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RESEARCH ARTICLE

Moisture-dependent physicochemical characteristics and microstructure of karonda (*Carissa carandas* L.) fruit

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Abstract

Karonda (*Carissa carandas* L.) fruits hold significant importance in traditional medicine due to its rich composition of "bioactive compounds" including anthocyanin, quercetin and tannins. It is abundant in antioxidants such as vitamin C, flavonoids and phenolic compounds and boasts anti-diabetic, hepato-protective and immune-boosting properties. The present study examined physico-chemical characteristics of karonda at different moisture levels (74 % to 82 %) due to their susceptibility to moisture content during processing. Moisture content of fruit at the time of harvest was found to be 77.99 ± 0.82 % (wet basis). Dimensional characteristics increased while sphericity and aspect ratio decreased with rise in moisture level. Average polar, equatorial and minor diameters ranged from 12.7 to 19.2 mm, 12.3 to 15.0 mm and 12.1 to 14.7 mm, respectively. Gravimetric properties, such as thousand fruit mass, bulk density, true density and porosity declined with decreasing moisture content. Frictional properties exhibited decrement with decreasing moisture level, indicating changes in the fruit's surface characteristics. The mean coefficients of friction for steel, plywood and rubber were 4.10, 3.8 and 3.36, respectively. Firmness decreased from 5.4 N to 1.9 N. Color attributes were affected by increased redness and colour intensity at higher moisture levels. Overall, the study underscores the necessity of understanding the moisture-dependent physical and chemical properties of karonda for optimizing fruit utilization in the form of value-added products.

Keywords

chemical characteristics; color; Karonda; physical characteristics

Introduction

The underutilized fruit Karonda (*Carissa carandas* L.) belongs to the berry-type citrus fruits of Himalayan origin. Karonda plants were traditionally grown in rural and sub-urban parts of India as protective hedge plants due to thorns and dense foliage (1). The shrub produces several bright pink edible fruits, adding ornamentation to the garden (2). The fruits are ellipsoid in shape, with white colour when immature and turning pink to purple upon maturity and ripening, respectively (3). Among 32 known species of karonda, *Carissa carandas*, *Carissa spinarum* and *Carissa grandiflora* are a few economically important species. In India, Maharashtra, West Bengal, Bihar, Odisha, Gujarat, Madhya Pradesh, Rajasthan and Uttar Pradesh are the typical locations to find karonda (4). It is cultivated commercially at Kashi of Uttar Pradesh and the Southern parts of West Bengal (5).

Karonda is abundant in iron and provides ample vitamin C, A and B complexes along with essential minerals, including calcium, phosphorous, potassium, sodium and sulphur. It also possesses medicinal properties in the form of hepato-protective and anti-hyperglycemic attributes (6). People involved in collecting and selling karonda fruits belong to tribal regions, who are unaware of post-harvest management of karonda. Presence of high moisture and soft flesh favors short storage stability (1). These factors paved the way for small scale food processors to promote several value added products such as dried karonda raisins, wine, pickle etc. (7) from karonda. It in turn necessitates the development of processing equipment such as grader, cutter, pulper, de-seeder etc. pertaining to the unique shape and size of the fruit. Fruits' physical characteristics must be understood in order to design and develop such processing equipment effectively (8).

Physical attributes such as dimension, surface area and volume are pertinent to the design of grading systems. Mechanical characteristics of fruit plays vital role in such methods involving pressure - cutting and pulping. Gravimetric properties such as mass and density and surface area are vital in design of cleaning, separation and conveying systems. Also, these physico-chemical characteristics and microstructure of fruits are readily influenced by change in its moisture content. Several researchers have reported physical properties and their dependence on moisture level for small fruits such as myrobalan (8), jackfruit seeds (9), pepper (10), cherry etc. Such findings are not reported yet for karonda fruits as per knowledge of the authors. Consequently, the current study intends to assess numerous moisture-dependent physico-chemical characteristics and microstructure of karonda fruit. The outcomes of this study can enhance rural communities' livelihoods, create additional income opportunities and help in equipment design and value addition related to karonda.

Materials and Methods

Sample preparation

Fully mature fresh karonda fruits (about 5 kg), locally known as chirukila or kalakai were harvested from the orchard of Tamil Nadu Agricultural University (11.0131°N and 76.9326 °E), Coimbatore, India in the month of June by the hand-picking method. Fruits were transferred to the Food Process Engineering Laboratory, TNAU and sorted manually to eliminate the extraneous matter present such as twigs, pedicel and immature fruits. Fruits were washed with distilled water to get rid of dirt and latex adhering to the skin, pat dried using muslin cloth and kept in cold store at 5 ± 1 °C and 85 ± 5 % RH until further investigation.

Moisture content

The primary moisture level in karonda fruit at the time of harvest was assessed by hot-air oven at 105 °C till persistent weight of fruit was attained. It was found to be 77.99 ± 0.82 % (w.b.). Based on the natural moisture content of karonda fruit and moisture content preferred for processing and storage, it was certain to estimate the physical and chemical characteristics of karonda fruits at moisture content of 74 %, 78 % and 82 % (w.b.). Desired moisture level in karonda fruit was obtained by adding water or removing water through the tray drying method at 40 °C. Amount of water added/removed (Q) was calculated by method (11) using Equation 1.

$$Q = \frac{Wi\,(M_f - M_i)}{(100 - M_f)} \quad \text{Eqn 1}$$

where Wi is initial weight of sample, Mf and Mi are final and initial moisture content of sample respectively.

Physical characteristics

The size of the oval fruits was described by their axial dimensions (Fig. 1). 20 fruits were randomly selected and the axial dimensions of each fruit like polar diameter (L), equatorial diameter (W) and minor diameter (T) were measured using a digital caliper (M/s. Mitu Toyo, Japan) with least count of ± 0.01 mm. An electronic weighing balance (SF-400A Electronic Compact Scale) with an accuracy of ± 0.01 g was used to measure individual fruit's mass (m). Geometric mean diameter (D_g) and arithmetic mean diameter (D_a) was derived from the measured values of axial dimensions as per Equation 2 & 3 specified by (12). Surface area (SA) and sphericity (S_p) of karonda fruit was estimated using Equation 4 & 5 mentioned by (13). Aspect ratio (AR) of fruits were studied to get detailed idea about its shape and was calculated using Equation 6 described by (14).

$$D_g = \{LWT\}^{1/3} \quad \text{Eqn. 2}$$

$$D_a = \frac{1}{3}(L + W + T) \quad \text{Eqn. 3}$$

$$SA = \pi {D_g}^2 \quad \text{Eqn. 4}$$

$$S_p = \frac{D_g}{L} \quad \text{Eqn. 5}$$

$$AR = \frac{W}{L} \times 100 \quad \text{Eqn. 6}$$

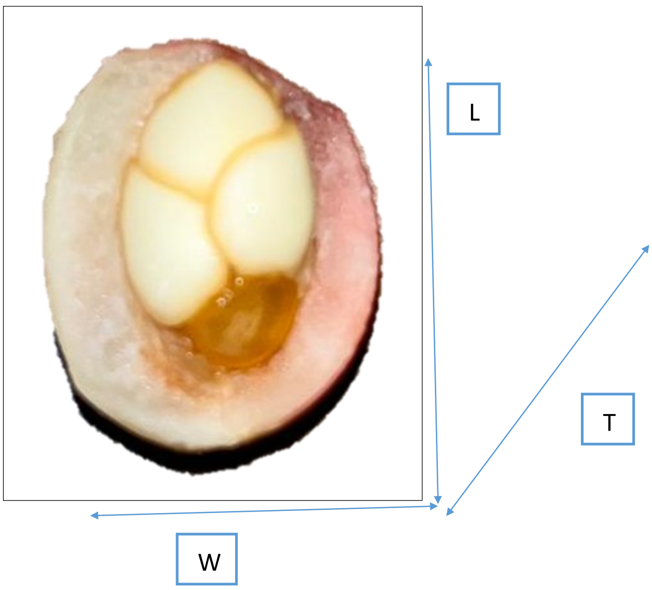


Fig. 1. Cross-sectional view and characteristic dimensions of karonda fruit.

Thousand karonda fruit mass (M) was measured as per method stated by (14) using Equation 7. True density (ρ_t) was determined according to water displacement method involving Equation 8. Bulk density (ρ_b) and porosity (% ε) was figured out by Equation 9 consistent with (11).

$$\rho_b = \frac{Mass\ of\ contained\ fruits}{Volume\ of\ container} \quad \text{Eqn. 7}$$

$$\rho_t = \frac{mass\ of\ fruits\ contained}{Volume\ of\ water\ displaced} \quad \text{Eqn. 8}$$

$$\%\,\varepsilon = \left[1 - \frac{\rho_b}{\rho_t}\right] \times 100 \quad \text{Eqn. 9}$$

Frictional and mechanical characteristics

Coefficient of static friction (μ) at three unlike surfaces i.e., stainless steel (μ_s), plywood (μ_p) and rubber (μ_r) as well as angle of repose (θ) was evaluated by Equation 10 following the process termed by (8). Angle of repose was determined using Equation 11.

$$\mu = \frac{F_W}{N} \quad \text{Eqn. 10}$$

$$\theta = Tan^{-1}\frac{2H}{D} \quad \text{Eqn. 11}$$

To test the firmness (F_p) of karonda fruit, sample was loaded longitudinally at the workspace of computerized Texture analyzer (Shimadzu EZ-SX) and a piercing needle jig of 3 mm diameter was allowed to penetrate the fruit at 1.0 mm/sec pre-test speed. The minimum force required to punch a karonda fruit was noted in replication of three with different samples (11).

Chemical characteristics and color

Acidity of fruits are described by their pH value. To determine karonda fruit's pH, 10 fruits were randomly selected in triplicates. They were properly washed and cut into 2 halves to facilitate removal of seeds. Cut fruits were ground to obtain pulp. The pH of samples in triplet was measured using a digital pH meter. Pulp prepared was used to measure TSS of fruit using a handheld refractometer.

Color attributes of karonda fruit was quantified with the help of hand held Spectro colorimeter (Lovibond LC 100 tintometer). The instrument was first calibrated against a white background and then measurement of color of fruit was carried out in triplicate. The L* value indicates lightness on 0 to 100 scale. Color from green to redness and blue to yellowness is represented by a* and b* value respectively. Color intensity of dullness to vivid is represented by chroma (C) value while hue (H°) represents the color angle in degree (15).

Microstructure

The microstructure of fruit samples at three different moisture content was examined through Scanning Electron Microscope (SEM). Peel of the fruit samples were cut to a thickness of 1 mm using a scalpel. Sample preparation was performed according to (16). Sample was observed for structural changes and micrographs were obtained using SEM (FEI, Czech Republic EDEX Quanta 250).

Statistical analysis

The investigation involved analyzing the moisture-dependent physico-chemical characteristics of karonda fruit through statistical methods. The data, expressed as mean values with their respective standard deviations, underwent one-way ANOVA to determine the coefficient of determination. Additionally, Tokay's HSD test was verified with a significance level of $p < 0.05$ using SPSS 16.0. Correlations among various physical properties and fruit mass were assessed using SPSS 16.0, while Microsoft Excel 2013 was employed for graph processing.

Results and Discussion

Physical characteristics

The physical characteristics of karonda at the moisture level of 74 %, 78 % and 84 % is presented in Fig. 2 (A to F). Moisture content significantly ($p<0.01$) influenced the geometrical properties of karonda. The mean value of the axial dimensions (polar, equatorial & minor) declined from 19.29 mm to 12.75 mm, 15.03 mm to 12.34 mm and 14.78 mm to 12.16 mm respectively with decrease in moisture level. The results were compared with similar fruits to get an idea of fruit size. Dimensions of karonda were similar to olives (17) but lower than that of Algerian dates (18), myrobalan fruit (8) and Indian coffee plum (19). A uniform decrease in principal dimensions with variation in moisture did not instigate shape modification.

The D_g, D_a and SA also decreased from 16.23 mm to 12.41 mm, 16.36 mm to 12.42 mm and 828.65 mm^2 to 487.01 $mm^{2,}$ respectively, with a decrement in moisture content. This was due to the dependency on axial dimensions, which were found to decrease. The possible reason for shrinkage is the release of moisture from intracellular spaces, which decreases physical characteristics (20). However, D_g was greater than equatorial and minor diameter. Parallel findings were stated for axial dimensions and geometric mean diameter of myrobalan (8) and about sorghum grains (21). Properties like mean and equivalent diameter are critical design considerations of separation and grading equipment.

Sphericity of karonda at three moisture levels increased with the decrease in moisture contents (Fig. 2E). However, the sphericity value of karonda was equivalent to olives (17) and lower than that of jackfruit seeds, as reported (9). This is because karonda shrinks more along with its polar diameter upon removal of the moisture. Increasing value of sphericity indicates tendency of fruit towards roundness as well as roll ability, which is an important property for designing conveying equipment (11). The aspect ratio increased with reduced moisture levels. This increment was due to the inverse relationship between aspect ratio and length, which was found to fall with a decreasing moisture level. A more excellent aspect ratio implies that the fruit will slide instead of roll (22).

The effect of moisture level on physical properties was notable (*$p<0.01$*), excluding true density. A thousand-unit mass (M) of karonda berry increased linearly from 1.2 kg to 2.3 kg with elevation in moisture levels. Upon comparison with other similar-sized fruits, M of karonda was lesser than that of the halhali olive variety (1.9 kg) (17) and myrobalan fruit (4.9 kg) (8). An increase in fruit mass was reported for sorghum with increasing moisture (21). A probable cause could be moisture migration from the fruits at lower moisture levels. Table 1 shows the influence of moisture content on a thousand fruit mass and karonda fruit porosity.

Bulk density of karonda declined from 0.011 g/ml to 1.199 g/ml while the actual density reduced from 1.003 g/ml to 0.805 g/ml with decreasing moisture content (Fig. 2G). A decreasing trend for both ρ_b and ρ_t was observed by (23) meant for multiplier onion and (11) for plum kernels upon increase in moisture content. The value of ρ_b is less than ρ_t since voids are present between fruits which upsurge the volume of fruit while keeping the load constant. Porosity decreased from 31.9 % to 4.8 % with a reduction in the moisture content of karonda, which is in consistent with findings for sorghum (21) and multiplier onion (23). The reduction in porosity enhances the packing efficiency by reducing void spaces.

Frictional and mechanical characteristics

Influence of variation in moisture level on frictional and mechanical properties of karonda was found to be significant ($p < 0.05$) except θ (Table 1). Mean value for coefficient of friction for steel, plywood and rubber were 4.10, 3.8 and 3.36 respectively (Fig. 2H). As the moisture level increased, μ_s, μ_p and μ_r increased linearly. Parallel style for apricot kernels was specified by (13). This may be due to the fact that cohesion among particles reduces at a lesser moisture percentage. Angle of repose extended from 0.699° to 0.912° with increasing moisture content. A similar trend was stated for plum kernels (11) and (9) for jackfruit seeds. However, an increasing trend in the angle of repose for sorghum was reported (21). Higher values of the angle of repose may be attributed to huge berry size. It is also influenced by shape, size, moisture content and fruit orientation.

The force required to puncture fresh fruit longitudinally was 5.47 N. It decreased with increasing or decreasing moisture levels (Table 1). This can be due to softening of tissues by the application of heat. Hardness of plum kernel depicted decreasing trend upon increase in moisture as reported by (11). The smaller difference observed between the firmness of samples defines the intact skin of karonda with decreasing moisture content.

Chemical characteristics and color

The influence of moisture content on pH and TSS of karonda is shown in Table 1. pH of karonda fruit increased from 2.72 to 2.85 upon decreasing moisture content, indicating a reduction in acidity. Thi trend suggests that upon losing moisture, concentration of organic acids may decrease or undergo transformation. TSS of karonda berry increased significantly with decreasing moisture, indicating the concentration of soluble solids. A similar pattern is depicted in the drying or ripening process of fruits, which makes the fruit taste sweeter. The TSS of fresh karonda fruit was similar to that of Indian coffee plum (19). The rise in TSS is an essential factor in determining fruit quality, as it influences sweetness, flavor and processing suitability for value-added products such as jams, jellies and beverages. The pH as well as TSS of karonda fruit was found to be much lesser than sapota (24), representing the acidic nature of fruit.

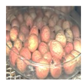
Changes in color about moisture were evaluated using L*, a*, b*, C, H and ΔE. Table 2 shows that increased moisture level increases redness and colour intensity (C). Color of fresh fruits acts as an indicator of freshness, maturity and quality (13). The mean value of L* and b* declined from 69.4 to 43.2 and 22.6 to 16.5, respectively, while a* value increased from 12.2 to 40.4. The related trend was acknowledged for apricot (13) and sapota (24) with alteration in moisture content. Karonda's skin color

Table 1. Influence of moisture level on some physicochemical properties of karonda fruit

Parameters	Moisture Content (percent wet basis)*			C.D.
	82 percent	78 percent	74 percent	
1000 Fruit mass (M), g	$2323.33^{a} \pm 1.334$	$1533.33^{b} \pm 1.525$	$1278.67^{c} \pm 1.146$	4.74
Porosity (ε), %	$31.973^{a} \pm 1.246$	$10.743^{b} \pm 3.967$	$4.863^{b} \pm 1.021$	8.719
Angle of repose (θ), °	$0.912^{a} \pm 0.085$	$0.699^{a} \pm 0.032$	$0.727^{a} \pm 0.059$	NS
Firmness (F_p), N	$3.933^{b} \pm 0.133$	$5.467^{a} \pm 0.145$	$1.933^{c} \pm 0.176$	0.539
pH	$2.727^{b} \pm 0.037$	$2.813^{ab} \pm 0.009$	$2.85^{a} \pm 0.012$	0.08
TSS (° Brix)	$5.567^{c} \pm 0.033$	$27^{b} \pm 0.289$	$35.5^{a} \pm 0.289$	0.834

*Different letters within the same row in superscript indicate significant differences *(p<0.0)5* among mean ± S.D. of three replicates. NS: not significant

Table 2. Variation in colour of karonda fruit as a function of moisture content

MC, % (wb)	L*	a*	b*	C	h	ΔE	Karonda fruit
74	69.4 ± 2.76	12.2 ± 3.86	22.6 ± 0.40	25.9 ± 1.32	62.1 ± 8.22	40.1 ± 2.98	
78	54.9 ± 2.05	27.9 ± 1.49	23.7 ± 0.82	36.6 ± 1.68	40.4 ± 0.62	58.1 ± 2.33	
82	43.2 ± 1.90	40.4 ± 1.31	16.5 ± 3.92	43.7 ± 2.08	22.1 ± 4.74	71.7 ± 0.38	

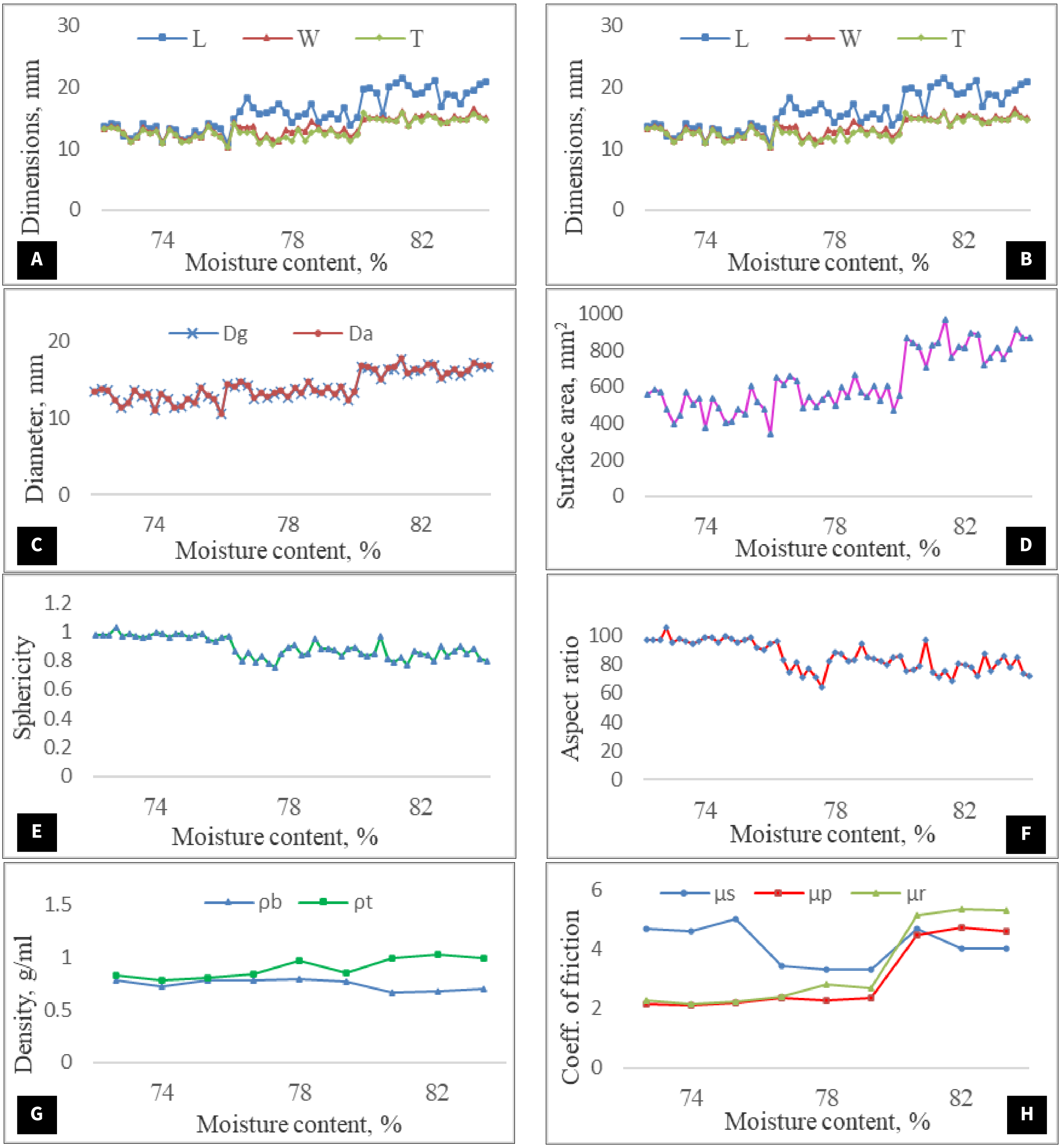


Fig. 2. Influence of moisture level on engineering properties (A) size, (B) fruit mass, (C) geometric and arithmetic mean diameter, (D) surface area, (E) sphericity, (F) aspect ratio (G) bulk and true density and (H) coefficient of friction - steel, plywood and rubber of karonda fruits.

L: Polar diameter, W: Equatorial diameter, T: Minor diameter, Dg: geometric mean diameter, Da: arithmetic mean diameter, ρb: bulk density, ρt: true density, μs: coefficient of friction - steel, μp: coefficient of friction - plywood, μr: coefficient of friction - rubber.

changes from dark to light with the decrease in moisture content. With the increase in moisture level, rehydration of pigments increases, which could be a probable reason for lower L* and b* values at higher moisture content (25).

Microstructure

Fig. 3 illustrates how karonda peel samples were cut to perform SEM analysis and the surface microstructure of karonda fruit peel at 500X magnification. The image displays a rough, irregular surface texture with a heterogeneous composition of various elements and the presence of cavities and pockets. This irregular topography is characteristic of the complex microstructure found in fruit peels. Comparison among microstructures revealed that Image 3B and 3C have a rougher, more irregular surface texture, while Image 3D appears smoother and more uniform. Image 3C exhibits larger gaps and cavities compared to the other two images, suggesting a more open and loosely structured surface. It shows more prominent elongated elements, such as plant cell fibers from the fruit peel. As per author's knowledge, microstructure of karonda fruit peel at a varied moisture content is evaluated for the first time using a scanning electron microscope. These microstructures are consistent with the outer layer or peel

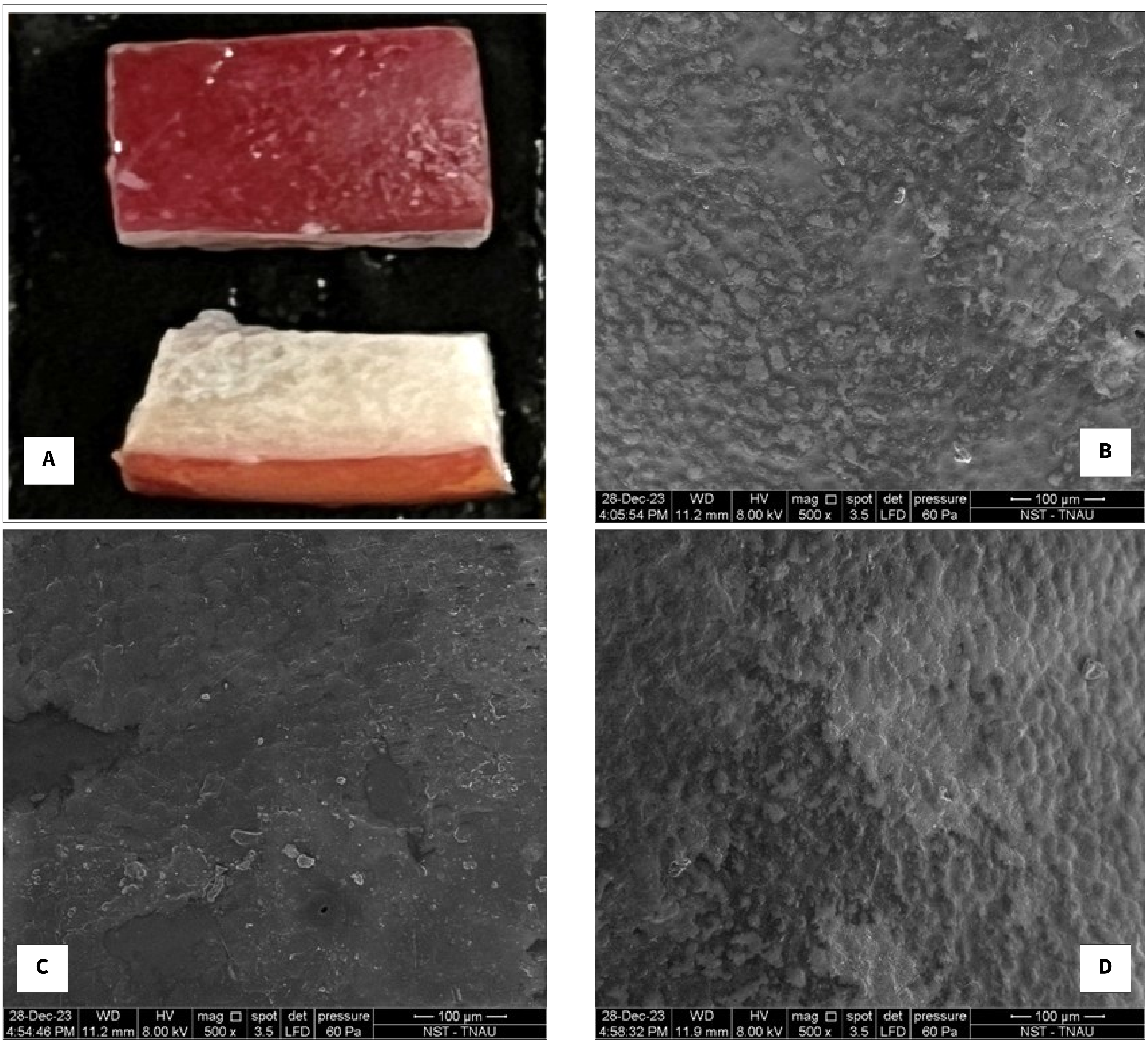


Fig. 3. Karonda peel cuts (A) and microstructure of karonda fruit skin with changing moisture content (B, C and D).

of certain fruits such as apple (26) and orange peel (27). The irregular texture, particulate matter and fibrous structures are the typical heterogeneous composition of fruit peels, which consist of various layers and components, including the cuticle, epidermal cells and underlying tissue. The presence of cracks and fissures could be attributed to the sample preparation process, which may involve dehydration or other treatments that can alter the surface morphology (28).

Conclusion

The study comprehensively evaluated the impact of moisture content on geometrical, gravimetric, frictional and mechanical property as well as microstructure of karonda fruits. The key outcomes indicate that the moisture content had a linear relationship with axial dimensions, equivalent diameter, surface area, thousand-unit mass, true density, porosity and puncture force while it inversely affected sphericity and aspect ratio. The study also reveals that frictional properties vary with moisture, influencing fruit handling and equipment design. Outcomes on physico-chemical properties as a function of moisture could be vital for people involved in manufacturing of processing machinery as well as value added products to enhance the utilization of karonda fruit. Future research should explore advanced imaging and computational modeling which could provide deeper insights into microstructural transformations, aiding in the development of improved packaging and storage solutions for ripe as well as unripe karonda fruits.

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Authors' contributions

KN carried out the experiment, took observations, analysed and interpreted the data and drafted the manuscript. BM conceptualised the research, project administration and edited the final manuscript. RA contributed by guiding the formal analysis, data interpretation and reviewing the manuscript. PT helped in methodology associated with the research. MI helped to formulate the concept and revised the manuscript. RR helped with data analysis. UN contributed to reviewing and editing of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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