Physical properties of delinted cotton seeds

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Abstract
Various physical properties of delinted cotton seeds of variety AKA-5 were determined at five moisture content levels in the range 5.63 to 33.08 % d.b. and were evaluated as a function of moisture content. It was found that with increase in moisture content, seed size, sphericity, seed volume and 1000 seeds mass increased linearly from 4.54 to 5.02 mm, 0.659 to 0.672, 42 to 62 mm$^3$, and 52.48 to 60.96 g, respectively, whereas, bulk density and true density decreased linearly from 728 to 563 kg/m$^3$ and 1171 to 1034 kg/m$^3$, respectively. In the same moisture range, the bulk porosity, angle of repose and terminal velocity increased linearly from 37.83 to 45.50%, 28.65 to 32.06° and 12.5 to 14.6 m/s, respectively with increase in moisture content. Also, the static coefficient of friction of delinted cotton seeds increased linearly against surfaces of six structural materials, namely, stainless steel (0.24–0.30), aluminum (0.30–0.37), galvanised iron (0.32–0.38), mild steel (0.34–0.41), plywood (0.35–0.42) and rubber (0.38–0.44), with the moisture content in the experimental range (5.63 to 33.08 % dry basis).

Keywords: Delinted cotton seeds, physical properties, moisture content

Introduction
Cotton (*Gossypium hirsutum*) is most important fiber crop in the world as well as in India. Cottonseed contains about 12–20% oil and 40–43% protein. The cotton seeds are subjected to various types of physical processing in seed processing plants, before they are placed at the disposal of farmers for sowing. Therefore, the knowledge of various physical properties of delinted cotton seeds is essential for the design of equipment and facilities for the handling, conveying, separation, drying, aeration, storing and processing of the delinted cotton seeds. Various types of cleaning, grading and separation equipment are designed on the basis of physical properties of grain as a function of moisture content. This information is valuable not only to engineers but also to food scientists and processors and plant breeders. These properties are dependent on moisture content and temperature. Some physical properties of fuzzy cotton seed of few varieties have been noted. Various physical properties, namely, percent mass distribution, dimensions, sphericity, 1000 seed mass, projected area, bulk density, true density and friction coefficient were determined by Manimehalai and Viswanathan (2006) for the well-dried fuzzy cottonseeds of MCU 5, LRA 5166 and Rajat 5 varieties in the moisture content range of 8.20–8.94% dry basis. Some physical properties of delinted and bare cotton seed were evaluated as a function of moisture content by Ozarslan (2002). He reported that linear dimensions, sphericity, thousand seed mass, projected area, volume, terminal velocity and static coefficient of friction increased with moisture content within the range 8.33–13.78% dry basis whereas, bulk density, true density, porosity and shelling resistance decreased with increasing moisture content. Abalone *et al.* (2004) determined physical properties of amaranth seeds

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(Amaranthus cruentus). In their work, true density, specific volume, bulk density, porosity and shrinkage coefficient of amaranth grain were correlated with moisture content. Erica Bau’mler et al. (2006) investigated the effect of moisture content on some physical properties and fracture resistance of the safflower seeds typically cultivated in Argentina. Their results showed that the modifications of moisture content of safflower seed caused a little variation in its size, its hull thickness being the most affected. The volume and weight of the seed, the expansion coefficient, the equivalent diameter and the sphericity increased linearly with the increase in the seed moisture content. The true density varied nonlinearly in the considered range of moisture content. At the same time, an increase in moisture content yields a decrease in bulk density trend and an increased linearly for the porosity of the bed of grain. Sacilik et al. (2003) determined various physical properties of hemp seed and found as a function of moisture content. Review of literature revealed that till date few research findings have been reported on the thermal properties of fuzzy cotton seed. However, data on physical properties on delinted cotton seeds is scanty. Therefore, the present study was undertaken to determine the moisture content dependent some physical properties of delinted cotton seeds.

Materials and Methods

Sample preparation: The delinted cotton seeds of AKA-5 variety were procured from the Maharashtra State Seed Corporation, Akola, Maharashtra State, India. The seeds were cleaned and graded. The sample was again cleaned in order to remove any remaining impurities present. The test sample of delinted cotton seeds was sun dried to reduce the moisture content to 5.63 % d.b. Sun dried sample was moistened with a calculated quantity of water by using Eq. 1 and conditioned to raise its moisture content to desired levels by adding a predetermined quantity of distilled water to the seed sub-lot of 3 kg and was thoroughly mixed in rotating drum.

\[ W_1(100+M_2) = W_2(100+M_1) \]  

(1)

where \( W_1 \) and \( W_2 \) are initial and final weight of the sample, \( g \) and \( M_1 \) and \( M_2 \) are initial and final moisture content of the sample, % d.b. These re-wetted seed lots were sealed in high molecular high-density polyethylene bags (thickness 100 micron) of size 40 x 30 cm, which were kept inside the wet gunny bags for six hours at room temperature. Such seed lots were then conditioned in a refrigerator at a temperature of 5 ± 2°C for 10 days (Dutta et al., 1988). The seeds were stirred at regular interval of two days to ensure uniform re-wetting. This rewetting technique to attain desired moisture content in seed and grain has been used by Brusewitz (1975), Shepherd and Bhardwaj (1986) and Nimkar and Chattopadhyay (2001).

Moisture content of grain sample of known weight (about 25 g) was determined following a standard oven drying method at an air temperature 80 ± 2° in oven for 16 h and subsequently cooling in a desiccator for one hour (AOAC, 1975) before taking the final weight. Average of three replications was noted and reported as moisture content of sample.

Physical properties: Physical properties, namely, seed size, sphericity, volume, thousand seeds mass, bulk density, true density, bulk porosity, angle of repose, terminal velocity and static coefficient of friction of delinted cotton seeds were determined at five moisture content levels in the range 5.63 to 33.08 % d.b. Unless stated otherwise the average of three replications was taken in the experiments.

For grain size, the geometric mean diameter was considered as the size criterion. Three major principle axes of seed were measured with the help of vernier caliper (Mitutoyo, Japan) having a least count of 0.02 mm. An average of observations of 100 randomly selected sound seeds from each sample was calculated. The geometric mean diameter was considered as the seed size criterion (Eq. 2) (Mohsenin, 1970).

\[ D_m = (abc)^{1/3} \]  

(2)

where, \( D_m \) is size of the seed and \( a \) is the major axis in mm, \( b \) is the medium axis in mm and \( c \) is the minor axis in mm. According to Mohsenin
(1970) degree of sphericity was calculated using following expression:

$$\phi = \left(\frac{abc}{a}\right)^{1/3}$$

(3)

where $\Phi$ is sphericity of seed in decimal, $a$ is the major axis in mm, $b$ is the medium axis in mm and $c$ is the minor axis in mm.

The seed volume was determined by toluene displacement method. Seeds sample of about 5 g was dipped in toluene and the volume displaced by the seeds was noted. The true volume of seeds was divided by the number of seeds to find the seed volume (Singh and Goswami, 1996) 

To determine the thousand seeds mass, one thousand randomly selected sound seeds of delinted cotton seeds at various moisture levels were collected and weighed on an electronic top balance with a least count 0.001 g.

The bulk density was determined by filling a circular container of 500 mL volume with the seed from a height of 15 cm at a constant rate and then the contents were weighed without separate manual compaction of seeds. The bulk density was calculated from the mass of the seeds and the volume of the container (Mohsenin, 1970, Singh and Goswami, 1996). The ratio of mass of the sample to its true volume is termed as true density (Deshpande et al., 1993).

The porosity of delinted cotton seeds at various moisture contents was calculated from bulk and true densities using the relationship given by Mohsenin (1970) as follows:

$$\varepsilon = \left(\frac{\rho_s - \rho_b}{\rho_t}\right) \times 100$$

(4)

where, $\varepsilon$ is porosity in %, $\rho_t$ is true density, kg/m$^3$ and $\rho_b$ is bulk density in kg/m$^3$.

For determining the dynamic angle of repose, a plywood box of 300 $\times$ 300 $\times$ 300 mm size having a removable front panel was used. The box was filled with the seeds, and the front panel was quickly removed, allowing the seeds to flow to their natural slope.

The angle of repose was calculated using following formula:

$$\theta = \tan^{-1}\left(\frac{2h}{d}\right)$$

(5)

where, $h$ is the height of pile in mm and $d$ is the diameter of disc in mm.

The terminal velocities ($V_t$) of delinted cotton seeds at different moisture contents were measured using an air column. For each test, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material. The air velocity near the location of the seed suspension was measured by an electronic anemometer having a least count of 0.1 m/s (Singh and Goswami, 1996, Suthar and Das, 1996).

The static coefficient of friction of delinted cotton seeds was determined on six different materials, namely, stainless steel, aluminum, galvanized iron, mild steel, plywood and rubber sheet. A hollow metal cylinder 50 mm diameter and 50 mm high and open at both ends was filled with the seeds at the desired moisture content and placed on an adjustable tilting table. The cylinder was raised slightly so as not to touch the surface. The tilting surface was raised gradually by means of a screw device until the cylinder just started to slide down. The angle of the surface was read from a scale and the static coefficient of friction was taken as the tangent of this angle (Dutta et al., 1988)

**Results and Discussion**

The means and standard deviations of 100 measurements of each dimension of delinted cotton seed in the moisture range 5.63 to 33.08 % (dry basis) are as given in Table 1. The results indicated an increase of 11.19, 9.82 and 9.91 % in length, width and thickness of seeds, respectively, with the increase in moisture content from 5.63 to 33.08 % (dry basis). The variation in the seed size was also significant with increase in the moisture content in the range 5.63 to 33.08 % (dry basis) (Table 1). The grain size was increased by 10.57 %. The length (a), width (b), thickness (c) and size of seeds ($D_m$) showed linear relationship with the moisture content (Fig. 1) and can be represented by relationships:
a = 0.0272 × M + 6.4204 \quad (R^2 = 0.83) \quad (6)

b = 0.0145 × M + 3.8603 \quad (R^2 = 0.86) \quad (7)

c = 0.0118 × M + 3.4216 \quad (R^2 = 0.94) \quad (8)

\[ D_m = 0.0171 × M + 4.3755 \quad (R^2 = 0.85) \quad (9) \]

The sphericity values of delinted cotton seeds at different moisture content levels are given in Table 1 and graphically represented in Fig. 2. Sphericity was increased by 1.97% from 0.659 to 0.672 with increase in moisture content of delinted cotton seed from 5.63 to 33.08% (dry basis). The linear relationship between sphericity \( (\phi) \) and the moisture content was observed as given below:

\[ \phi = 0.0004 \times M + 0.6584 \quad (R^2 = 0.92) \quad (10) \]

The seed volume of delinted cotton seeds was found to be increased linearly from 42 to 62 mm\(^3\) in the moisture range of 5.63 to 33.08% (dry basis). The variation of seed volume with the moisture content is given in Table 1 and shown in Fig. 3. The relationship between the seed volume \( (V) \) and the moisture content is given by the following equation:

\[ V = 0.6634 \times M + 38.642 \quad (R^2 = 0.96) \quad \ldots\ldots\ldots (11) \]

\[ W_g = 50.59 + 0.30 \times M \quad (R^2 = 0.99) \quad (12) \]

Experimental values obtained for thousand grain mass of delinted cotton seed are given in Table 2. It was observed that thousand grain mass increased linearly with the increase in moisture content and this change was highly significant \( (p<0.01) \). The increase in thousand grain mass was 16.15% for the corresponding increase in the moisture content (5.63 to 33.08 dry basis). Similar results of the effect of grain moisture on thousand grain mass have been reported for soybean, chickpea, pigeon pea and green gram (Deshpande et al., 1993, Nimkar, 1997). Variation of thousand grain mass \( (W_g) \) with moisture content of the sample could be expressed by the following relationship:

\[ W_g = 50.59 + 0.30 \times M \quad (R^2 = 0.99) \quad (12) \]
Table 1: Principle dimensions, grain size and sphericity values of delinted cotton seeds

<table>
<thead>
<tr>
<th>Moisture content (M), %</th>
<th>Length (a), mm</th>
<th>Width (b), mm</th>
<th>Thickness (c), mm</th>
<th>Seed size (Dm), mm</th>
<th>Sphericity (ϕ)</th>
<th>Seed volume (V), mm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.63</td>
<td>6.70(0.388)</td>
<td>3.97(0.201)</td>
<td>3.53(0.261)</td>
<td>4.54</td>
<td>0.659</td>
<td>42</td>
</tr>
<tr>
<td>11.40</td>
<td>6.71(0.345)</td>
<td>4.03(0.285)</td>
<td>3.54(0.236)</td>
<td>4.56</td>
<td>0.665</td>
<td>48</td>
</tr>
<tr>
<td>19.27</td>
<td>6.74(0.282)</td>
<td>4.07(0.259)</td>
<td>3.62(0.254)</td>
<td>4.60</td>
<td>0.668</td>
<td>50</td>
</tr>
<tr>
<td>26.77</td>
<td>7.12(0.408)</td>
<td>4.27(0.278)</td>
<td>3.67(0.288)</td>
<td>4.80</td>
<td>0.670</td>
<td>55</td>
</tr>
<tr>
<td>33.08</td>
<td>7.45(0.407)</td>
<td>4.36(0.242)</td>
<td>3.88(0.310)</td>
<td>5.02</td>
<td>0.672</td>
<td>62</td>
</tr>
</tbody>
</table>

(Figures in parentheses are standard deviations)

The data on bulk density of delinted cotton seeds are given in Table 2. It is found to be decreasing significantly (p<0.01) with increase in moisture content. The decrease in bulk density with increase in moisture content indicated that the increase in mass owing to moisture in grain sample was lower than the accompanying volumetric expansion of the bulk.

Similar results have reported for soybean and green gram (Deshpande et al., 1993, Nimkar and Chattopadhyay, 1997). The bulk density (ρb) showed following relationship with moisture content:

$$\rho_b = 759.05 - 5.649 \times M \quad (R^2 = 0.98) \quad (13)$$

The experimental data for true density of delinted cotton seeds is given in Table 2. It is revealed that the true density decreased linearly with increase in moisture content and this change was highly significant (p<0.01). The results indicated that the decrease in true density was 13.24 % for corresponding increase of moisture content from 5.63 to 33.08 % d.b. This decrease in true density with increase in moisture content might be attributed due to relatively higher true volume as compared to corresponding mass of grain due to adsorption of water. The variation in true density (ρt) with moisture content could be represented by the following relationship:

$$\rho_t = 1190.0 - 4.5599 \times M \quad (R^2 = 0.97) \quad (14)$$

The results were similar to those reported by Garnayak et al. (2008) for Jatropha seeds. The bulk porosity, angle of repose and terminal velocity of seeds increased linearly with increase in moisture content (Table 2).

Table 2: Variation of physical properties of delinted cotton seed with moisture content

<table>
<thead>
<tr>
<th>Moisture content (M), %</th>
<th>Thousand seed mass (Wg), g</th>
<th>Bulk density (ρb), kg/m³</th>
<th>True density (ρt), kg/m³</th>
<th>Bulk porosity (%)</th>
<th>Angle of repose, degrees</th>
<th>Terminal velocity, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.63</td>
<td>52.48</td>
<td>728</td>
<td>1171</td>
<td>37.83</td>
<td>28.65</td>
<td>12.5</td>
</tr>
<tr>
<td>11.40</td>
<td>54.16</td>
<td>687</td>
<td>1127</td>
<td>39.05</td>
<td>29.20</td>
<td>12.9</td>
</tr>
<tr>
<td>19.27</td>
<td>56.17</td>
<td>656</td>
<td>1102</td>
<td>40.49</td>
<td>30.50</td>
<td>13.7</td>
</tr>
<tr>
<td>26.77</td>
<td>58.93</td>
<td>618</td>
<td>1078</td>
<td>43.49</td>
<td>31.78</td>
<td>14.4</td>
</tr>
</tbody>
</table>
### Table 3: Static coefficient of friction of delinted cotton seed against various surfaces

<table>
<thead>
<tr>
<th>Moisture content (M), % (dry basis)</th>
<th>Stainless steel</th>
<th>Aluminum</th>
<th>Galvanised iron</th>
<th>Mild steel</th>
<th>Plywood</th>
<th>Rubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.63</td>
<td>0.24</td>
<td>0.30</td>
<td>0.32</td>
<td>0.34</td>
<td>0.35</td>
<td>0.38</td>
</tr>
<tr>
<td>11.40</td>
<td>0.26</td>
<td>0.32</td>
<td>0.33</td>
<td>0.35</td>
<td>0.37</td>
<td>0.40</td>
</tr>
<tr>
<td>19.27</td>
<td>0.27</td>
<td>0.34</td>
<td>0.35</td>
<td>0.37</td>
<td>0.39</td>
<td>0.41</td>
</tr>
<tr>
<td>26.77</td>
<td>0.28</td>
<td>0.35</td>
<td>0.36</td>
<td>0.39</td>
<td>0.40</td>
<td>0.43</td>
</tr>
<tr>
<td>33.08</td>
<td>0.30</td>
<td>0.37</td>
<td>0.38</td>
<td>0.41</td>
<td>0.42</td>
<td>0.44</td>
</tr>
</tbody>
</table>

**Fig 4** Effect of moisture content on static coefficient of friction of delinted cotton seeds

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**Conclusions**

The physical properties of delinted cotton seeds of variety AKA-5 showed relationship with moisture content in the range 5.63 to 33.08 % dry basis. It was found that with increase in moisture content, seed size, sphericity, seed volume and 1000 seeds mass was increased whereas, bulk density and true density decreased linearly. The bulk porosity, angle of repose and terminal velocity of seeds increased linearly with increase in moisture content. Also, the static coefficient of friction of delinted cotton seeds increased linearly against surfaces of different structural materials.

**Acknowledgement**

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**References**


