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Properties of Cotton Seed in Relation to Design of a Pneumatic Seed Metering Device

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ABSTRACT: Seed size and its uniformity is an important factor in design and development of seed metering mechanism of any type of seed planter, which helps to optimize the structural parameters for optimum performance. Selected important physical and mechanical properties of three popular hybrids of cotton seeds were studied and its importance in pneumatic seed metering mechanism development discussed. The image analysis technique was used to measure linear dimensions of seed and data was compared and correlated with experimental method. The mean length, width and thickness of the selected varieties of cotton seeds were 8.84, 5.00 and 4.50 mm, respectively considered for the design of cells on the metering plate of cotton planter. The projected area and sphericity of the seed were 36.17, 39.86 and 29.73 mm^2 and 0.61, 0.64 and 0.67 for CH1, CH2 and CH3, respectively. Strong correlation was observed between experimental and image processing technique in length and width based linear seed dimensions. The average unit mass, 1000 seed mass, volume, true density, bulk density and porosity were varied between 0.079 to 0.098 g, 83.86 to 94.68 g, 89.63 to 99.47 mm^3, 1107.68 to1285.43 kg m^{-3}, 480.56 to 589.14 kg m^{-3}, 46.76 to 53.96% for all the selected varieties. The terminal velocity of cotton seed was varied between 7.46 to 9.86 m/s.

Key words: Cotton seed, physical and mechanical properties, image analysis and pneumatic seed planter

Cotton *(Gossypium hisutum)* the king of fiber crops is the most important commercial crop grown in many parts of the world as source of fiber and feed under large areas. India continued to maintain the largest area under cotton cultivation and second largest producer of seed cotton next to china with 35.29 and 24 percent of world cotton area and production, respectively (Anonymous, 2014). In recent decade, due to adoption of larger areas under improved hybrids and Bt cotton, seed cost combined with planting operation contributing to a major share of cost of cultivation in the country. In one hand, the Bt seed cost is many folds higher than desi cotton verities and on the other side, the farmers are not able to adopt existing seed planters, since the individual seed has to be precisely placed in the soil at set seed to seed spacing within the row. Hence, there is a need to design and develop pneumatic planters which are proven to be more precision planters to carry the planting operation of cotton and other high seed value crops like okra and other vegetable crops.

In design of any type of pneumatic planter either positive or negative pressure, the physical and mechanical properties of seed will play a major role. In addition to this, some of these properties will also influence in development of various other cotton processing machines like seed cleaners, graders, sorting machines, transportation components in the processing plant and oil expelling machinery. Unless various above listed machinery components are designed considering these properties of seeds, machines may not able to perform at desired optimum performance. The major design influencing seed physical and mechanical parameters are size, shape, mass, bulk density, true density, porosity and static coefficient of friction against various surfaces and aero dynamic property like terminal velocity (Mohsenin, 1978). In the last few decades, many researchers have investigated these properties for various agricultural crops. Physical and aerodynamic properties of soybean (Refik, *et al.,* 2006), sunflower seed (Gupta, *et al.,* 1997), corn seed varieties (Helmy, *et al.,* 2009) and pine nut (Faruk and Kubilay., 2005). In addition, the physical properties of delinted cotton have determined by Ozarslan (2002) and aerodynamic properties by Tabak and Wolf (1998).

Many of these researches determined some of physical properties by experimental method using conventional ordinary or dial type measuring instruments. This is very laborious and time consuming process. Hence, there is an urgent need of upgrading these experimental methods by utilizing the advanced electronic devices and computing systems, which drastically reduce human error in experimentation, besides simultaneously reading/computing various parameters of selected data sets. Very few researchers have adopted digital image processing techniques in determining seed linear dimensions. Digital image analysis is a new technique enables size measurements faster and more accurately without seed damage. Tanska, *et al.* (2005) tested image processing technique to determine the geometrical features of rapeseed, surface colour and also identification of impurities that are difficult to separate during the cleaning process. Kadlec, *et al.* (2006) dealt with shape characterization of pea seeds using image analysis to determine the specific surface area in micro-wave drying. Ercisli, *et al.* (2012) used an image processing system to determine the size and shape properties of ten walnut cultivars such as geometric mean diameter, sphericity, surface area, volume, shape factor, compactness, elongation and shape index.

Hence, the present study was taken up with twin objectives of to investigate competency of image processing technique in determining linear dimensions of 3 selected popular cotton hybrid (to avoid any conflict of interest, here as mentioned cotton hybrid 1 (CH1), cotton hybrid 2 (CH2) and cotton hybrid 3(CH3)) seeds and study pertinent physical, mechanical and aerodynamic properties which play a crucial role in design of pneumatic precision seed metering mechanism for cotton crop.

Materials and Methods

The cotton hybrids of CH1, CH2 and CH3 seeds obtained from the local seed processor were fully delinted and cleaned to remove unwanted dust and dirt particles from the seeds. The moisture content of the seeds was determined by oven drying at 105 ± 2 ˚ C for 24 h (Suthar and Das, 1996) and moisture calculated on per cent dry basis. All the properties were determined at safe storage moisture content, which was recommended for seeds.

Physical properties measurement

Linear dimensions: Physical properties of seed materials such as linear dimensions (length, width and thickness), shape, size, frontal area, density, specific gravity, projected area and other are very important in many problems associated with design or development of planting machine. These properties are useful for specifying the dimensions and setting of metering plate of a planter. The linear dimensions also play major role in design of hole size in seed final pickup device for air assisted seeders. One hundred seeds from each variety were picked randomly. The dimensions of each seed namely length (L), width (W) and thickness (T) were measured in three directions by using electronic digital caliper with 0.001 mm accuracy and digital image processing technique. The measurements were repeated 5 times for each seed of each variety.

Projected area (Pa): The projected area of the seed significantly influences the air stream velocity required to move the individual seed to the dropping point in pneumatic metering mechanism when multiple seeds cluster at the lower portion of seed box delivery tube in conveyance. Larger capacity seed chamber with small projected area seed in a rotary type device may increase clustering of multiple seeds around the seed carrying aperture by increasing multiple seed pickups and more gaps with bolder seed at low air pressure and higher speeds of rotor.

Sphericity (ϕ): Sphericity is an indirect measure of how much a selected seed is close to sphere, which is exploited singly or together with other characteristics to determine the free flowing or bridging tendencies of seed mass in many separators used in cleaning and seed planters. The sphericity of cotton seeds is calculated using the relationship described by Mohsenin (1978), by measuring seed linear dimensions in length, width and thickness wise.

$$\phi = \frac{(LWT)^{1/3}}{L} \quad \ldots 1$$

Where, ϕ is the sphericity of seed, L is the length (mm), W is the width (mm) and T is the thickness (mm).

Since, the projected area and sphericity are also geometrical parameters of a seed, these were also determined using image processing technique.

Image processing technique for determination of geometrical properties of seed

It is one of the accurate and reliable method used to determine the linear and geometrical properties of irregular seeds and other objects in recent years. The Technique mainly requires an image acquisition device like camera or scanner and analysis software. In this study a HP scanjet G3110 flatbed scanner was used to capture the seed images and they were processed by using the Image software to determine the linear geometrical dimensions of seeds. This software is Java based free image processing and analysis software, readily available, open source platform independent and public domain software developed at the National Institutes of Health (NIH), Bethesda, Maryland, USA (Rasband, 2008).

In order to acquire the images, seeds were spread over the scanner surface without touching to each other and scanned with high resolution to reduce shade effect. Then the images imported to personal computer and each image was analyzed using ImageJ software. The image analysis steps involved were depicted in figure1 and explained below in brief.

Image acquisition: The captured image was acquired to the system and read by the Image software as shown in Figure 2 (a).

Image adjust: The image adjust function will converts the colour to binary image. The optimization of image will be done automatically by the level based on an analysis of the image histogram. Creates a selection and the entire image will be optimized based on an analysis of the selection Figure 2 (b).

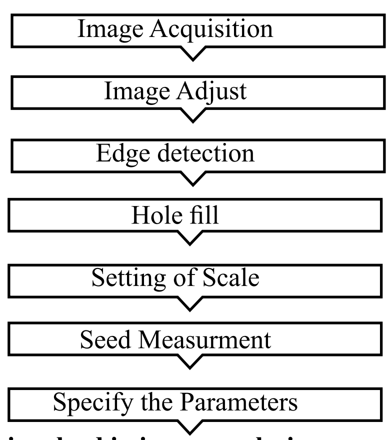

Fig. 1 : Steps involved in image analysis process to measure seed parameters

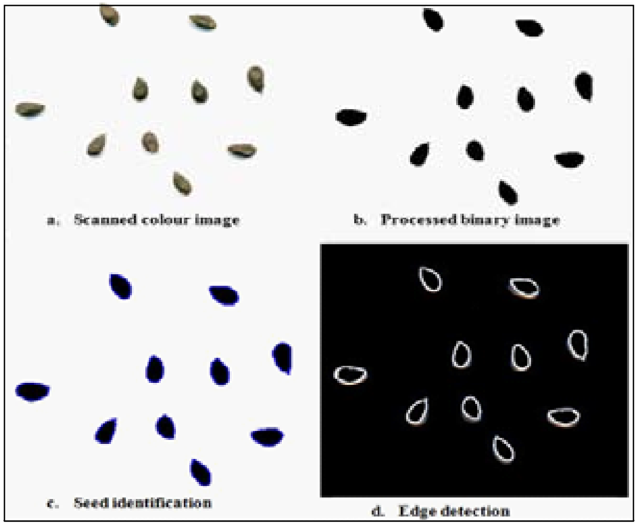

Fig. 2 : Views of cotton seed at different steps during image processing

Hole fill or seed identification: From the detected edges, the false objects need to be removed. This step identifies seed objects/edges from all identified edge objects. Edge sharpness, seed size were some parameters used to filter the false edge objects Figure 2 (c).

Edge detection: To identify seeds from images, edge detection algorithm would be used. This would be multiple edge contour or canny edge detector. In Image this can be performed by image process/ find edges option directly Figure 2(d).

Auto calibration or setting of scale: The setting of scale is an important step in measuring the seed property which converts the pixel value to the desired units of measurement. For this purpose, a coin was scanned and all the dimensions were determined following all the steps discussed in the image processing technique. Dimensions of the coin were also measured physically using a digital vernier caliper and a scale was developed by dividing the original dimensions by pixel values. This scale was used to determine length, width, perimeter and projected area of the seeds by multiplying with pixel values.

As a first step in establish the image analysis competency in selected seed properties calculation, linear seed dimensions length and width were measured using image analysis technique and followed by digital vernier caliper measurements. The data sets thus obtained were subjected to correlation analysis, having been found good agreement between digital caliper instrument data and image analysis data in liner dimension of cotton seeds, other properties like projected area, sphericity of the seeds were also determined using image analysis.

One thousand seed mass (m_{1000}): The thousand seed mass of cotton seeds of three varieties were determined by means of an electronic balance having a least count of 0.001 g.

Bulk density (ρ_b), True density (ρ_t) and Porosity (P_f): The true and bulk densities are considered for determining paging capacity, designing seed chamber in a pneumatic planter from where seed is subjected to vacuum or suction pressure and primary seed hopper dimensions in ordinary seed planters. The bulk density of the cotton seed was determined using the standard test weight procedure (Singh and Goswami, 1996), by filling a container of 500 ml with the seed from a height of 150 mm at a constant rate and then weighing the content. The ratio of the mass and volume was expressed as bulk density. During the experiment care was taken to avoid any compaction of the material in the container. The true density was determined using the toluene displacement method. The volume of toluene displaced was found by immersing a weighed quantity of cotton seed in the toluene (Singh and Goswami, 1996). The porosity of the seeds was determined by using relationship equation between bulk density and true density described by Mohsenin (1970) as given below.

$$Pf = (1-\rho_b/\rho_t)\ 100 \qquad \text{.... 2}$$

Where, Pf is the porosity in percent and ρ_b is the bulk density in kg m^{-3}, ρ_t is the true density in kg m^{-3}

Volume (V): The volume V of cotton seeds in mm^3 was determined from the equation 3, by knowing the true density of seed and unit mass.

$$V = (m/p_t)\ x\ 10^6 \qquad \text{.... 3}$$

Where, m is the unit mass of seed in g and ρ_t is the true density in kg m^{-3}.

Mechanical properties measurement

Angle of repose: The angle of repose of seeds depends on the shape and size of seed and the surface conditions. The angle of repose of the cotton seeds was determined by the method explained by Waziri and Mittal (1983), from the radius and height of the heap formed on a circular plate. In the apparatus, the seeds were allowed to fall on circular plate of 20 cm diameter from a height of 15 cm, so that a natural heap was formed. The average value of five replications for each variety was reported. The following equation was used to calculate the angle of repose of the selected seeds.

$$\theta = \tan^{-1}\left(\frac{h}{r}\right) \qquad \text{...4}$$

Where, θ is the angle of repose, h is the height of cone (mm) and r is the radius of cone (mm).

Coefficient of friction (μ_s): The friction coefficient of seeds is considered for selecting and determining the slopes of the seed hopper of the seed processor and in the design of seed hopper in seed planters. The experimental apparatus used in the static friction studies consisted of a frictionless pulley fitted on a frame, an open-ended cylinder to contain the sample, loading pan and test surfaces (Visvanathan, *et al.*, 1996). The seed container was placed on the test surface and filled with a known quantity of the seed. Weights were then added to the loading pan until the container began to slide.

The weight of the seeds and the added weights comprise the normal force and frictional force, respectively. The coefficient of static friction was calculated as the ratio.

$$\mu_s = \frac{F}{N} \quad \ldots 5$$

Where, μ_S is the coefficient of static friction; N is the normal force in static friction in Newtons (N), and F is the frictional force in static friction in N. The experiment was performed using the different test surfaces of mild steel, stainless steel, cardboard and Nylon sheet with five replications. For each replication, the seed in the sample container was emptied and refilled with a different sample.

Terminal velocity: The terminal velocity is an important parameter and considered in calculating the air suction needed in the metering devices in pneumatic planters. The terminal velocity for delinted cotton was measured experimentally by using laboratory terminal velocity apparatus. The setup consists of transparent glass tube to view the status of an object or seed under investigation in a flowing air stream which can be adjusted and a small hopper to release the seed controlled manner at the lower portion of the tube. A wire mesh is provided in transparent tube just above the air entrance. For each test a small amount of sample (nearly 100 g) was fed into the hopper. The air was blown form the bottom of the wire mess in the upward direction to suspend the seeds in the air stream for 30s. A regulating device fitted in the apparatus of the measuring apparatus varies the airflow rate. The most of the seeds after remaining in suspension for about 30 s were carried away and got collected in the collecting interceptor and heavier seeds if any fell in pan below the vertical transparent column after suspension. The air flow rate was varied till the air stream lifted most of the seeds. This airflow rate was used to calculate velocity using Eq. (6) described by Kachru, *et al.,* (1994). The air velocity which kept the seeds in suspension and calculated using Eq. (6) is termed as terminal velocity of cotton seed.

$$V_t\,(\mathrm{m/s}) = \frac{\text{Airflow rate for suspending the material, m}^3\,\text{h}^{-1}}{\text{Area of the cylinder, m}^2 \times 3600} \quad \ldots 6$$

In determining linear and geometrical parameters, 100 numbers of seed each from three varieties and for other properties five replications for each variety from same lot of samples were drawn and mean and standard values reported with appropriate statistical analysis.

Results and Discussion

Linear dimensions of seed and its correlation between manual and image process technique

The mean and standard deviation values of cotton seeds linear dimensions measured experimentally and image processing technique were summarized in Table 1 and its regression analysis in Table 2. In conventional method, the average lengths of cotton seeds were found to be 9.09, 9.20 and 8.26 mm, whereas in image analysis the same were 8.90, 9.04 and 8.10 mm for CH1, CH2 and CH3, respectively. The mean reduction in length of cotton seed in image processing technique was found to be 2.07%. The measured width of cotton seed varied within the range from 3.94 to 5.82 mm for the selected three varieties with mean values 4.82, 5.07 and 4.73 mm for CH1, CH2 and CH3, respectively in manual measurement. The mean width of cotton seed estimated by image analysis technique was 4.62, 4.90 and 4.63 mm for CH1, CH2 and CH3, respectively.

Good correlation was found in length and width of seed that measured using conventional measurement and image analysis technique and followed a linear relation with regression coefficients 0.889, 0.932 and 0.914 for length and 0.919, 0.924 and 0.945 for width of seed for CH1, CH2 and CH3, respectively (Table 2). However, the regression coefficients obtained in the present study were lower than what reported for basil seed by Razavi, *et al.,* (2010). This may be due to manual error while taking measurement of seeds with vernier calipers. Seed analysis by image processing also effected by several factors like quality of image, illumination during image acquisition, technique adopted for processing and setting of scale. The thickness of selected cotton seeds were varied between 3.57 to 5.10 mm with mean value of 4.32, 4.98 and 4.18 for CH1, CH2 and CH3, respectively. These axial dimensions are important in determining aperture or cell sizes in seed pickup roller or plate of planter, particularly in separation of materials and other parameters in agricultural machine designs.

Table 1 : Linear dimensions of different varieties of cotton seed (moisture 8.5 -10% db)

Linear dimensions of seed	No. of observations	Methods			
		Experimental		Image analysis	
		Mean	SD	Mean	SD
CH1					
Length, L (mm)	100	9.09	0.89	8.90	0.93
Width, W (mm)	100	4.82	0.51	4.62	0.58
Thickness, T (mm)	100	4.32	0.59		
CH2					
Length, L (mm)	100	9.20	0.92	9.04	0.87
Width, W (mm)	100	5.07	0.61	4.90	0.63
Thickness, T (mm)	100	4.98	0.53		
CH3					
Length, L (mm)	100	8.26	0.56	8.10	0.62
Width, W (mm)	100	4.73	0.43	4.63	0.32
Thickness, T (mm)	100	4.18	0.34		

Table 2 : The relationship between experimental (y, mm) and image analysis data (x, mm) determined for length and width of cotton seeds

	Seed length		Seed width	
Varieties	**Regression equation**	**R^2**	**Regression equation**	**R^2**
CH1	Y = 0.882X + 0.647	0.889	Y = 0.986X – 0.315	0.919
CH2	Y = 0.938X + 0.053	0.932	Y = 0.925X – 0.026	0.924
CH3	Y = 1.050X - 0.877	0.914	Y = 1.0X – 0.368	0.945

Physical properties

Various physical, mechanical and aero dynamic properties studied in this experiment for all the three varieties of cotton seeds at storage moisture content were presented in Table 3, 4 and 5 for CH1, CH2 and CH3 respectively. Among the varieties, the projected area was higher for CH2 (39.86 mm^2) followed by CH1 (36.173 mm^2) and CH3 (29.73 mm^2). Ozarslan (2002) reported that, the variation in the projected areas with moisture contents of delinted cotton seed could be represented by linear equation. In absence of any other technique to directly measure seed size, the geometric mean of the axial dimensions is useful in the estimation of the projected area of the seed. The projected area of the seed particle generally indicative of its pattern of behavior in a flowing air of air assisted seeder distribution head (old models of pneumatic seeders) and as well as ease of separating foreign materials from the seed particles during the cleaning by pneumatic means. The standard deviations of cotton seed varieties are low, which indicates that, all three varieties are well graded and uniform in size.

The sphericity of the cotton seeds determined by image analysis technique and also calculated at respective moisture content by using Eq. (1), was presented in the Table 3, 4 and 5. The sphericity values obtained in the image analysis were found to be slightly less than the calculated values from the linear dimensions. The mean sphericity values recorded were 0.61, 0.64 and 0.67 with varnier and 0.58, 0.61 and 0.61 in image processing technique for CH1, CH2 and CH3, respectively. If sphericity is less than 0.9, the seed belongs to oblate group and sphericity greater than 1.1, it belongs to oblong group. The remaining seed with intermediate sphericity index values are considered to be round or more spherical in nature. The sphericity value of cotton seed (0.61 to 0.67) obtained in the present study suggests that, the seeds are of hemispherical shape. Movement of non spherical seed is usually slower under gravity. Since, the metered seeds are to be transferred to the seed placement device quickly, the lower sphericity value of cotton is to be taken into consideration for designing the slope of the seed tubes of pneumatic planter.

The seed weight affects seed flow from seed metering device to the boot and also influences the design of seed hopper. Hence, one thousand seed mass of cotton was determined. It is seen that, the mean mass of 1000 seeds were 94.68, 83.86 and 89.26g for CH1, CH2 and CH3, respectively and mean values were presented in the Table 3, 4 and 5. The thousand seed mass of delinted cotton seed increased linearly from 104.06 to 109.64 g as the moisture content increased from 8.33 to 13.78 percent (db) (Ozarslan, 2002), similarly the fuzzy cotton seed mass was reported 36.5 to 138.3, 41.4 to 127.6 and 38.7 to 127.4 g for the three varieties, MCU 5, LRA 5166 and Rajat 5 respectively by Manimehalai and Viswanathan (2006). The average volume of a single seed of cotton for CH1, CH2 and CH3 was found to be 93.92, 89.47 and 86.63 mm^3. In a study reported by Ozarslan, (2002), the average volume varied from 95.4 to 109.6 mm^3 for delinted cotton.

The average true density and bulk density values were found to be 1107.68, 1285.43 and 1235.9 kg m^{-3} and 589.14, 576.77 and 480.56 kg m^{-3} for CH1, CH2 and CH3, respectively. Among selected varieties, the bulk density was higher for CH1, followed by CH2 and CH3. The true density values of the cotton seed in the present study were closer to the values reported by Ozarslan (2002) for delinted cotton seed. The values of the true density and bulk density of delinted cotton seeds in the moisture level range 8.33 to 13.78 percent (db) varied from 1091 to 1000 kg m^{-3} and 642 to 610 kg m^{-3} and had linear relationship. Manimehalai and Viswanathan (2006) reported, bulk density of undivided mass of fuzzy cotton seeds was 226, 203 and 269 kg m^{-3} for the varieties for MCU5, LRA 5166 and Rajat 5, respectively. The estimated porosity values (Equation 2) of cotton seed was found to be 46.76, 53.96 and 52.64 for CH1, CH2 and CH3, respectively. Ozarslan (2002) reported that, the porosity of cotton seed was found to decrease with the increase in moisture content.

Mechanical and aero dynamic properties

The angle of repose 39.20, 35.36 and 38.57º for CH1, CH2 and CH3, respectively at safe storage moisture content. The coefficient of static friction for the three varieties of cotton seeds against three material surfaces i.e mild steel, card board and nylon sheet are also given in Table 3, 4 and 5. As seen from the table, the coefficient of static friction for the cotton seed varieties against each surface is closer, indicating that the friction property is not affected by the variety of cotton crop. Among the selected surfaces, mild steel offered the maximum coefficient of static friction followed by card board and nylon sheet. The static coefficient of friction for delinted cotton seed (Ozarslan, 2002) increased with moisture content on selected structural surfaces, *viz*., stainless steel, galvanized iron, plywood and rubber. This is due to the increased adhesion between the seed and the material surfaces at higher moisture values. The relationship between moisture content and static coefficient of friction on the tested surfaces were followed a linear relationship.

The terminal velocity of crops seed is one of the important parameter and required for designing of pneumatic planter for seed picking and conveying it to delivery system. The gravimetric properties of seed mass and bulk density and geometrical properties such as shape, size etc. are some of the parameters which influence the terminal velocity of seed. The CH1 cotton seed recorded higher terminal velocities and the mean observed terminal velocities were varied in the range of 9.16 – 9.86 ms^{-1} for CH1, CH2 (8.07 – 8.62 m/s) and CH3 (7.46 – 7.79 m/s). The higher weight and bulk density of CH1 seed might have contributed to posses higher terminal velocity when compared with other two varieties.

Table 3 : Physical and mechanical properties of CH1 cotton seeds (moisture 9.86%db)

Properties	No. of observations	Methods			
		Experimental		Image analysis	
		Mean	SD	Mean	SD
Projected area, P_a (mm^2)	100	-	-	36.17	1.83
Sphericity, Ø	100	0.61	0.15	0.58	0.12
Unit Mass (g)	100	0.098	0.22		
Mass of 1000 seed (g)	5	94.68	4.98		
Volume, V (mm^3)	10	93.92	3.28		
True density, ρ_t (kg m^{-3})	10	1107.68	4.61		
Bulk density , ρ_b (kg m^{-3})	5	589.14	2.58		
Porosity, P_f (%)	5	46.76	2.02		
Angle of repose, θ (º)	5	39.20	2.36		
Static coefficient of friction (μ) on					
Mild steel	5	0.43			
Card board	5	0.41			
Nylon sheet	5	0.30			
Terminal Velocity, (m/s)	5	9.42			

Table 4 : Physical and mechanical properties of CH2 cotton seed (moisture 8.63% db)

Properties	No. of observations	Methods			
		Experimental		Image analysis	
		Mean	SD	Mean	SD
Projected area, P_a (mm^2)	100	-	-	39.86	1.63
Sphericity, Ø	100	0.64	0.083	0.61	0.076
Unit Mass (g)	100	0.086	0.36		
Mass of 1000 seed (g)	5	83.86	2.89		
Volume, V (mm^3)	10	89.47	2.79		
True density, ρ_t (kg m^{-3})	10	1285.43	5.03		
Bulk density , ρ_b (kg m^{-3})	5	576.77	2.67		
Porosity, P_f (%)	5	53.96	2.74		
Angle of repose, θ (º)	5	35.36	1.67		
Static coefficient of friction, μ					
Mild steel	5	0.45			
Card board	5	0.38			
Nylon sheet	5	0.33			
Terminal Velocity, (m/s)	5	8.49			

Table 5 : Physical and mechanical properties of CH3 cotton seed (moisture 9.37% db)

Properties	No. of observations	Methods			
		Experimental		Image analysis	
		Mean	SD	Mean	SD
Projected area, P_a (mm^2)	100	-	-	29.73	1.35
Sphericity, Ø	100	0.67	0.05	0.61	0.14
Unit mass (g)	100	0.079	0.31		
Mass of 1000 seed (g)	5	89.26	2.93		
Volume, V (mm^3)	10	86.63	3.12		
True density, ρ_t (kg m^{-3})	10	1235.90	7.53		
Bulk density , ρ_b (kg m^{-3})	5	480.56	3.63		
Porosity, P_f (%)	5	52.64	2.89		
Angle of repose, θ (º)	5	38.57	1.36		
Static coefficient of friction, μ					
Mild steel	5	0.45			
Card board	5	0.39			
Nylon sheet	5	0.31			
Terminal velocity,(m/s)	5	7.52			

Conclusion

A strong correlation between image analysis technique and experimental method was found for cotton seed length and width for all the selected three varieties. The length of cotton seed in image analysis was lower than experimental method. This may be due to human error or method followed during the acquisition and analysis of the image.

The average length, width and thickness of the selected varieties of cotton seed were 8.84, 5.00 and 4.50 mm, respectively, which was considered for the design of cells on the metering roller of cotton planter. The projected area and sphericity of the seed were 36.17, 39.86 and 29.73 mm^2 and 0.61, 0.64 and 0.67 for cultivars CH1, CH2 and CH3, respectively.

Angle of repose for cotton seed varied between 35.36 to 39.20º for selected varieties. Mild steel surface had the highest coefficient of friction and lowest was against nylon sheet. The terminal velocity of cotton seed was varied between 7.46 to 9.86 m s^{-1} for all the selected three varieties.

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