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Study of some engineering properties of dry chilli (*Capsicum annuum* L.) cultivars of India

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■ **ABSTRACT :** This paper describes some of the engineering properties of six chilli (*Capsicum annuum* L.) cultivars, *viz.,* Byadgi, Guntur sanam, Mathania, Kashmiri, Reshampatti and Teja which would aid in designing the equipment and apparatus for processing of dry chilli such as sorting, grading drying, destalking, size reduction and transportation. The significant difference was observed among the geometrical properties (length, width, and thickness), gravimetric properties (bulk and true density), optical (color scales L*, a*, b*), aerodynamic (terminal velocity), mechanical (hardness) and frictional (co-efficient of friction). Among geometrical properties, the whole fruit lengths were ranged from 83.83 to146.03 mm, width 9.66 to 41.41 mm and thickness 3.86 to 11.11 mm. The stalk length, width and crown height of the fruit ranged from 25.90 to 34.87, 3.03 to 5.64 and 4.11 to 8.43, respectively, these values can be used to fabricate chilli destalking machine. The bulk and true density were observed from 100 to 130 kg/m^3 and 260 to 560 kg/m^3, respectively, these values can be used to design the hopper or in vacuum packing. Colour scales varied from 19.80 to 27.56 for L*, 7.21 to 23.15 for a* and 8.53 to 17.61 for b*, these values may be used to colour graders for grading the chilli based on colour. The hardness of the fruit pod varied from 37 to 198.03 N/mm^2 and for stalk from 32.83 to 127.54 N/mm^2, these values may be used to design size reducing, seed extracting equipment. The terminal velocity (experimental and theoretical) values varied from 3.66 to 9.03 m/s and 5.33 to 10.69 m/s, respectively, these values may be used to design dryers. Co-efficient of friction values for MS, aluminum and for steel varied from 0.46 to 0.65, 0.36 to 0.55 and 0.34 to 0.48, respectively, these values may be used in designing the hopper, conveyors and destalking machines.

■ **KEY WORDS :** Chilli, Destalking, Mechanization, Destemming, Guntur sanam

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India, the largest producer, consumer and exporter of dried chillies in the world with production of 13.76 mt, consumption of 8.8 mt and exports 4.4 million tonne for the year 2017-18 (AMIC, 2019). The red chillies are usually harvested manually at moisture content 65-70% (w.b) which is reduced to 8-12% (w.b) through drying process in order to extend their shelf-life upto 24 months (Kaleemullah and Kailappan, 2006 and Chetti *et al*., 2014). Subsequently, the dried chillies are subjected to various unit operations such as sorting, grading, destalking ordestemming, size reduction and/or seed extraction, packaging etc. In India, the sorting and grading are labour-oriented and requires intensive operation (Akila *et al*., 2019). Whereas, destalking of chilli is carried out at the trader's level manually. It is estimated that it requires about 106 lakh labour days to handle the country's total chilli production of 16 lakh metric tons). This time-consuming operation creates stockpile during harvest season and creates glut for marketing. This causes many processors to ground the chilli into powder without destalking, adulteration deteriorating in its quality (Jalgaonkar and Mahawar*,* 2017). Mean while, development of chilli seed extraction technology through machineries has been placed under top preference by Indian National Commission on Women to reduce drudgery on farm women (Alam, 2006). The above constraints or non-mechanization may be some of the reasons resulting in post-harvest losses in the chilli which is reported to be 15-40 per cent (Rajendra and Saxena, 2009). Thus, mechanization in processing red chilli remains a challenge. However, technical intervention in mapping the post-harvest management of chilli not only gauges the degree of losses but also establishes link between distinct value chain constraints with respective post-harvestlosses and their limitations. Post-harvest handlings at farm level and shelf-life issues at distribution level were identified as vulnerable hot-spots under processing losses (Srinivas *et al.,* 2018). Improved varieties of chilli and production systems combined with precise postharvest techniques can reduce waste and maximizes the produce, which ultimately can increase the supply of fresh dry chilli in markets and for processing industries. The level of stress that the crop endures in the field will influence yield, pungency, fruit colour, diseases and ultimately, postharvest quality. Hence, all unit operations beginning from the harvesting to packing at field level decides the commercial value of the produce. The present study aimed to determine and recognize a database of some engineering properties of popular chilli cultivars of India which play an important role in designing and developing specific machines that are involved in unit operations for dry chilli.

■ METHODOLOGY

Representative samples of six dried chilli varieties (Byadgi , Guntur sanam, Mathania, Kashmiri, Rehsam Patti and Teja) were procured from local market, Udaipur, Rajasthan, India. The 50 fruit from each variety were evaluated in the department of Processing and Food Engineering, CTAE, MPUAT of Udaipur, Rajasthan, India. Foreign matters in the form of discolored, broken chilli were removed and uniformly oven dried before subjecting for evaluation. Fig. 1 shows the photographs of six chilli cultivars under study.

Physical attribute measurements:

The moisture content (MC, % w.b) of chilli was determined by using dry oven method. The chilli mass (M, g) was recorded by an electronic balance (with an accuracy of 0.01 g). Linear dimensions of whole chilli such as length (L, mm), width (W, mm), thickness (T, mm), stalk length (S_l, mm), Stalk width (S_w, mm) and Crown height (C_h, mm) were measured by using a digital caliper gauge with a sensitivity of 0.01 mm. The arithmetic mean (Da, mm), geometric mean diameter (D_g, mm), surface area (S, mm^2), spericity index (Φ, %) and size (δ, mm) were calculated using the equations 1 to 5, respectively (Mohsenin, 1980; Song and Litchfield, 1991 and Fathollahzadeh *et al.,* 2008).

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

$$D_g = (LWT)^3 \quad ....(2)$$

$$S = \pi D_g^2 \quad ....(3)$$

$$\Phi = \frac{D_g}{L} \quad ....(4)$$

$$\delta = (LWT)^{0.33} \quad ....(5)$$

Gravimetric properties:

The true density (ρ_t), which is defined asthe ratio of the mass of a sample to its solid volume was determined by using the liquid displacement method using pycnometer and toluene (Caparino *et al.*, 2012) whereas, bulk density (ρ_b) of chilli determined based on the volume occupied by the bulk sample using the standard hectometer method (Carman, 1996; Konak *et al.,* 2002 and Tabil *et al.*, 1999). Subsequently using eq. 6, porosity (P, %) was calculated (Dash *et al.,* 2008).

$$P = \left(1 - \frac{\rho_b}{\rho_t}\right) x\,100 \quad ....(6)$$

Colour property:

Colour measurement was done using a Hunter colorimeter D25 optical sensor (Hunter Associates Laboratory, VA, USA) on the basis of 3 variables (L^*,

a^*, b^* value). The L^* value signifies the lightness (100 for white and 0 for black), a^* value represents greenness and redness (-80 for green and 80 for red), whereas, the b^* value signifies changes from blueness to yellowness (-80 for blue and 80 for yellow).

Aero-dynamic properties:

An experimental setup containing vertical air tunnel with a glass tube connected to blower wasused to determine terminal velocity. 5 dry chillies from each variety were randomly selected for measurement. The chilli samples were placed on a mesh screen in vertical tube. The air velocity of blower was adjusted by the regulator until the chilli began to float. The air velocity near where the chilli became suspended was measured with digital anemometer having a least count of 0.1 m/s. Terminal velocity (theoretical, $V_{t(t)}$ and experimented $V_{t(e)}$ of aerodynamic properties of dry chillies were determined and compared theoretical valueusing eq. 7 and 8 (Gorial and O' Callaghan, 1990).

$$[Vt_{(t)}]^2 = \frac{4g\, D_e \rho_t \left(\frac{6z}{\pi}\right)}{3\rho_a\, 0.44} \quad \text{.... (7)}$$

$$Z = \frac{\pi}{6}\left(\frac{D_e}{D_g}\right)^3 (\Phi) \quad \text{....(8)}$$

where; $V_{t\,(t)}$ = The theoretical terminal velocity in m/s, g = Gravitational acceleration in m/s^2 (ρ_a= True density of air in kg/m^3, z = Shape factor, $V_{t(e)}$= Terminal velocity experimentally measured in m/s.

Mechanical property:

The textural properties (Hardness) was evaluated using TA. HD plus textural analyzer (Stable Micro System; Version: 07, 13 H; load cell 250N), detection precession >0.015%, detecting stroke 20 cm, detection speed 0.1-500 mm/min and method used: compression (Shi *et al.,* 2017).

Frictional property:

The co-efficients of static friction on three different frictional surfaces, namely stainless steel, mild steel, Aluminium were measured for chilli using the inclined plate method (Al-Maima and Ahmad, 2002). The friction tests were replicated 20 times for each surface. The co-efficient of static friction was calculated from the eq.9.

$$\mu_s = \tan\theta \quad \text{....(9)}$$

where, μ_s was the static co-efficient of friction and θ (deg) was the tilt angle of the friction device.

Proportion of chilli components :

20 randomly selected dry chilli fruit were weighed for individual components *i.e.,* stalk (Ss), seed (Sd) and pod (Sp). The proportionate of dry chilli components are expressed in percentage and were calculated by dividing the mass of each part of the component to the whole mass of the fruit.

Statistical analysis:

Results from replications of all cultivars were expressed as mean ± standard error and were subjected a variance analysis (ANOVA) using SPSS 16.0. Significance between observed means were determined by Ducans Post hoc multiple comparisons. Significance was accepted at $p \leq 0.05$.

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Geometrical attributes :

The geometrical properties of all chilli cultivar at comparable moisture content are presented in the Table 1. The determination of moisture content is an important criteria as it influences crop processing and other physical attributes (Ilori *et al*., 2010).

The moisture content was ranged from 7.26 to 8.98 per cent, it can be observed that varieties differed in geometrical properties. The average whole chilli length

A: Guntur Sanam, B: Byadgi, C: Teja, D: Reshampatti, E: Mathania F: Kashmiri

Fig. 1 : Different chilli varieties

was highest in Mathania (146.03 mm) and lowest in Teja (83.33 mm), while width and thickness were highest in Reshampatti (41.41, 11.11 mm) and lowest in Teja (9.66, 3.86 mm), respectively. Whereas, stalk length and stalk thickness were highest for Kashmiri variety (34.87, 5.64 mm) and were lowest for Teja variety (25.90, 3.03 mm), respectively. The AMD was found to be highest in Mathania and lowest in Teja variety, whereas GMD, surface area and spericity index were found to be highest in Reshampatti and lowest in Teja variety and among all varieties Reshampatti was larger in size and Teja was smaller.

Colour property:

Depending on the variety, chilli may vary in colour from dark blackish red to orange yellow. The red colour in chilli is due to the presence of cartenoid pigments like capsanthin (major pigment 35%), as shown in Table 1, colour value was graded as L^*-White to black (100-0), a^*-red (+a) to green (-a), b^*-yellow (+b) to blue (-b). The given samples had values of L as 19.80 to 27.56, indicating darker the colour. Similarly, values of a* as (+7.21 to +23.15) indicating the richness of red colour. Likewise, values of b^*ranged between (+8.53 to +17.61) in the all varieties. L^* values in the Table 3 shows that there is no much significance difference exits between varieties expect Kashmiri variety. These colour values confirms that all the samples had bright red with relative yellow colour recommended by BIS (IS 2322:1998).

Gravimetric properties:

Among the varieties, the mean values for bulk

Table 1: Some of the physical attributes of different chilli varieties

Parameters	Varieties							
	Byadgi	Guntur sanam	Mathania	Kashmiri	Rehsam patti	Teja	F value	P value
Mc (%)	7.26 ± 0.46^{b}	8.98 ± 0.34^{c}	8.71 ± 0.17^{bc}	7.60 ± 0.64^{ab}	7.94 ± 1.13^{abc}	8.11 ± 0.89^{abc}	2.70	0.07^{NS}
L (mm)	126.64 ± 2.7^{d}	109.40 ± 14^{bc}	146.03 ± 4.6^{e}	122.54 ± 4.8^{cd}	106.82 ± 7.84^{b}	83.83 ± 4.26^{a}	24.16	0.000^{S}
W (mm)	16.96 ± 0.92^{b}	16.72 ± 2.88^{b}	18.92 ± 1.35^{b}	25.36 ± 5.08^{c}	41.41 ± 3.15^{d}	9.66 ± 0.49^{a}	45.57	0.000^{S}
T (mm)	9.16 ± 1.00^{c}	6.30 ± 0.64^{b}	6.81 ± 0.89^{b}	9.00 ± 1.00^{c}	11.11 ± 0.23^{d}	3.86 ± 1.16^{a}	24.26	0.000^{S}
S_l (mm)	33.21 ± 3.0^{bc}	27.55 ± 4.4^{ab}	32.03 ± 3.5^{bc}	34.87 ± 2.6^{c}	28.23 ± 3.78^{ab}	25.90 ± 0.55^{a}	3.65	0.031^{S}
S_t (mm)	4.8 ± 0.71^{bc}	3.06 ± 3.06^{a}	4.33 ± 0.68^{b}	5.64 ± 0.35^{c}	4.78 ± 0.79^{bc}	3.03 ± 0.02^{a}	10.84	0.001^{S}
C_h (mm)	7.6 ± 1.3^{bc}	8.43 ± 0.45^{c}	7.64 ± 0.55^{bc}	6.86 ± 7.48^{b}	4.11 ± 1.09^{a}	4.60 ± 0.04^{a}	14.97	0.000^{S}
Da (mm)	50.92 ± 0.9^{c}	44.14 ± 5.66^{b}	57.25 ± 1.66^{d}	52.30 ± 3.61^{cd}	53.11 ± 3.53^{cd}	32.45 ± 1.94^{a}	21.86	0.000^{S}
Dg (mm)	26.08 ± 0.73^{c}	21.85 ± 2.39^{b}	25.67 ± 0.38^{c}	29.28 ± 3.29^{c}	35.32 ± 1.86^{d}	14.17 ± 1.84^{a}	37.74	0.000^{S}
S (mm^2)	19.65 ± 3.04^{b}	15.11 ± 3.21^{b}	20.69 ± 0.62^{b}	27.16 ± 6.21^{c}	39.24 ± 4.13^{d}	6.38 ± 1.69^{a}	28.40	0.000^{S}
ϕ (%)	0.20 ± 0.0^{b}	0.20 ± 0.01^{b}	0.17 ± 0.0^{a}	0.23 ± 0.02^{c}	0.33 ± 0.01^{d}	0.16 ± 0.01^{a}	76.36	0.000^{S}
ε (mm)	26.87 ± 0.76^{a}	22.48 ± 2.47^{b}	26.43 ± 0.40^{c}	30.20 ± 3.42^{c}	36.48 ± 1.94^{c}	14.52 ± 1.9^{d}	37.68	0.000^{S}
L^*	24.27 ± 2.16^{b}	27.32 ± 0.57^{b}	27.29 ± 3.23^{b}	19.80 ± 2.5^{a}	24.58 ± 2.25^{b}	27.56 ± 2.3^{b}	5.83	0.009^{S}
a^*	16.81 ± 0.49^{d}	13.41 ± 2.25^{c}	22.15 ± 0.93^{e}	10.19 ± 2.04^{b}	7.21 ± 0.91^{a}	23.15 ± 3.13^{e}	63.71	0.000^{S}
b^*	12.05 ± 1.69^{b}	9.4 ± 1.15^{a}	13.20 ± 1.42^{b}	8.53 ± 1.45^{a}	11.94 ± 1.18^{b}	17.61 ± 1.5^{c}	29.81	0.000^{S}

NS = Non-significant

Table 2 : Shows the gravimetric properties of different chilli varieties

Parameters	Varieties							
	Byadgi	Guntur sanam	Mathania	Kashmiri	Rehsam patti	Teja	F value	P value
ρ_b (g/cc)	0.06 ± 0.0^{a}	0.13 ± 0.03^{c}	0.08 ± 0.01^{ab}	0.1 ± 0.0^{bc}	0.1 ± 0.0^{bc}	0.12 ± 0.02^{c}	6.66	0.006^{S}
P (%)	88.26 ± 0.47^{c}	50.51 ± 15.07^{a}	81.67 ± 8.9^{c}	79.63 ± 3.20^{c}	61.24 ± 8.14^{ab}	74.95 ± 6.5^{bc}	8.43	0.001^{S}

Table 3: Experimental and theoretical terminal velocity values of chilli varieties

Parameters	Varieties							
	Byadgi	Guntur sanam	Mathania	Kashmiri	Rehsam Patti	Teja	F value	P value
$V_{t(t)}$ (m/s)	5.66 ± 1.05^{b}	3.66 ± 0.86^{a}	5.03 ± 1.72^{ab}	9.03 ± 0.70^{c}	6.46 ± 0.6^{b}	5.8 ± 0.51^{b}	13.74	0.000^{S}
$V_{t(e)}$ (m/s)	5.41 ± 0.6^{a}	5.83 ± 0.69^{ab}	5.47 ± 1.11^{a}	10.69 ± 1.98^{c}	6.94 ± 0.82^{b}	5.33 ± 0.69^{a}	26.07	0.000^{S}

density (ρ_b, kg/m^3) was highest in Guntur sanam chilli (130) followed by Teja (120), Mathania (80), Byadgi (60), Reshampatti and Kashmiri chilli (10). Similarly porosity (P, %) was higher in Byadgi (88.26%) followed by Mathania (81.67%), Kashmiri (79.63%), Teja (74.95%), Reshampatti (61.24%) and Guntur (50.51%). Table 2. Shows the gravimetric properties of different chilli varieties. Mahawar and Jalgaonkar (2017) reported similar findings. The higher porosity could be due to presence of more void spaces between chilli fruit and also may bedue to cell structures (Correa *et al*., 2007). Bulk density, true density and porosity are major considerations in designing aeration systems, near-ambient drying and in designing airflow rate of stored mass (Bern and Charity, 1975). These theories are also used to predict the structural loads in storage structures with bulk density as a basic factor (Lvin, 1970).

Aerodynamic property:

The experimental and theoretical terminal velocity of chilli varieties used in the study is shown in Table 3. The Kashmiri variety had highest average experimental and theoretical value 10.69 and 9.03 m/s, respectively. Whereas, lowest experimental value was found for Teja variety with 5.33 m/s and theoretically lowest was for Guntur sanam variety with 3.66 m/s. The difference in experimental and theoretical values may be due to irregular shape and their rotationin the air stream. The Aerodynamic property of chilli can be utilized in designing dryers, threshers, cleaning and grading equipment.

Mechanical and frictional property :

Hardness of fruit was found to be highest in Kashmiri followed by Reshampatti, Teja, Byadgi, Mathania and Guntur sanam with hardness value of 198.03, 157.96, 61.31, 45.05, 40.44, 37 N/mm^2, respectively. Whereas, hardness of stalk was found to be highest in Mathania followed by Byadgi, Kashmiri, Reshampatti, Guntur sanam and Teja with hardness value of 127.54, 119.42, 78.10, 71.46, 66.06 and 32.83 N/mm^2, respectively. Hardness of the both fruit and stalk varied comparatively, the hardness of fruit is used in designing size reduction equipments and whereas, hardness of stalk in designing destalking machine.

It was observed that the roughness of mild steel surface gave ahigher resistance against flow than that of aluminum and steel which were smoother and thus, co-efficient of friction is lesser in these two materials than MS. The value ranged from 0.46 to 0.65 for MS, 0.36 to 0.55 for aluminum and 0.34 to 0.48 for steel. These properties are used in designing hopper, destalking machine and cleaning unit. The values of hardness and co-efficient of friction are presented in Table 4.

Proportion of chilli components:

As shown in Table 5. Among the chilli varieties the fruit content (pod) was highest in Byadgi (85.91%), seed content in Teja (60%) and stalk content in Reshampatti (6.72%). The similar findings were reported by (Bidari *et al.,* 2009 and Mahawar and Jalgaonkar, 2017). These in for mation are useful in producing the seed extracting

Table 4 : Hardness and co-efficient of static friction of different varieties of chilli

Parameters	Varieties							
	Byadgi	Guntur	Mathania	Kashmiri	Rehsam Patti	Teja	F value	P value
μ_s (MS)	0.54±0.06^{ab}	0.50±0.08^{a}	0.65±0.08^{b}	0.57±0.00^{ab}	0.46±0.07^{a}	0.48±0.06^{a}	3.83	0.03^{NS}
μ_s (Aluminum)	0.48±0.03^{b}	0.38±0.04^{a}	0.38±0.04^{a}	0.55±0.04^{b}	0.36±0.64^{a}	0.36±0.05^{a}	7.45	0.04^{NS}
μ_s (Steel)	0.38±0.02^{ab}	0.36±0.02^{a}	0.48±0.08^{b}	0.48±0.08^{b}	0.44±0.02^{ab}	0.34±0.05^{a}	3.55	0.04^{NS}
Hardness (Fruit)	45.05±2.15^{ab}	40.44±6.12^{a}	37.00±7.2^{a}	198.03±12.2^{d}	157.96±22.1^{c}	61.31±2.68^{b}	145.41	0.000^{S}
Hardness (Stalk)	119.42±3.2^{d}	66.06±5.95^{b}	127.54±14.7^{d}	78.10±2.17^{c}	71.46±1.85^{bc}	32.83±2.75^{a}	105.04	0.000^{S}

NS=Non-significant

Table 5: Proportion of chilli components

Parameters	Varieties							
	Byadgi	Guntur	Mathania	Kashmiri	Rehsam Patti	Teja	F value	P value
Stalk content (%)	2.10±0.72^{a}	3.62±0.30^{b}	3.43±0.60^{ab}	3.91±0.77^{b}	6.72±0.68^{c}	3.33±0.6^{ab}	16.34	0.000^{S}
Seed content (%)	11.96±1.43^{a}	20.19±1.57^{bc}	21.27±3.14^{bc}	23.53±3.0^{c}	17.60±1.94^{b}	60±3.84^{d}	143.24	0.000^{S}
Pod content (%)	85.91±5.04^{c}	76.16±2.21^{b}	75.38±0.80^{b}	72.55±2.03^{b}	75.68±2.91^{b}	36.67±3.05^{a}	90.59	0.000^{S}

equipments; value added products such as chilli powder, oleoresin etc. and also in deciding the market value of the chilli and its products.

Conclusion:

This study researched the engineering properties of six different varieties of chilli *viz.,* Byadgi, Guntur sanam sanam, Mathania, Kashmiri, Rehsampatti and Teja. The statistical analysis for individual property showed that the existence of significant difference ($p<0.05$) between all six chilli varieties. The information on engineering properties of dry chill paves a way for technical intervention in design and development of various technologies that are used in unit operation for chilli varieties, which in turn minimizes post-harvest losses and helps in revenue generation to farmers, processors and exporters.

Conflicts of interest:

Authors declare no conflicts of interest and any financial competitiveness for the present work. The research is an original work neither published nor under consideration for publication anywhere.

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