Original Research Article

An Investigation on the effect of Moisture Content on the Engineering Properties of Cotton Seed for Pneumatic Planter Design

ABSTRACT

Aim: The aim of this investigation was to analyze the physical, gravimetric, frictional, aerodynamic, and mechanical characteristics of cotton seeds at three different moisture content levels, ranging from 8% to 14% on a dry basis to develop a power tiller-operated pneumatic planter.

Study design: Completely Randomized Design and Tukey pairwise test in done on the SAS OnDemand for Academic platform was used for the study.

Place and Duration of Study: Department of Farm Machinery and Power Engineering (FMPE), Department of Agricultural Processing and Food Engineering (APFE) and Department of Agricultural Structures Civil and Environmental Engineering (ASCEE), College of Agricultural Engineering and Technology (CAET), Odisha University of Agriculture and Technology (OUAT), between July 2022 and August 2022.

Methodology: This study was conducted to determine the engineering properties of cotton seeds namely BS–279, RCH–659 and KCHH–2739 as a function of moisture content. The different properties of these cotton seeds were studied in the engineering property laboratory and UTM laboratory of the CAET, OUAT, Bhubaneswar. The objective of this study was to investigate some moisture-dependent physical, gravimetric, frictional, aerodynamic, and mechanical properties of cotton seeds. The aim of this investigation was to analyze the physical, gravimetric, frictional, aerodynamic, and mechanical characteristics of cotton seeds at three different moisture content levels, ranging from 8% to 14% on a dry basis. These moisture content levels were referred to as M_1 (8-10%), M_2 (10-12%), and M_3 (12-14%).

Results: The geometric mean diameter, sphericity, aspect ratio, thousand seed weight, angle of repose and terminal velocity were found to be in the range of 5.05–6.57 mm, 60–67%, 0.51–0.59,78.70–103.67 g, 39.75–44.75° and 9.26–13.28 ms^{-1} respectively as moisture content of seed increased from 8 to 14% dry basis. The mean diameter, volume, porosity, terminal velocity and coefficient of friction showed a positive correlation with the moisture content. The bulk density, true density and porosity of seed decreased from initial range of 637.82–696.12 to 524.12–607.60 kgm^{-3}, 1155.00–1266.12 to 868.28–1007.60 kgm^{-3} and 43.23–44.96 to 39.75–41.55% respectively with an increase in moisture content. Rupture force was found to be negatively correlated with moisture content and loading rate.

Conclusion: The effect of moisture content on all dependent parameters was found to be significant (α=0.05) under Tukey pair wise test but these were non-significant for the varieties of cotton seeds considered under the study. These engineering properties can be considered while designing of planters and other sowing machinery, harvesters, ginning, and oil extraction machines of cotton seed.

Keywords: Cotton seed, Engineering properties, Pneumatic planter

1. INTRODUCTION

Cotton, scientifically known as Gossypium and commonly referred to as the white gold of India due to its significant economic value, is cultivated in various regions across the globe. It serves as a valuable source of edible vegetable oil, fiber, and feed in the form of oil cake. The seeds of cotton contain approximately 12-20% oil and 40-43% protein [21]. India stands as the world's foremost country in cotton production, with a vast area of 13.35 million hectares dedicated to cotton cultivation, accounting for 41% of the global cotton-growing region. In terms of output, India holds a prominent position, producing 2.9 million bales of 480 pounds (equivalent to 3.71 million bales of 170 kg). However, the productivity per hectare in India still lags behind that of many other major cotton-producing nations [3].

Cotton represents approximately 65% of the total raw material demand in the Indian textile industry. The properties of this agricultural material are crucial in designing appropriate machinery and equipment for various processes such as planting, harvesting, transportation, processing, and storage. Hence, it is essential to ascertain its engineering properties in relation to moisture content. Size and density play a significant role in effectively separating seeds from unwanted materials using oscillating chaffers. Sphericity aids in designing hoppers and decorticating equipment for the nut [19].

Bulk density and porosity are critical properties in developing aeration and drying systems, as they impact the airflow resistance within the stored mass [32]. The angle of repose and coefficient of friction are valuable for determining the ideal inclination of seed hoppers in sowing machinery, ginning machines, silos, and storage containers, ensuring smooth sliding. The coefficient of friction between the seed and the wall is a significant parameter for estimating seed pressure on walls [2]. Additionally, this characteristic aids in selecting suitable materials for seed hoppers. Porosity affects the airflow resistance in bulk material beds, and data on this property are necessary for designing drying processes [6].

Rupture force is a beneficial characteristic for seed oil extraction, while pneumatic conveying characteristics such as terminal velocity play a crucial role in handling and processing the product. They can be utilized in the design of air screens, cleaning and grading equipment [14]. Mechanical properties like stress, strain, hardness, and compressive strength are vital for engineers working with agricultural products. These properties help determine the power requirements for different operations and ensure efficient handling and processing [13].

The objective of this study was to investigate some moisture-dependent physical, gravimetric, frictional, aerodynamic, and mechanical properties of cotton seeds to develop a power tiller-operated pneumatic planter.

2. MATERIALS AND METHODS

In Odisha and across India, several high-yielding and hybrid cotton varieties, including BS-279, RCH-659, and KCHH-2739, are commonly cultivated. A sample of BS-279 cotton seeds was obtained from AICRP on cotton in Bhawanipatna, Odisha, while RCH-659 and KCHH-2739 seeds (Fig 1) were acquired from authorized seed suppliers. These seeds were thoroughly delinted, ensuring their purity and absence of impurities, and were selected for laboratory analysis.

The different properties of these cotton seeds were studied in the engineering property laboratory and UTM laboratory of the College of Agricultural Engineering and Technology, OUAT, Bhubaneswar. The aim of this investigation was to analyze the physical, gravimetric, frictional, aerodynamic, and mechanical characteristics of cotton seeds at three different moisture content levels, ranging from 8% to 14% on a dry basis. These moisture content levels were referred to as M_1 (8-10%), M_2 (10-12%), and M_3 (12-14%). The physical properties of the cotton seeds, including length, width, thickness, geometric mean diameter, volume, and sphericity, were examined. Gravimetric properties such as thousand seed weight, bulk density, true density, and porosity were measured. Frictional properties, namely the angle of repose and static coefficient of friction, were evaluated by testing the seeds against two different metal surfaces, namely galvanized iron (GI) sheet and mild steel (MS) sheet. Furthermore, the aerodynamic property of terminal velocity and the mechanical property of rupture force were determined.

BS-279 **RCH-659** **KCHH-2739**

Fig. 1 Varieties of cotton seed

2.1 Moisture content

The initial moisture content of the seeds was determined using a digital moisture meter (Indosaw, Universal 9800 model) that operates based on the principle of electrical conductivity of the material, which is directly proportional to the moisture percentage. For each test, 30 grams of seeds (as per instrument calibration) were evaluated using the digital moisture meter, and the process was repeated three times to ensure accuracy [22].

Recognizing the significance of moisture in the properties of agricultural materials, one kilogram of each cotton variety was conditioned to study three different levels of moisture content ranging from 8% to 14%. The moisture content was adjusted using Equation (1) as outlined by Sutar *et al.,* [29].

$$W_1(100+M_f) = W_2\,(100+M_i) \qquad (1)$$

Where W_1 and W_2 are initial and final weight of the sample, g and M_i and M_f are initial and final moisture content of the sample, % db respectively. To achieve the desired moisture content, the re-wetted seed lots were carefully sealed in high molecular high-density polyethylene bags (100 micron thickness) measuring 40 x 30 cm. These bags were then placed inside wet gunny bags and left at room temperature for a duration of six hours. Subsequently, the seed lots were conditioned in a refrigerator maintained at a temperature of 5 ± 2ºC for a period of 10 days [17]. Throughout this period, the seeds were periodically stirred at intervals of two days to ensure uniform distribution of moisture. A similar rewetting technique for achieving specific moisture content in seeds and grains has been employed by Jadhav *et al*., [10]; Sakare *et al.,* [25]; Shelake *et al.,* [27].

2.2 Physical properties

100g of cotton seeds were selected at random from the bulk sample for the three moisture levels of 8-10%, 10-12% and 12-14%. The required number of seeds were selected for each moisture level and it was used to evaluate the following physical properties of the three varieties of cotton seed viz. BS-279, RCH-659 and KCHH- 2739 for the study.

<u>2.2.1 Size</u>

The size of a seed is typically described by its length (l), width (w), and thickness (t). Previous literature has demonstrated that these axial dimensions, including length, width, and thickness, are commonly measured using vernier calipers or micrometer screw gauges [10, 12, 25]. In the present study, the axial dimensions of the seeds at different moisture levels were measured using a vernier caliper (make: Kristeel; model: 2914; least count: 0.02 mm). The geometric mean diameter (GMD) of the seed was determined using Equations (2) provided by Mohsenin [17], which were also used by Ajav and Fakayode [1] and Jadhav *et al.,* [10]. The GMD holds significance in the design of pneumatic planters, as the orifice sizes should be equal to or smaller than 50% of the GMD [28]. To determine the size, a total of 20 observations were recorded for each type of seed. GMD was determined using following relation,

Geometric mean diameter (D_g) = $\sqrt[3]{lwt}$ (2)

where l = length (maximum diameter), w = width (intermediate diameter) and t = thickness (minimum diameter) of seeds, in mm.

2.2.2 Shape

Sphericity (Ø) and aspect ratio of seed samples were determined using Eqs. 3 and 4 given by Mohsenin [17] and Jadhav *et al.,* [9] respectively.

Sphericity (Ø) = $\left(\sqrt[3]{lwt}/l\right) \times 100$ (3)

Aspect ratio = (w/l) (4)

2.2.3 Volume

Volume of the single seed was calculated by using Eqs. 5 [4, 5, 30].

Volume (v) = $\frac{\pi}{6}(lwt)$ (5)

Where, v = volume, mm^3

2.3 Gravimetric Properties

2.3.1 Thousand Seed Weight

A digital seed counter (make: Wiswo; max count: 9999) that operates on the basis of electromagnetic vibrations and optoelectronics was used to collect five random samples of 1,000 seeds of three distinct varieties. By using a digital weighing balance (brand: Wensar; model: PGB 1000; accuracy: 0.01 g), the samples that had been counted were then weighted. The count of the samples was manually checked as well [9].

2.3.2 Bulk Density

For the determination of bulk density, the samples were placed in a container with a known volume and weighed using a digital weighing balance (make: Wensar; model: PGB 1000; accuracy: 0.01 g). The bulk density of the seeds was then calculated by dividing the weight of the seeds in the container (in kilograms) by the volume of the container (in cubic meters). This method of calculating bulk density is consistent with the approach utilized by Jadhav *et al*., (9) and Sakare *et al*., [25]. To ensure accuracy, the experiment was replicated five times for each type of seed sample, following the expression specified in Equation (6) as adopted by Sharma *et al*., [26].

Bulk density (ρ_b) = $\frac{Ws}{V} \times 100$ (6)

Where ρ_b= Bulk density of seeds, kg/m^3; W_s= Weight of the seed, kg; V = Bulk volume occupied by the sample, m^3.

2.3.3 True Density

True density indicates the density of seeds neglecting the pore spaces between them. It was determined by the toluene displacement method [16]. Toluene filled in measuring cylinder was displaced by known weight of seed sample to obtain true weight (kg) per unit volume (m^3). Five replications for each type of seed sample were carried out using Eqs. (7).

True density (ρ_t) = $\frac{Ws}{Vt} \times 100$ (7)

where, ρ_t = true density, kgm^{-3}; V_t = true volume of seed, m^3

2.3.4 Porosity

Porosity is the portion of seed bulk not occupied by the seeds. It can be determined if bulk and true density are known using following Eqs. (8) [16].

$$\text{Porosity } (\eta) = \frac{\rho t - \rho b}{\rho t} \times 100 \qquad (8)$$

where, η = porosity, %

2.4 Frictional Properties

2.4.1 Angle of Repose

The angle of repose represents the incline formed by the seeds when heaped on a horizontal surface (forming a cone shape). The angle of repose was determined by employing a setup described in the literature [16], which involved a circular base with a funnel for releasing seeds from a specified height. To ensure accuracy, five replications were conducted for each type of seed sample.

$$\text{Angle of repose } (\Theta) = tan^{-1}(2 \quad /d) \qquad (9)$$

Where, ϴ = Angle of repose, Degrees (˚); h = height of cone formed by seeds, mm; d = diameter of the base of cone formed by seeds, mm.

2.4.2 Static Coefficient of Friction (µ)

Coefficient of friction is expressed as ratio of the frictional force (F) to the normal force (N) acting on the contact surface [12]. The coefficient of friction for the same material differs with different platforms. Hence, coefficient of friction of cotton seed samples was determined on GI sheet and MS sheet with five replications.

2.5 Aerodynamic Property

Terminal Velocity

Terminal velocity is one of the important aerodynamic properties of agricultural materials as far as design of airflow-related equipment is concerned. It is an important parameter and considered in calculating air suction needed in the metering device in pneumatic planter. Terminal velocity was measured by putting the seeds in vertical column at the bottom of which airflow was provided using electric blower [9, 24]. Digital anemometer (make: HTC; model: AVM-06; least count: 0.01 ms^{-1}) was used to record terminal velocity i.e. air velocity at which seeds were in suspension. Ten replications were taken for the determination of terminal velocity with each variety of seeds.

2.6 Mechanical Property

2.6.1 Rupture force

The mechanical property namely, rupture force was determined using following standard procedures. A Universal Testing Machine (make: Tinius Olsen; model: H5KT; accuracy: 0.1 N) was utilized for determination of the rupture force. Seeds of three varieties of cotton at three different moisture content levels at three different loading rates were loaded individually in the loading platform of the machine and compressed until rupture occurred as indicated by a bio-yield point in the force-deformation curve. Once the bio-yield was detected, the loading was stopped [1, 13, 18].

2.7 Statistical analysis for pair wise comparison of engineering properties of cotton seed

SAS 9.3 software was used to carry out ANOVA and pairwise comparison using Tukey test. Data presented in mean ± standard deviation (SD). It was analysed and checked for their significance at $p \leq 0.05$ and $\alpha = 0.05$ for ANOVA and pairwise comparison test respectively.

3. RESULTS AND DISCUSSION

The result of experiments that have been carried out for determining various properties viz. physical, gravimetric, frictional, aerodynamic and mechanical properties of three varieties of cotton seeds at three different levels of moisture content ranges have been discussed under different headings and sub-headings.

3.1 Physical properties of cotton seeds

The results of the physical properties of cotton seeds like size and shape have been discussed below.

3.1.1 Size

Length, width, thickness, geometric mean diameter (GMD) and volume of cotton seeds were studied under three levels of moisture content ranges viz. M_1 (8–10), M_2 (10–12) and M_3 (12–14), % db. The details of the statistical parameters for physical properties are shown in Table 1. It is observed that due to increase in moisture level from 8 to 14 % db, the length of cotton seeds increased from 8.36±0.43 to 9.16±0.75 mm, 8.67±0.22 to 9.58±0.41 mm and 8.77±0.72 to 10.2±0.50 mm for BS-279, RCH-659 and KCHH-2739 varieties respectively. The width for these three varieties also increased from 4.29±0.24 to 5.29±0.70 mm, 4.60±0.37 to 5.14±0.37 mm and 4.36±0.74 to 5.58±0.55 mm, respectively in that order. Following the similar trend, thickness increased from 3.58±0.33 to 4.48±0.33 mm, 3.88±0.42 to 4.60±0.23 mm, 4.26±0.55 to 4.80±0.49 mm respectively for those varieties. It is evident from the Table 2 that physical parameters of all the varieties of cotton seeds are positively correlated with the moisture content. Increasing the moisture content from M_1 to M_3, the GMD increased from 5.04±0.30 to 6.00±0.48 mm, 5.36±0.25 to 6.44±0.16 mm and 5.80±0.46 to 6.87±0.22 mm for the varieties BS-279, RCH-659 and KCHH-2739 respectively. These properties are important in the determination of the volume of seeds at various moisture levels. In same order due to increase in moisture content their corresponding volume for BS-279, RCH-659 and KCHH-2739 were ranged from 67.65±12.16 to 114.86±28.21 mm^3, 81.00±11.86 to 102.34±9.18 mm^3 and 85.68±20.04 to 142.69±14.64 mm^3 respectively. The results are in congruence with the findings of Asadzadeh [14] and Sutar *et al*., [29]. The GMD value is important to specify the orifice size of pneumatic planter. Orifice size of metering plate of the pneumatic planter should be 50% of GMD [15, 28]. According to these studies, orifice size for cotton seeds should be equal or less than 2.88±0.26 mm, for satisfactory operation of pneumatic planters.

3.1.2 Shape

In the present study, sphericity and aspect ratio of seeds were considered as shape parameters. Sphericity and aspect ratio of BS-279, RCH-659 and KCHH-2739 increased with an increase in moisture content (Table 1). The values of sphericity increased from 60.30±1.55 to 65.62±3.75 %, 61.84±2.75 to 64.18±1.29 % and 62.10±3.40 to 63.50±4.48 % for BS-279, RCH-659 and KCHH-2739 varieties respectively. The results are in congruence with the findings of the studies conducted by Sutar *et al.,* [29] and Kilickan and Guner [14]. Corresponding values of aspect ratio are also increasing from 0.51±0.02 to 0.58±0.06, 0.53±0.04 to 0.54±0.06 and 0.50±0.10 to 0.55±0.07 for BS-279, RCH-659 and KCHH-2739 varieties respectively.

Table 1 Statistical parameters for physical, gravimetric, frictional, aerodynamic andmechanical properties of cotton seeds

Properties	Seed Property		BS-279 M$_1$	BS-279 M$_2$	BS-279 M$_3$	RCH-659 M$_1$	RCH-659 M$_2$	RCH-659 M$_3$	KCHH-2739 M$_1$	KCHH-2739 M$_2$	KCHH-2739 M$_3$
Physical	l	Mean	8.36	8.60	9.16	8.67	9.18	9.58	8.77	9.58	10.23
		SD	0.43	0.43	0.75	0.22	0.67	0.41	0.72	0.26	0.50
		CV	5.18	5.00	8.22	2.53	7.28	4.26	8.23	2.70	4.88
	w	Mean	4.29	4.87	5.29	4.60	4.90	5.14	4.36	5.08	5.58
		SD	0.24	0.24	0.70	0.37	0.19	0.37	0.74	0.46	0.55
		CV	5.61	4.94	13.24	8.13	3.81	7.14	16.97	8.97	9.78
	t	Mean	3.58	3.88	4.48	3.88	4.54	4.60	4.26	4.56	4.80
		SD	0.33	0.33	0.33	0.42	0.37	0.23	0.55	0.36	0.49
		CV	9.34	8.62	7.47	10.84	8.18	5.09	12.92	7.99	10.31
	GMD	Mean	5.04	5.45	6.00	5.36	5.89	6.09	5.44	6.05	6.48
		SD	0.30	0.23	0.48	0.25	0.37	0.16	0.46	0.27	0.22
		CV	6.03	4.13	8.01	4.73	6.239	2.62	8.46	4.43	3.36
	v	Mean	67.65	85.11	114.86	81.00	107.78	118.30	85.68	116.33	142.69
		SD	12.16	10.45	28.21	11.86	19.42	9.18	20.04	16.15	14.64
		CV	17.980	12.274	24.559	14.642	18.013	7.762	23.391	13.884	10.261
Gravimetric	TSW	Mean	78.17	79.61	83.39	90.27	97.47	102.34	93.22	95.84	98.53
		SD	1.21	0.89	0.89	1.58	0.74	0.78	1.18	2.00	3.14
		CV	1.551	1.119	1.068	1.745	0.763	0.763	1.261	2.090	3.190
	ρ_b	Mean	657.60	637.60	607.60	696.12	607.52	524.12	637.82	598.82	568.82
		SD	38.45	38.45	38.45	10.02	3.23	4.80	6.54	6.54	6.54
		CV	5.847	6.030	6.328	1.440	0.531	0.916	1.025	1.092	1.150
	ρ_t	Mean	1157.60	1087.60	1007.60	1266.12	1040.92	868.28	1155.00	1053.00	974.40
		SD	38.45	38.45	38.45	47.80	32.82	14.66	34.12	34.12	40.06
		CV	3.321	3.535	3.816	3.775	3.153	1.689	2.954	3.240	4.111
	η	Mean	43.23	41.42	39.75	44.96	41.59	39.75	44.75	43.09	41.55
		SD	1.47	1.50	1.56	1.96	1.90	0.28	1.44	1.63	2.27
		CV	3.401	3.626	3.923	4.350	4.576	0.693	3.212	3.777	5.473
Frictional	AoR	Mean	34.72	37.57	39.36	36.06	39.93	41.62	38.74	40.97	41.67
		SD	1.14	1.55	0.95	1.16	1.70	1.16	0.93	1.45	1.36
		CV	3.280	4.118	2.424	3.214	4.264	2.782	2.398	3.544	3.275

	Cof_{GI}	Mean	0.44	0.46	0.49	0.44	0.46	0.49	0.45	0.47	0.49
		SD	0.01	0.04	0.02	0.01	0.04	0.02	0.03	0.05	0.02
		CV	3.251	8.558	4.853	3.251	8.558	4.198	6.786	9.913	4.999
	Cof_{MS}	Mean	0.34	0.36	0.38	0.36	0.33	0.38	0.34	0.37	0.39
		SD	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		CV	3.314	3.642	2.213	3.602	2.532	3.032	3.393	2.274	2.156
Aerodynamic	*TV*	Mean	9.26	10.22	11.68	10.23	12.82	13.82	10.14	11.13	12.84
		SD	0.68	0.50	0.60	0.77	1.13	0.38	0.49	0.66	0.89
		CV	7.388	4.897	5.121	7.560	8.782	2.729	4.828	5.891	6.935
Mechanical	Rf_{10}	Mean	108.54	80.76	61.82	113.84	78.54	55.48	115.16	83.24	59.20
		SD	13.01	2.91	5.25	18.30	5.99	3.32	10.41	6.63	2.76
		CV	11.990	3.604	8.487	16.072	7.629	5.979	9.037	7.966	4.666
	Rf_{20}	Mean	100.26	68.86	48.98	97.52	67.56	47.16	100.54	70.60	48.36
		SD	7.22	4.44	4.55	3.09	5.07	3.27	5.51	3.76	3.31
		CV	7.197	6.444	9.295	3.173	7.508	6.932	5.484	5.332	6.854
	Rf_{30}	Mean	94.40	66.64	38.70	90.26	62.82	36.60	93.22	68.00	30.96
		SD	3.37	4.46	3.30	3.66	4.92	2.08	3.26	6.85	2.71
		CV	3.569	6.695	8.515	4.052	7.830	5.692	3.499	10.073	8.756

3.2 Tukey test results of physical properties of cotton seeds

Tukey comparison for least squares means (LSM) of physical properties for seed varieties and moisture content has been presented in Table 3. As far as the size is concerned length, width, thickness and GMD of RCH-659 and KCHH-2739 are at par but these parameters are found to be different for BS-279 variety wherelength, thickness and GMD are at par, but width is different. The varietal effect on the volume of seed is found to be significant at 5% level of significance. The effect of MC is highly significant for length, width, GMD and volume but in case of thickness it is found to be same for M_2 and M_3 but different for M_1. The effect of varieties and MC are at par for both the shape parameters viz. sphericity and aspect ratio.

3.3 Gravimetric properties of cotton seeds

Gravimetric properties like thousand seed weight, bulk density, true density and porosity of cotton seeds were determined. Statistical parameters, viz. means, standard deviation and coefficient of variation of cotton seeds have been presented in Table 1. Thousand seed weight of BS-279, RCH-659 and KCHH-2739 increased from 78.17±1.21 to 83.39±0.89 mm, 90.27±1.58 to 102.34±0.78 mm and 93.22±1.18 to 98.53±3.14 mm, respectively. Bulk and true densities decreased as moisture content increased from 8 to 14%. The corresponding values decreased from 657.60±38.45 to 607±38.45 and 1157.60±38.45 to 1007.60±38.45 kgm^{-3} for BS-279, from 696.12±10.02 to 524.12±4.80 kgm^{-3} and 1266.12±47.80 to 868.28±14.66 kgm^{-3} for RCH-659 whereas 637.82±6.54 to 568±6.54 kgm^{-3} and 1155.00±34.12 to 974.40±40.06 kgm^{-3} for KCHH-2739 variety. Porosity of the cotton seeds decreased from 43.23±1.47to 39.75±1.56%, 44.96±1.96 to 39.75±0.28% and 44.75±1.44 to 41.55±2.27% with increase in moisture content from 8 to 14% db for the varieties of BS-279, RCH-659 and KCHH-2739 respectively.

From the Table 2, it is observed that thousand seed weight of cotton seeds of all selected varieties are positively correlated while bulk density, true density and porosity are negatively correlated. Similar results were reported by Asadzadeh [4]; Ramesh *et al.* [24] and Sutar *et al.* [29]. Gravimetric parameters are important for theoretical calculations of minimum suction pressure required for seed picking by the pneumatic metering device and also for designing the size of seed hopper [23, 28]. Considering seed rate of 2 kgha^{-1} with field capacity of 0.18 ha h^{-1}, volume of seed box should be around 0.006 m^3 to accommodate 2.16 kg of cotton seeds.

Table 2 Regression equation as a function of moisture content with their respective coefficient of determination for given physical and gravimetric parameters

Properties	Parameter	Variety	Regression Equation	R^2
Physical	Length, mm	BS-279	7.906 + 0.400MC	0.949
		RCH-659	8.230 + 0.456MC	0.995
		KCHH-2739	8.065 + 0.730MC	0.995
	Width, mm	BS-279	3.814 + 0.500MC	0.991
		RCH-659	4.342 + 0.268MC	0.995
		KCHH-2739	3.785 + 0.612MC	0.989
	Thickness, mm	BS-279	3.080 + 0.450MC	0.964
		RCH-659	3.620 + 0.360MC	0.812
		KCHH-2739	4.000 + 0.270MC	0.995
	Geometric Mean Diameter, mm	BS-279	4.538 + 0.479MC	0.992
		RCH-659	5.049 + 0.364MC	0.937
		KCHH-2739	4.950 + 0.519MC	0.990
	Volume, mm^3	BS-279	41.99 + 23.60MC	0.977
		RCH-659	65.05 + 18.65MC	0.940
		KCHH-2739	57.88 + 28.50MC	0.998
	Sphericity	BS-279	57.81 + 2.659MC	0.986
		RCH-659	60.87 + 1.172MC	0.915

		KCHH-2739	61.50 + 0.702MC	0.938
	Aspect ratio	BS-279	0.487 + 0.032MC	0.872
		RCH-659	0.527 + 0.003MC	0.969
		KCHH-2739	0.478 + 0.023MC	0.972
Gravimetric	Thousand Seed Weight, g	BS-279	75.17 + 2.610MC	0.94
		RCH-659	84.62 + 6.035MC	0.987
		KCHH-2739	90.55 + 2.653MC	0.999
	Bulk Density, kgm^{-3}	BS-279	684.2 - 25MC	0.986
		RCH-659	781.2 - 86MC	0.999
		KCHH-2739	670.8 - 34.50MC	0.994
	True Density, kgm^{-3}	BS-279	1234 - 75MC	0.998
		RCH-659	1459 - 198.1MC	0.998
		KCHH-2739	1237 - 90.3MC	0.977
	Porosity, %	BS-279	44.95 - 1.743MC	0.999
		RCH-659	47.02 - 2.497MC	0.977
		KCHH-2739	46.61 - 1.706MC	0.996

Within the rows, mean ± SD

3.4 Tukey test results of gravimetric properties of cotton seeds

Tukey comparison test results for LSM of seed variety and moisture content for gravimetric properties are shown in Table 3.The effect of MC for all the gravimetric properties is found to be significant at 5% level of significance. The effect of varieties is observed to be at par for true density. But thousand seed weight, bulk density and porosity of RCH-659 & KCHH-2739 varieties are at par in pair whereas these parameters are found to be different for BS-279 variety.

Table 3 Tukey comparison for least squares means (LSM) of physical and gravimetric properties for seed variety and moisture content

Properties	Levels	Seed variety			Moisture Content (%, db)		
		BS-279	RCH-659	KCHH-2739	8-10	10-12	12-14
Physical	LSM of length, mm	9.52^{b}	9.14^{a}	8.70^{a}	8.59^{c}	9.12^{b}	9.65^{a}
	LSM of Width, mm	4.81^{a}	4.87^{a}	5.00^{a}	4.41^{c}	4.95^{b}	5.33^{a}
	LSM of thickness, mm	3.98^{b}	4.34^{a}	4.54^{a}	3.90^{b}	4.32^{a}	4.62^{a}
	LSM of GMD, mm	5.45^{b}	5.78^{a}	5.99^{a}	5.28^{c}	5.79^{b}	6.18^{a}
	LSM of volume, mm	89.20^{b}	102.35^{ab}	114.90^{ac}	78.10^{c}	103.07^{b}	125.28^{a}
	LSM of Sphericity	0.63^{a}	0.63^{a}	0.62^{a}	0.61^{a}	0.63^{ab}	0.64^{b}
	LSM of Aspect ratio	0.55^{a}	0.53^{a}	0.52^{a}	0.51^{a}	0.54^{a}	0.55^{a}
Gravimetric	LSM of 1000 seed weight, mm	80.39^{b}	96.69^{a}	95.86^{a}	87.22^{c}	90.97^{b}	94.75^{a}
	LSM of Bulk density, kg/m^3	634.27^{a}	609.25^{b}	601.82^{b}	663.84^{c}	614.64^{b}	566.84^{a}
	LSM of True density, kg/m^3	1084.27^{a}	1058.99^{a}	1060.80^{a}	1192.90^{a}	1060.50^{b}	950.64^{c}
	LSM of Porosity, mm	41.46^{a}	42.10^{ab}	43.13^{ab}	44.31^{a}	42.03^{b}	40.34^{c}

Within the same row of same under line, LSM Same letter in superscript for particular independent and dependent parameter are not significantly different

3.5 Frictional properties of cotton seeds

Statistical parameters for frictional properties of cotton seeds are presented in the Table 1. Angle of repose of BS-279, RCH-659 and KCHH-2739 increased due to wetting and ranged between34.72±1.14 to 39.36±0.95˚, 36.06±1.16 to 41.62±1.16 ˚ and 38.74±0.93 to 41.67±1.36 ˚, respectively. Inclination of seed box should be more than angle of repose for easy flow of seeds towards metering device [5, 11].

Static coefficients of friction for all the varieties of seeds were found to be more in higher level of moisture content than lower level. From the Table 1, it is observed that values of coefficient friction for GI sheet varied from 0.44±0.01 to 0.49±0.02, 0.44±0.01 to 0.49±0.02 and 0.45±0.03 to 0.49±0.02 for BS-279, RCH-659 and KCHH-2739 varieties. Corresponding values for MS sheet platform varied from 0.34±0.01 to 0.38±0.01, 0.36±0.01 to 0.38±0.01 and 0.34±0.01 to 0.39±0.01for BS-279, RCH-659 and KCHH-2739 respectively. It is observed that the coefficient of friction of MS sheet is lower than GI sheet. Therefore, MS sheet may be preferred for fabrication of the seed hopper [5, 11]. It is observed form the Table 4 that angle of repose and static coefficient of friction are positively correlated with moisture content.

Table 4 Regression equation as a function of moisture content with their respective coefficient of determination for given frictional, aerodynamic and mechanical parameters

Properties	Parameter	Variety	Regression Equation	R^2
Frictional	AoR	BS-279	32.57 + 2.322MC	0.983
		RCH-659	33.64 + 2.781MC	0.951
		KCHH-2739	37.52 + 1.466MC	0.916
	$CoF_{GI\ sheet}$	BS-279	0.406 + 0.028MC	0.999
		RCH-659	0.405 + 0.029MC	0.999
		KCHH-2739	0.426 + 0.021MC	0.995
	$CoF_{MS\ sheet}$	BS-279	0.326 + 0.017MC	0.989
		RCH-659	0.312 + 0.026MC	0.982
		KCHH-2739	0.314 + 0.021MC	0.961
Aerodynamic	Terminal Velocity, ms^{-1}	BS-279	7.966 + 1.210MC	0.986
		RCH-659	8.698 + 1.795MC	0.938
		KCHH-2739	8.666 + 1.352MC	0.977
Mechanical	Rupture force (10 mm min^{-1})	BS-279	130.4 - 23.36MC	0.988
		RCH-659	140.9 - 29.18MC	0.985
		KCHH-2739	141.8 - 27.98MC	0.993
	Rupture force (20 mm min^{-1})	BS-279	123.9 - 25.64MC	0.983
		RCH-659	121.1 - 25.18MC	0.988
		KCHH-2739	125.3 - 26.09MC	0.992
	Rupture force (30 mm min^{-1})	BS-279	122.2 - 27.85MC	0.999
		RCH-659	116.8 - 26.83MC	0.999
		KCHH-2739	126.3 - 31.13MC	0.988

Within the rows, mean ± SD

3.6 Tukey test results of frictional properties of cotton seeds

Table 5 shows Tukey comparison for LSM of frictional properties for seed varieties and moisture content. Results showed that the effect of moisture content and varieties are found to be significant for angle of repose only and the effect of variety on LSM of static coefficient of friction on GI sheet and MS sheet platform were found to be par. Moisture content has significant effect on coefficient of friction for both the surfaces.

Table 5 Tukey comparison for least squares means (LSM) of frictional properties, aerodynamic and mechanical for seed variety and moisture content

Properties	Level	Seed variety			Moisture Content (%, db)		
		BS-279	RCH-659	KCHH-2739	8-10	10-12	12-14
Frictional	LSM of Angle of repose, °	37.21^{c}	39.20^{b}	40.46^{a}	36.50^{c}	39.49^{b}	40.88^{a}
	LSM of CoF_{GI}	0.46^{a}	0.46^{a}	0.47^{a}	0.44^{c}	0.46^{b}	0.49^{a}
	LSM of CoF_{MS}	0.36^{a}	0.35^{a}	0.36^{a}	0.34^{b}	0.35^{b}	0.38^{a}
Aerodynamic	LSM of TV, m/s	10.38^{c}	12.28^{a}	11.37^{b}	9.87^{c}	11.39^{b}	12.77^{a}
Mechanical	LSM of RF_{10}	83.70^{a}	82.62^{a}	85.86^{a}	112.5^{a}	80.84^{b}	50.83^{c}
	LSM of RF_{20}	72.70^{a}	70.74^{a}	73.16^{a}	99.44^{a}	69.00^{b}	48.16^{c}
	LSM of RF_{30}	66.58^{a}	63.22^{a}	64.06^{a}	92.62^{a}	65.82^{b}	35.42^{c}

Within the same row of same under line, LSM Same letter in superscript for particular independent and dependent parameter are not significantly different.

3.7 Aerodynamic property of cotton seeds

Statistical parameter on aerodynamic property (terminal velocity) of the seeds is presented in Table 1. It is observed that terminal velocity increase with increase in moisture content from 9.26±0.68 to 11.68±0.60 ms^{-1}, 10.23±0.77 to 13.82±0.38 ms^{-1} and 10.14±0.49 to 12.84±0.89 ms^{-1} for BS-279, RCH-659 and KCHH-2739 respectively. Terminal velocity of cotton seed shows positive correlation with moisture content (Table 4) for all the varieties. This aerodynamic property was found to be important in case of minimum air velocity required for sucking the seeds by pneumatic device [8, 31].

3.8 Mechanical property of cotton seeds

The statistical parameters of rupture force of all the varieties of cotton seeds under horizontal loading position at three different loading rates were measured and the results have been shown in Table 1. The rupture force for the varieties viz. BS-279, RCH-659 and KCHH-2739 were observed to be 108±13.01 to 61.82±5.25, 113.84±18.30 to 55.48±3.32 and 115.16±10.41 to 59.20±2.76 N, for 10 $mmmin^{-1}$ loading rate respectively. The corresponding values at 20 mm min^{-1} were found to be 100.26±7.22 to 48.98±4.55 N, 97.52±3.09 to 47.16±3.27 N and 100.54±5.51 to 48.36±3.31 N. For the loading rate at 30 mm min^{-1}, it was observed to be 94.40±3.37 to 38.70±3.30 N, 90.26±3.66 to 36.60±2.08 N and 93.22±3.26 to 30.96±2.71 N respectively. This trend indicates that seeds with lower moisture content require high compression strength to crack [13, 18, 20 for sunflower seed, beachwood seed, African star apple respectively].

Rupture force of cotton seeds was determined under change in moisture content from 8 to 14% db shown in Table 4. The experimental results showed that the force needed to rupture (crack) the seed is a function of both moisture content and loading rate. As shown in Table 4, the force required to rupture the seeds is negatively correlated with moisture content as well as loading rate.

3.9 Tukey test results of aerodynamic and mechanical properties of cotton seeds

Table 5 shows Tukey comparison for LSM of terminal velocity and rupture force for seed variety and moisture content. Results showed that the effect of seed varieties and MC were significant (α=0.05) for terminal velocity. LSM of rupture force for all seed verities at all loading rates were found to be at par whereas the effect of moisture content is found to be significant.

4. CONCLUSION

Some moisture-dependent properties of the three varieties of cotton seeds in the moisture content range of 8–14% db were studied and the based on the experimental results the following conclusions could be made.

The effect of moisture content on the physical, gravimetric, frictional, aerodynamic and mechanical properties of BS-279, RCH-659 and KCHH-2739 seeds were significant (α= 0.05) for Tukey pair wise test. But the effect of varieties on these properties was found to be at par. It was observed that physical, frictional and terminal velocity increasedwith increase in moisture content, but rupture force and gravimetric properties showed a reverse trend except thousand seed weight. Mild steel is found to be most suitable material for fabricating seed hopper of cotton seeds at lower moisture content (8-10% db) as it produces less friction than GI material under the study. The force required to rupture the seed decreased as moisture content and loading rate increased at horizontal loading position. These properties could be taken into consideration for designing of planters and other sowing machinery, harvesters,ginning and oil extraction machines of cotton seed. This information can play an important role for designing the pneumatic planters.

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