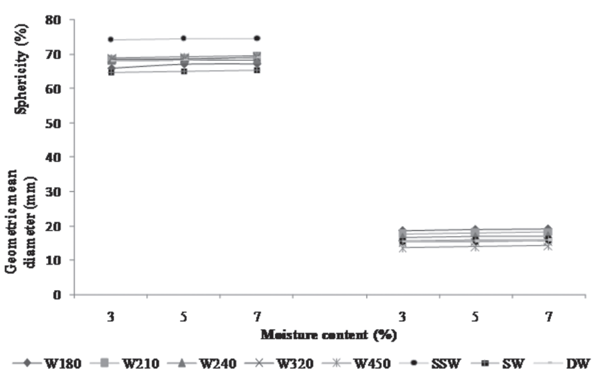

Fig. 3. Changes in sphericity and geometric mean diameter of cashew kernels influenced by moisture content

7 per cent d.b and depicted in Fig. 2 and Fig. 3. In general, tri-axial dimension increased with increase in moisture content for all grades of cashew kernels. It was observed that expansion of cashew kernels was more pronounced in intermediate axis followed by minor axis and major axis irrespective of the cashew kernel grades selected. Possibly, shape of the kernel having more surface area in the intermediate axis exposed to moisture infusion could be the reason for higher expansion compared to other two axes. Similar results were observed in the case of pistachio nut (Hsu *et al.,* 1991), castor nut (Olaoye, 2000), soybean (Deshpande *et al.,* 1993) and arecanut kernel (Kallemullah and Gunasekar, 2002). Geometric mean diameter and sphericity of cashew kernels in the specified moisture linearly ranged from 13.5 to 19.1 and from 65.8 to 69.5 for primary grades and from 15.1 to 15.9 and from 64.7 to 74.4 for secondary grades of cashew kernels, respectively. Increase in geometric mean diameter and sphericity was found to be 2.9 per cent and 1.3 per cent for primary grades and 2.6 per cent and 0.9 per cent for secondary grades respectively when moisture increased from 3 to 7 per cent d.b. Statistical analysis of geometric properties of cashew kernels is presented in Table 2. Linear regression equations of physical properties *viz.,* sphericity, geometric mean diameter and 100-kernel weight as a function of moisture content with their coefficient of determination are given in Table 3. These linear behaviours are in accordance with almond (Aydin, 2003), coffee bean (Chandrasekar and Viswanathan, 1999), soybean (Deshpande *et al.,* 1993) and white lupin (Ogut, 1998).

Table 2. Geometric characteristics of various grades of cashew kernels at 5 per cent d.b. (Mean values ± SD)

Cashew kernel grades	Length (mm)	Width (mm)	Thickness (mm)	Effective width (mm)	100-Kernel weight (g)	Sphericity (%)	Geometric mean diameter (mm)
W180	26.3±0.9[d]	18.1±0.5[f]	13.3±0.6[d]	13.3±0.5[d]	271.7±23.5[e]	67.0±1.6[b]	19.0±0.4[e]
W210	26.1±0.5[d]	17.4±0.8[e]	12.7±0.7[c]	12.4±0.6[c]	222.1±14.2[d]	67.7±1.4[b]	17.9±0.6[d]
W240	24.7±1.0[c]	15.9±0.6[d]	1228±1.1[c]	11.6±1.4[b]	191.7±18.6[c]	68.3±1.9[b]	16.8±0.9[c]
W320	22.5±0.7[b]	14.1±0.2[b]	11.2±0.5[b]	10.6±0.5[a]	161.4±10.5[b]	68.6±1.1[c]	15.3±0.2[b]
W450	20.6±0.7[a]	13.3±0.5[a]	9.8±0.6[a]	10.4±0.5[a]	108.5±9.7[a]	69.1±1.9[c]	13.8±1.3[a]
SW	24.2±1.2[c]	15.9±0.7[d]	11.1±0.5[b]	11.0±0.4[b]	184.3±15.1[c]	74.4±2.0[d]	15.3±0.7[b]
SWS	23.0±1.5[b]	14.9±0.6[c]	10.7±1.4[b]	10.4±0.6[a]	158.7±16.7[b]	68.5±2.5[b]	15.5±0.5[b]
DW	22.7±1.2[b]	15.3±1.2[c]	10.2±0.7[a]	10.3±0.9[a]	157.1±25.2[b]	65.0±1.8[a]	15.7±0.9[b]

Means in column with same letter are not significantly different at $P \leq 0.05$

Table 3. Empirical relationship representing geometrical properties of cashew kernel and moisture content

Grades	Sphericity	R^2	Geometric mean diameter	R^2	100-kernel weight	R^2
W180	Y = 0.639x + 65.30	0.805	Y = 0.254x + 18.37	0.958	Y = 2.675x + 258.8	0.996
W210	Y = 0.560x + 67.55	0.999	Y = 0.248x + 17.38	0.998	Y = 2.050x + 211.1	0.992
W240	Y = 0.105x + 67.91	0.84	Y = 0.240x + 16.39	0.989	Y= 1.975x + 182.4	0.999
W320	Y = 0.188x + 68.28	0.844	Y = 0.185x + 14.93	0.993	Y = 1.600x + 175.8	0.995
W450	Y = 0.404x + 68.30	0.999	Y = 0.256x + 13.22	0.998	Y = 1.300x + 153.0	0.995
SWS	Y = 0.143x + 73.97	0.728	Y = 0.138x + 14.99	0.993	Y = 1.175x + 150.7	0.992
SW	Y = 0.334x + 64.31	0.999	Y = 0.229x + 15.24	0.977	Y = 2.175x + 134.4	0.977
DW	Y = 0.414x + 67.71	0.987	Y = 0.218x + 15.15	0.977	Y = 2.750x + 94.05	0.991

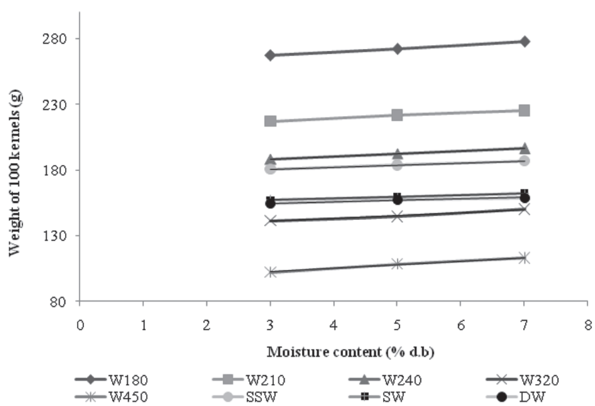

Fig. 4. Changes in weight of 100-kernels influenced by moisture content

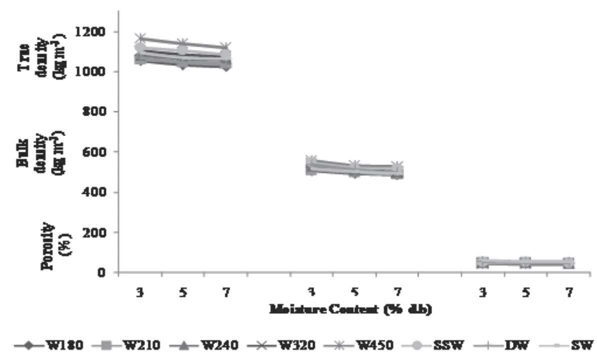

Fig. 5. Changes in true density, bulk density and porosity of cashew kernels influenced by moisture content

Change in one hundred kernel weight due to increasing moisture content of cashew kernel is shown in Fig. 4. It is evident that the increase in mass could result from the addition of moisture and primary grade of cashew kernels recorded an average increase of 5.4 per cent while in secondary grade kernels it was 3.2 per cent in the specified range of moisture tested. Hardening of kernels owing to high temperature during processing and uneven surface could be the contributing reasons lowering infusion of moisture for the secondary grade cashew kernels. Regression equation representing the relationship between 100-kernel weight and moisture content is given in Table 3.

Variation in bulk density, true density and porosity of cashew kernels with moisture content is depicted in Fig. 5. Bulk density decreased from 544.4 to 494.5 kg m^{-3}; true density from 1162.9 to

Table 4. Empirical relationship representing gravimetric properties of cashew kernels and moisture content

Grades	True density	R^2	Bulk density	R^2	Porosity	R^2
W180	y = -14.31x + 1065	0.946	y = -10.16x + 514.8	0.965	y = -2.430x + 55.77	0.985
W210	y = -16.95x + 1081	0.966	y = -9.996x + 519.5	0.983	y = -1.868x + 53.19	0.913
W240	y = -9.881x + 1087	0.847	y = -15.94x + 543.0	0.983	y = -1.588x + 51.44	0.906
W320	y = -15.15x + 1115	0.976	y = -21.66x + 562.6	0.932	y = -1.933x + 50.05	0.996
W450	y = -22.26x + 1184	0.998	y = -13.61x + 565.7	0.850	y = -1.738x + 46.49	0.981
SWS	y = -17.81x + 1139	0.993	y = -14.45x + 559.3	0.873	y = -0.818x + 52.11	0.964
DW	y = -8.750x + 1067	0.959	y = -19.17x + 554.2	0.952	y = -2.513x + 58.53	0.960
SW	y = -16.14x + 1107	0.883	y = -11.83x + 528.8	0.975	y = -2.579x + 60.77	0.891

1024.7 kg m^{-3} and porosity from 58.7 to 41.1 per cent irrespective of primary or secondary grade of cashew kernels in the moisture range tested. This negative linear relationship of gravimetric properties with moisture content was also observed by Gupta and Das (1977) for sunflower, Viswanathan *et al.* (1996) for neemnut, Baryeh (2001) for bambara groundnut and Aydin (2002) for hazelnut. Empirical relationship between gravimetric properties of cashew kernels and moisture is given in Table 4. High value of coefficient of determination indicates strong bearing of moisture content on gravimetric properties. Disproportionate mass gain resulting from moisture infusion with the accompanying volumetric expansion is the contributing factor for the declining trend in the bulk density of cashew kernels with addition of moisture. The decrease in true density with increase in moisture content could be attributed to relatively higher kernel volume as compared to corresponding mass attained due to absorption of moisture. Porosity of different food and agricultural material respond differently to changes in moisture and these changes could be attributed to their morphologic properties.

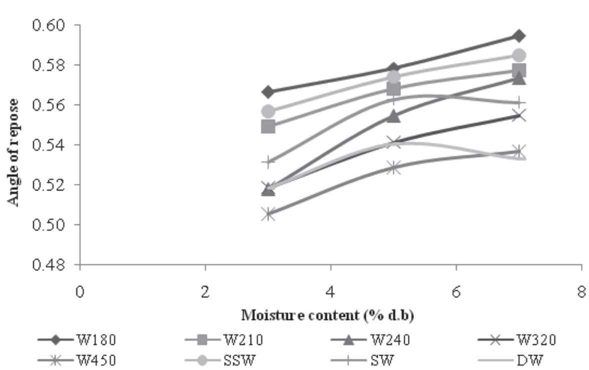

Fig. 6. Angle of repose of cashew kernels influenced by moisture content

The experimental values of angle of repose of cashew kernels at various moisture levels are illustrated in Fig. 6. Mean values of angle of repose increased from 0.5 to 0.6 for the primary grades whereas it increased from 0.5 to 0.6 for the secondary grade of cashew kernels with the increase in moisture content from 3 to 7 per cent d.b. Data on angle repose revealed that WW180 recorded

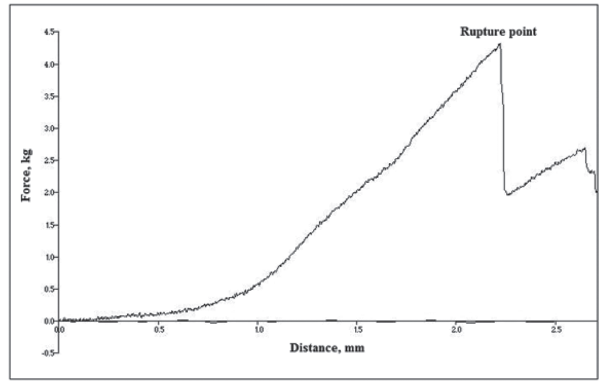

Fig. 7. Typical force – distance curve for compressed cashew kernels

highest value of 0.6 at 7 per cent d.b and value of DW observed to be the lowest of 0.5 at moisture content of 3 per cent d.b. Owing to the presence of carbohydrate in cashew kernels and it's reaction with moisture during absorption process developing adhesiveness, offered resistance to sliding of kernels. Besides, as indicated by Pradhan *et al.* (2008), increasing trend of angle of repose with moisture content occurs because surface layer of moisture surrounding the particle hold the aggregate of kernels together by the surface tension. This increasing trend of angle of repose with moisture content restricting the ease of sliding was observed in pistachio nut (Galedar *et al.,* 2008).

Force required to developing rupture in the cashew kernel while employing uni-axial compression load is presented in Fig. 7. It is evident from Fig. 8 that the rupture force is negatively

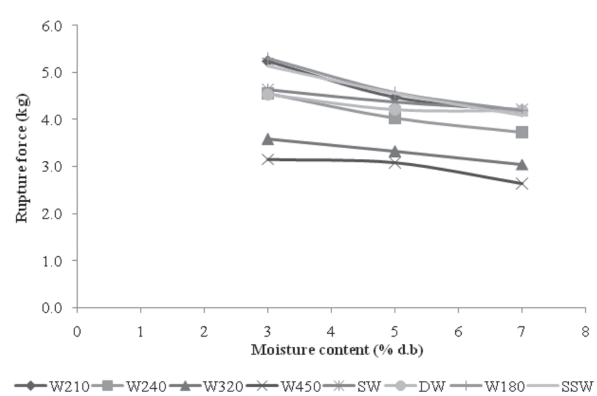

Fig. 8. Rupture force of cashew kernels influenced by moisture content

Table 5. Empirical relationship representing mechanical properties of cashew kernels and moisture content (%)

Grades	Angle of repose	R^2	Rupture force	R^2
W180	Y = 0.007x + 0.544	0.994	Y = -0.276x + 6.068	0.969
W210	Y = 0.007x + 0.529	0.960	Y = -0.265x + 5.955	0.942
W240	Y = 0.013x + 0.479	0.967	Y = -0.206x + 5.126	0.977
W320	Y = 0.009x + 0.492	0.978	Y = -0.133x + 3.980	1.000
W450	Y = 0.007x + 0.484	0.926	Y = -0.129x + 3.597	0.855
SWS	Y = 0.007x + 0.536	0.981	Y = -0.259x + 5.889	0.996
DW	Y = 0.007x + 0.514	0.712	Y = -0.083x + 4.722	0.795
SW	Y = 0.003x + 0.512	0.820	Y = -0.105x + 4.940	0.997

correlated and decreased as the moisture content increased from 3 to 7 per cent d.b. Rupture force value ranged between 2.6 to 5.3 kg for the primary grades and ranged from 4.2 to 5.1 kg for the secondary grade in the specified moisture level. Softening of surface texture of cashew kernels irrespective of grades resulted in lower values of rupture force at higher moisture content. Similar results have been reported in apricot kernel by Fathollahzadeh and Rajabipour (2008), soyabean by Tavakoli *et al.* (2009), lentil seeds by Bagherpour *et al.* (2009), faba bean by Mohammed and Mohammed (2009) and peanut by Hossein *et al.* (2011). However, Khazaei (2007) reported an increase in rupture force with the increase in size in almonds and *Jatropha curcas* respectively. Equation representing the change in the mechanical properties of cashew kernels in the moisture range of 3 to 7 per cent d.b is given in Table 5.

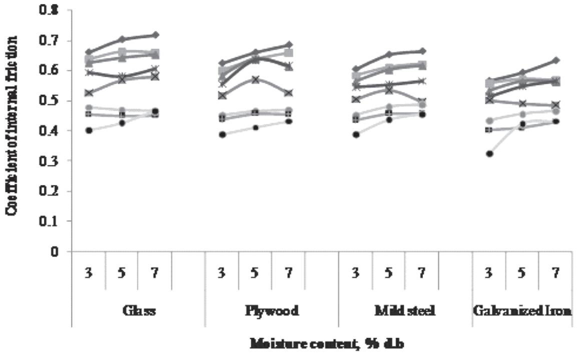

Fig. 9. Coefficient of internal friction of cashew kernels influenced by moisture content

Influence of moisture on coefficient of internal friction of cashew kernels against various surfaces *viz.*, cardboard, glass, galvanized iron and mild steel are represented in Fig. 9. Coefficient of internal friction was found to increase for all base surfaces with the increase in moisture content from 3 per cent to 7 per cent d.b. This is due to the increased cohesive force of cashew kernels on the contact surface at higher moisture levels. Mean values of coefficient of internal friction ranged from 0.40 to 0.72 for glass, 0.39 to 0.68 for plywood, 0.39 to 0.66 for mild steel and from 0.32 to 0.63 for galvanized iron. Coefficient of internal friction was found to be the highest for kernels on glass, while galvanized iron recorded a minimum. Simillar results were reported by Shepherd and Bhardwaj (1986); Dutta *et al.* (1988); Garnayak *et al.* (2008) and Pradhan *et al.* (2008) for pigeon pea, gram, jatropha seed and karanja kernel respectively.

Physico-mechanical properties of the cashew kernels investigated were found to be moisture dependent irrespective of the grades used.

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