Research Article

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Post-harvest evaluation of Arabica and Robusta coffee for physical, mechanical and aerodynamic properties

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Abstract

Knowledge about physicomechanical and aerodynamic properties is indispensable for any crop that undergoes post-harvest processing; coffee is no exception. These properties are the most crucial parameters for designing and developing processing machinery and storage structure. As far as coffee is concerned, these properties are imperative for designing dryers, hullers, peeler-cum-polisher and size graders. Though coffee is one of the leading plantation crops in India, published reports on physical, mechanical and aerodynamic properties are rather limited. In this direction, a study was attempted to generate data in respect of physical (length, width, thickness, volume, surface area, thousand seed weight, bulk density, true density and porosity), mechanical (angle of repose and co-efficient of friction) and aerodynamic (terminal velocity) property in different coffee types (parchment, cherry and clean coffees of both Arabica and Robusta varieties). At the prescribed moisture content of 11 per cent, the length, width, thickness, volume and surface area were significantly higher (p=0.05) in cherry coffee, followed by parchment and clean coffees. The porosity, bulk density and true density were found in the order of 45 to 58 per cent, 395 to 466 kg m^{-3} and 856 to 944 kg m^{-3} for cherry, 56 to 57 per cent, 400 to 410 kg m^{-3}, 950 to 966 kg m^{-3} for parchment and 37.5 to 44 per cent, 691 to 780 kg m^{-3} and 1,106 to 1,401 kg m^{-3} for clean coffee, respectively. There were no significant differences between coffee types in respect of angle of repose, co-efficient of friction and terminal velocity. The data generated under this study can be harnessed while configuring or improving the coffee processing machinery and helps achieve the final product with desirable quality characteristics.

Keywords: Aerodynamic properties, coffee bean, mechanical properties, physical properties

Introduction

In India, coffee is one of the major plantation crops. India exports over 70 per cent of coffee to various destinations and fetches substantial foreign exchange. India produces about 2.94 per cent of total world's coffee production and is ranked sixth in the world. Coffee is grown to the extent of 4.18 lakh hectares in India, and the annual coffee production is around 2.98 lakh MT with a productivity level of 713 kg ha^{-1}. The traditional coffee-growing states include Karnataka, Kerala and Tamil Nadu. The coffee-growing areas of Andhra Pradesh and Odisha are categorized as non-traditional areas. The total area under coffee cultivation in Karnataka state is 2.26 lakh hectares with a production of 2 lakh MT, and the productivity level is 897 kg ha^{-1} (Anonymous, 2021).

In India, two different coffee species, *viz.*, *Coffea arabica* (Arabica) and *Coffea canephora* (Robusta) are commercially grown. Arabica produces superior and mild quality coffee than Robusta. In India, coffee is processed mainly in two ways: wet and dry. Wet-processed coffee results in the production of parchment coffee or plantation coffee, while the dry method produces cherry coffee. About 85 to 90 per cent of Arabica coffees are handled through the wet method, whereas 85 to 90 per cent of Robusta coffee is processed by the dry method because of the difficulty in removal of sticky mucilage adhered to the coffee bean. In wet processing, the fruit skin and mucilage are removed and beans inside the parchment cover are sun dried until the moisture level reaches 11 per cent (w. b.).

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The dried parchment coffee is subjected to peeling and polishing at curing to remove the parchment cover to obtain clean coffee. The parchment coffee, prepared by the wet method, is favoured in the market because of its superior quality. In the case of the dry method, the harvested fruits are sun-dried in the clean drying yard after sorting the unripe and over-dried coffee fruits as it spoils the quality of coffee. The dry cherries are subjected to hulling at the curing works to obtain clean coffee (Anonymous, 2014).

Assessment of physicomechanical attributes of farm produce will be the utmost essential task for designing the primary and secondary handling machinery. This information is also useful for engineers and food scientists for conducting research on the design and development of processing machineries such as pulpers, washers, dryers, graders and roasters at the primary and secondary processing levels. Reports on physical, mechanical, and aerodynamic properties have been published for different crops such as oil palm (Davis, 2012), coconut (Alonge and Adetunji, 2011), palmyra (Vengaiah *et al*., 2021), cashew nut (Aware *et al*., 2007), rubber (Findik *et al*., 2004), cocoa (Aleida *et al*.,2019) and areca nut (Kaleemullah and John, 2002). As far as coffee is concerned, limited reports have been published on its engineering properties (Chandrasekar and Viswanathan, 1999; Afonso *et al*., 2007; Mikru *et al*., 2019). Therefore, a detailed study was undertaken in different coffee types (parchment, cherry and clean coffees of both Arabica and Robusta cultivars) covering all parameters.

Materials and methods

Description of the study area

The study was conducted at Central Coffee Research Institute (CCRI) in Chikkamagaluru district in Karnataka State, India. The coffee samples were obtained from CCRI Farm during 2019-2020 and 2020-2021 harvesting seasons. The fresh fruits of both Arabica and Robusta cultivars were processed by wet and dry methods, following standard estate practices. The resulting samples, *viz*., parchment coffee, cherry coffee and clean coffee, were evaluated for various parameters at a moisture level of 11 per cent (w. b.).

Measurement of physical attributes of coffee

The physical attributes of parchment coffee, cherry coffee and clean coffee were estimated following the standard procedures described by Mikru *et al.* (2019).

Linear dimensions

Length, width and thickness were estimated using a digital vernier caliper (Baker Lcd Model No. SDN 10) with an accuracy of ± 0.02 mm. The three principal dimensions *viz.*, length (L) was measured along the major axis, width (W) was measured along the minor axis and thickness (T) was measured opposite side of the measured width.

Geometric mean diameter

This property was estimated from the linear dimensions recorded using the following mathematical expression:

$$Dg = \sqrt[3]{LxWxT}, \text{ (mm)} \tag{1}$$

Surface area

The surface area of coffee samples was calculated from the geometric mean diameter obtained following the detailed on Kuala *et al.* (2018).

$$\text{Surface area} = \pi\,(Dgm)^2\,(mm^2) \tag{2}$$

Sphericity

Sphericity (S) is the criteria for describing the shape of the coffee samples and calculated by the following formula (Mohsenin, 1986).

$$S = \frac{\text{Geometric mean diameter}}{\text{Length}} \text{x100} \tag{3}$$

Aspect ratio

The average length (L) and width (W) of coffee samples were measured then this property was computed by using the below formula:

$$Ra = \frac{W}{L} \tag{4}$$

Shape index

The average dimensions (length, width and thickness) of coffee samples were measured, and the shape index (SI) was calculated by the following equation (Abdullah *et al.*, 1993)

$$SI = \frac{L}{\sqrt{WxT}} \quad (5)$$

The coffee bean is considered an oval if the shape index is more than 1.5 and it is considered spherical if the shape index is below 1.5 (Rathinakumari *et al.*, 2015).

Volume

The volume of the coffee samples was computed from the below formula, considering the length, width and thickness of an individual sample.

$$V = \frac{\pi}{6} LxWxT \ (mm^3) \quad (6)$$

Thousand bean weight

Thousand randomly selected coffee beans of different forms are weighed with the help of an analytical weighing balance (Precisa make 320 XB, Switzerland). The weight (kg) was recorded in triplicates.

Bulk density

The density of the coffee sample was estimated by packing the weighed samples in the graduated cylinder, which had a known volume of 500 mL from the height of 30 cm at a constant rate. Samples packed in a cylinder were allowed to settle gently, and density was recorded in triplicates. (Chandrasekar and Viswanathan, 1999).

$$\text{Bulk density} = \frac{\text{Weight of sample in container (kg m}^{-3})}{\text{Volume of container}} \quad (7)$$

True density

The true density of coffee samples was measured by using the liquid displacement method. Weighed twenty-five numbers of coffees of different forms were poured into the known volume of toluene in a measuring cylinder. The level of the toluene before and after dropping the samples was noted, and the density was determined by this method thrice.

$$\text{True volume (mm)} \left\{ \begin{array}{c}\text{Final toluene}\\ \text{level in}\\ \text{measuring jar}\end{array} \right\} - \left\{ \begin{array}{c}\text{Initial toluene}\\ \text{level in}\\ \text{measuring jar}\end{array} \right\}$$

$$\text{True density} = \frac{\text{Weight of sample}}{\text{True volume of sample}} \text{(kg m}^{-3}) \quad (8)$$

Porosity

This property was evaluated in triplicates by considering the bulk density and true density of individual coffees, and the porosity of coffee samples was obtained with the help of the following expression.

$$\text{Porosity (\%)} = \frac{TD - BD}{TD} \times 100 \quad (9)$$

Where TD -True density and BD - Bulk density

Mechanical properties

Angle of repose

The angle between the base as well the slope of the cone on a plane surface is when a granular material is dropped perpendicularly to the horizontal surface. The 'emptying method' was adopted to measure the repose angle. The samples were filled in the cone placed on the plain surface and let down the samples to flow freely. The angle of repose was calculated from the height and length of the pile (Mohsenin, 1986).

$$\text{Angle of repose } (\theta) = \tan^{-1} \frac{H}{L} \quad (10)$$

Where, θ- repose angle (°); H and L - height and length of heap formed (mm).

Co-efficient of static friction

The inclined plane method was adopted to estimate the coefficient of static friction (μ_s) of coffee samples. Plywood, mild steel, and glass were the test surfaces used for the experiment. The top edge of the test surface was placed with the samples. The surface inclined was tilted when the samples began to flow, leaving the inclined surface. Scale is provided to measure the angle of inclination with the horizontal, and this angle is taken as an angle of internal friction. The tangent of the angle was taken as the coefficient of friction between the surface and the sample (Mohsenin, 1986).

$$\mu_s = \tan\theta \qquad (11)$$

Where μ_s - co-efficient of static friction; θ - the angle of inclination of material surface (º)

Aerodynamic properties

Terminal velocity

The terminal velocities of coffee samples and other matters were measured using the air column system. In every experiment, a sample was plunged into the airflow from the peak of the air column to suspend the material into the airflow. The hot wire anemometer (WEATHER tronics Inc. Model - 2440) has the least count of 0.01 m s^{-1}. The air velocities near the coffee samples, husk, dried leaves and twigs were measured using the hot wire anemometer.

Statistical data analysis

The data obtained were subjected to statistical analysis, and the differences between physical, mechanical, and aerodynamic properties among cherry, parchment and clean coffee of Arabica and Robusta cultivars were analyzed with the analysis of variance (ANOVA) by using OPSTAT Statistical Software Package developed for Agriculture Research Workers.

Results and discussion

Physical properties

Physical properties are summarised in Table 1.

Linear dimensions

The data on linear dimensions *viz*., length, width and thickness were found to be significantly higher for the Arabica variety than Robusta. Among the different forms of coffee, the length, width and thickness of cherry coffee were found to be significantly higher than parchment and clean coffee. The linear dimensions are very important in designing any agricultural/food processing machinery for sorting and grading (Rathinakumari *et al*., 2015).

Volume and surface area

Volume and surface area were significantly higher for the Arabica variety than for Robusta. Among the different forms of coffee, the volume and surface area for the cherry form of coffee were found to be significantly higher than parchment and clean coffee. These properties help in calculating the storage capacity per unit area (Tabatabaeefar and Rajabipour, 2005).

Weight of 1000 units, bulk density, true density and porosity

The weight of 1000 unit value was found non-significant among the different varieties tested but found to be significantly higher for the cherry coffee (1.82 kg) than parchment (0.19 kg) and clean coffee (0.18 kg). The bulk density values were found to be

Table 1. Physical properties of cherry, parchment and clean coffee of Arabica and Robusta varieties

Parameters	Cherry			Parchment			Clean coffee		
	A	R	SE (±m)	A	R	SE (±m)	A	R	SE (±m)
Length (mm)	14.18	12.50	0.24	11.47	9.82	0.13	10.04	8.60	0.18
Width (mm)	11.66	10.81	0.17	7.85	7.37	0.09	6.74	6.56	0.09
Thickness (mm)	9.53	9.04	0.16	4.80	4.69	0.06	3.93	4.07	0.05
Volume (mm^3)	834.63	648.64	31.23	227.47	178.65	5.80	139.48	121.27	4.96
Surface area (mm^2)	426.42	343.66	0.34	172.62	147.12	3.05	125.00	53.22	5.21
Sphericity (%)	82.11	83.65	0.15	64.59	69.73	0.08	63.14	70.07	0.95
Aspect ratio	0.85	0.87	0.65	0.76	0.75	0.02	0.71	0.76	0.04
Shape index	1.35	1.27	0.04	1.88	1.67	0.06	1.96	1.67	0.03
Wt. of 1000 units (kg)	1.82	1.38	0.05	0.19	0.19	0.01	0.18	0.18	0.02
Bulk density (kg m^{-3})	395.00	466.00	0.40	410.00	407.00	0.70	691.00	780.00	46.93
True density (kg m^{-3})	944.00	856.00	1.70	966.00	950.00	2.16	1106.0	1401.0	1.17
Porosity	58.15	45.46	0.10	57.55	57.15	0.55	37.52	44.32	0.58

A-Arabica, R-Robusta

significantly higher for the Robusta than Arabica, and a significant difference was observed among the different forms of coffee tested. The true density values were found to be significantly higher for the Arabica variety than Robusta but exhibits the least significant difference among the different forms of coffee tested. The porosity values were found non-significant among the different varieties tested but found higher for the cherry (58.15%), followed by parchment (57.55%) and clean coffee (44.32%) coffee. These parameters are essential to estimate the rigidity of the instruments and design the storage structures. This parameter influences the structural loads and helps quantify the loads per unit volume. It ensures better heat exchange and aeration during heating, drying and cooling operations (Tabatabaeefar and Rajabipour, 2005).

Sphericity, aspect ratio and shape index

The recorded data indicated that the sphericity, aspect ratio and shape index values were non-significant between the coffee varieties tested. Among the different forms of coffee tested, the sphericity and aspect ratio were found to be significantly higher for the cherry coffee (83.65 and 0.87), followed by parchment (69.73 and 0.76) and clean coffee (70.06 and 0.76). The cherry is spherical in nature, as the shape index is less than 1.5, whereas the parchment and clean coffees are oval, as the shape index is more than 1.5. These values were used in designing the air-screen grain cleaners, various mechanical separators, and pulping and secondary processing machinery. The products with more sphericity in nature exhibit higher rolling in nature which is crucial to design inlet and outlet chutes and troughs to handle the products (Nisha and Amarjeet, 2017).

Mechanical properties

Angle of repose

The estimated angle of repose for cherry, parchment and clean coffee was found to be non-significant among the variety and different forms of coffee tested (Table 2). The values obtained were of paramount importance in deciding the inlet and outlet openings and the inclination necessary for the product flow (Chandrasekar and Viswanathan, 1999).

Table 2 Angle of average repose value for cherry, parchment and clean coffee.

Coffee variety	Cherry	Parchment	Clean coffee
Arabica	36.19°	37.20°	33.06°
Robusta	32.70°	36.80°	31.42°
SE(±m)	2.54	3.11	4.40
CD @ 5%	NS	NS	NS

Co-efficient of friction

The coefficient of friction for the cherry coffee, parchment and clean coffee of the Arabica and Robusta varieties were determined against three types of structural surfaces and were presented in Table 3. The data indicated that the coefficient of friction was found to be non-significant between the varieties and different forms of coffee tested but found significant against three types of structural surfaces tested. Details about the frictional property will benefit the manufacturers and engineers to compute the power required in establishing the

Table 3. Co-efficient of frictional average values for cherry, parchment and clean coffee

Surfaces	Arabica			Robusta		
	Cherry	Parchment	Clean coffee	Cherry	Parchment	Clean coffee
MS sheet	0.353	0.340	0.363	0.283 *	0.280 *	0.280 *
GI sheet	0.373 *	0.370 *	0.380 *	0.447	0.450	0.443
Glass	0.377	0.367	0.383	0.387	0.383	0.387
	SE (±m)			CD@ 5%		
Factor (A)	0.013			NS		
Factor (B)	0.016			NS		
Factor (C)	0.016			0.047		
Factor (A*B*C)	0.040			NS		

Table 4. Average terminal velocity (m s^{-1}) values for cherry, parchment, clean coffee and extraneous matters

Cultivar	Cherry	Parchment	Clean coffee	Husk	Dried leaves	Twigs
Arabica	9.4	5.3	7.3	3.8	2.2	3.2
Robusta	8.8	5.7	7.7	3.6	1.9	3.0
		SE (±m)			CD@ 5%	
Factor (A)		0.039			0.117	
Factor (B)		0.068			0.202	
Factor (A*B)		0.097			0.285	

secondary processing utilities like hullers and peeler-cum-polishers and in choosing the right type of material for fabricating the machinery (Maduako and Hamman, 2004).

Aerodynamic property

Terminal velocity

The average terminal velocity of cherry, parchment, clean coffee and admixtures was found to be significant among the cultivars and different forms of coffee tested (Table 4). Terminal velocity is useful in deciding the blower speed for winnowing and aspiration units (Rathinakumari *et al*., 2015).

Conclusion

The physical properties such as length, width, thickness, volume, surface area, thousand seed weight, bulk density, true density and porosity were determined as these physical properties of beans play a very important role in deciding the proper clearance in case of hullers and also very necessary to design bulking machines, graders and polishers at the secondary processing units. The mechanical properties such as angle of repose and co-efficient of friction and aerodynamic property, *i.e.,* terminal velocity, are very helpful for the design of feed hopper slope, outlets, storage structures, aspiration units and post-harvest processing equipment under Indian agro-climatic conditions.

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