Studies on improved Gossypium arboreum cotton: Part I— Fibre quality parameters

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The improved Gossypium arboreum cultivars, along with the traditionally grown Gossypium arboreum and Gossypium hirsutum cultivars, have been collected and evaluated comprehensively for fibre quality parameters (physical, morphological and structural). The comparative analysis of the data clearly establishes the parity between improved G. arboreum and traditionally grown G. hirsutum strains. A noticeable qualitative improvement with respect to most of the parameters evaluated, has been observed in comparison to the conventionally cultivated G. arboreum strain RG-8. In addition to that, the improved G. arboreum cultivars seem to retain the inherent trait of the species of producing highly mature fibre.

Keywords: Cotton, Fibre quality, Gossypium arboreum, Gossypium hirsutum

1 Introduction

Amongst all the cotton growing countries, India has the highest acreage under cotton, which almost doubled since independence. The cotton produced in the country encompasses a wide spectrum of staple length from 15 mm to 40 mm and spinning range from 6s to 120s. With regards to cotton production, the progress made by India has few parallels in the world. The country has transformed over the years from being a large net importer of cotton, exporting only around 8500 MT of Bengal Desi cotton (G. arboreum), to becoming a major exporter of medium staple hirsutum cotton. Among all the four cotton species domesticated for commercial cultivation, the species G. hirsutum commands a major share with respect to the area as well as production. The dominance of G. hirsutum species is not only confined to India but also is a global phenomenon. In India, though all the four domesticated species of cotton (G. arboreum, G. herbaceum, G. barbadense and G. hirsutum) are grown successfully, the fact remains that the area under other species is just nominal as compared to the species G. hirsutum. Cotton cultivation has always been a challenge not only in India but also all over the globe with regards to insect pest infestation.

Among all the cotton species under cultivation, species G. arboreum is blessed with some inherent agronomical, entomological and physiological attributes. Species G. arboreum possesses many favourable traits for cotton production, which the upland cotton cultivars lack. Drought tolerance, resistance to diseases like root rot and insect pests like bollworms and aphids1 makes species G. arboreum well adapt to dry land (rain fed) conditions and low input cultivation practices. Owing to the positive attributes associated with the species G. arboreum, to withstand biotic and abiotic stresses and being inherently hardy, more and more impetus is being laid on bringing improvement in fibre quality of the strains belonging to the species because fibre quality, particularly strength, length and micronaire (a measure of fibre fineness and maturity), is critical in maximising price returns to growers and accessing premium markets.

G. arboreum cotton, in general, is characterised with poor fibre quality traits, not fit for processing on modern processing machines and till very recently not much attention has been paid towards the fibre quality improvement, mainly owing to the fact that superior quality G. hirsutum cotton was readily available. In order to bring fibre quality improvement in G. arboreum cotton, primarily the conventional breeding methods are prevalent as a major tool; however some
innovative breeding techniques (introgression)\(^b\) are also being put in to practice to good effect, of late. In the recent past with the use of conventional and introgression breeding methodologies, substantial improvement in fibre quality of the \(G. \text{arboreum}\) strains has been reported\(^{2,3}\), thus generating a lot of interest among the cotton fraternity. This paper, first in the series of the two papers, reports the study on the evaluation of the whole gamut of fibre to fabric made from improved \(G. \text{arboreum}\) cotton to provide a comprehensive status of fibre quality of improved \(G. \text{arboreum}\) strains, particularly in the light of huge requirement for medium-long staple cotton by user industry in the years to come. Since fibre is the first and foremost in the chain, part one of the series presents and analyses the results pertaining to the physical, morphological and structural properties of fibres drawn from selected improved \(G. \text{arboreum}\) strains vis-à-vis \(G. \text{hirsutum}\) strains of comparative quality traits and conventional \(G. \text{arboreum}\) strain.

2 Materials and Methods

Four improved \(G. \text{arboreum}\) genotypes (PA-255, DLSA-17, MDL-2463 and Jawahar Tapati) developed using various breeding techniques with optimum yield levels and acceptable quality characteristics, along with two medium staple \(G. \text{hirsutum}\) strains (Bikaneri Narma and LRA-5166) and one traditional \(G. \text{arboreum}\) strain (RG-8) were used for the study. The varieties PA-255, MDL-2463 and Jawahar Tapati are developed by using conventional breeding techniques at Marathawada Agricultural University, Parbhani (Maharashtra), Agricultural Research Station, Mudhol (Andhra Pradesh), and Jawaharlal Nehru Krishi Vishwa Vidhyalaya, Regional Station, Khandwa (Madhya Pradesh) respectively. The variety DLSA-17 is developed through introgression at University of Agricultural Sciences, Dharwad (Karnataka). \(G. \text{arboreum}\) strain RG-8 is a short stapled, coarse and widely cultivated in irrigated cotton tract of North India, whereas \(G. \text{hirsutum}\) strains Bikaneri Narma and LRA-5166 have wide adaptability and considered as national check for medium and medium long staple group. The seed cotton samples, procured from experimental trials planted and grown under direct supervision of agricultural researchers, were ginned and analysed for various fibre quality parameters. The genotype codes (shown in the brackets) of all the varieties used are PA-255 or Parbhani Turab (PA), DLSA-17(DL), MDL-2463(MD), Jawahar Tapati(JT), RG-8(RG), Bikaneri Narma (BN), and LRA-5166(LR).

2.1 Physical Quality Parameters

Measurements were primarily made with an HVI (High Volume Instrument) and AFIS (Advanced Fibre Information System). The lint samples were evaluated as per standard test methods and tests were replicated five times on both the instruments. Also, conventional methods were used to evaluate some of the parameters, viz. bundle strength (Stelometer), maturity (spacer technique & NaOH method) and tex values (cut and weigh). This was mainly done to make comparison when working on different instruments with different operating principle and methodology. The single fibre tensile characteristics were evaluated by using Instron Tensile Tester (Model 4400) with 1.00 cm gauge length and the mean values reported correspond to the data on 100 fibres.

2.2 Morphological and Structural Parameters

2.2.1 Convolution Frequency, Angle and Structural Reversals

The number of convolutions per unit length of the fibre was determined by using the method adopted by Betrabet \textit{et al}.\(^4\), examining the central 10 mm length of the fibre. The convolution angle was calculated by employing a quick method standardized by Betrabet \textit{et al}.\(^4\) with the help of data recorded for ribbon width and the pitch of convolution. The convolution angle, defined as the angle which the twist makes with the axis of the fibre, was calculated using Meredith’s expression\(^5\) \[\tan \theta = \pi/2(D/C),\] where \(D\) is the ribbon width, \(C\) is the pitch. The fibre specimen scanned for the determination of convolution frequency was also used for the measurement of wall thickness and ribbon width\(^5,6\). The identification and measurement of structural reversals was carried out as per the methodology\(^7\) developed at CIRCOT. The specimens used for determining reversal frequency were the same fibres as used for the determination of convolutions and other fibre dimensions discussed.
above. The average and CV% for 100 fibres were calculated and reported.

2.2.2 Cross-sectional Perimeter, Area and Circularity
With scanning electron microscope (SEM) cross-sectional profiles of fibre were obtained and three parameters, namely the perimeter of the fibre (P), area enclosed by outer profile (A), and area of lumen (A') were estimated by using a super planix (α). The circularity or shape factor (ε) of the fibre cross-section was calculated using the formula $\varepsilon = 4\pi A / P^2$. The degree of thickening was also evaluated using the formula $\theta = 4\pi (A-A')/P^2$. The average and CV% for 100 fibres were calculated and reported for each variety.

2.2.3 Crystallinity, Crystallite Size and Orientation
Crystallinity was determined as per the standard test method using nickel filtered CuKα X-ray radiation emerging from a stabilized Philips X-ray generator. The intensity profile recorded was corrected for air scattering that was obtained by matching a run without the sample under identical conditions. Crystallinity was calculated by the method reported by Segal et al. using the indices established by Chidambareswaran et al. Crystallite size was determined from the strongest peak using Scherrer equation $D_{hkl} = k\lambda / (\beta \cos \theta)$, where $D_{hkl}$ is the dimension of the crystal perpendicular to the (hkl) plane from which reflection arises; λ, the wavelength of the X-rays; θ, the Bragg angle reflection, β, the angular broadening (in radians) of the reflection; and k, a constant having a value of about 0.9. Herman's X-ray orientation factor and 50% X-ray angle, two commonly used indices for characterizing the fibrillar orientation, were estimated from X-ray diffractograms obtained from bundle of well parallelized fibres recorded on a Philips X-ray diffractometer. Herman's orientation factor ($f_\alpha$) was computed from the intensity profile by using the standard procedure. All the samples were evaluated at the standard atmospheric conditions of 65 ± 2% RH and 27± 2°C temperature.

2.3 Statistical Analysis
The data obtained was statistically analysed using Completely Randomized Design (CRD). Duncan's multiple range test was also applied for individual comparison of mean values among various quality parameters using SPSS 11.5 statistical software programme.

3 Results and Discussion
3.1 Gross Fibre Properties
3.1.1 HVI Fibre Properties
The results of analysis of variance of the data (Table 1) elaborates that the difference between improved G. arboreum strains and conventional G. arboreum strain RG-8 is highly significant. The 2.5% span length (SL) values recorded for improved arboreum genotypes are found to be at par with those recorded for hirsutum genotypes; the improved arboreum genotype PA-255 recording highest 2.5% span length (27.6 mm) which is about 70% higher than that of the conventional arboreum strain RG-8. Fibre length has always been considered a major hindrance in processing G. arboreum cotton efficiently on high speed machines. In modern textile processing system, fibre length is recognised as a major contributor to yarn strength and processing performance. In fact, longer fibre is desirable for the production of finer and low twist yarns such as those used in knitting industry. However, with respect to the fibre length requirements of modern textile industry, there exists an upper limit specified for increasing fibre length of medium staple cottons (25-30 mm) to enhance their spinning performance, particularly for open-end-rotor spinning systems. The fibre length uniformity ratio (UR) values (48-50) recorded for improved arboreum cotton though are found to be significantly low as compared to conventional arboreum cotton RG-8 (56), the values are however significantly higher than those obtained for G. hirsutum strains (46). Fibre length uniformity is important in determining the utility of lint and has a direct influence on yarn strength, elongation, evenness, hand, structure and hairiness as well as on yarn twist. Higher uniformity values are indicative of the fact that the yarn spun from such fibres will be uniform in size and strength and there will be lesser fibre wastage. The cotton with a low uniformity index is likely to have high percentage of short fibres and such cotton may be difficult to process and is likely to produce low quality yarn. Higher length uniformity and lower short fibre content are desired characteristics from the viewpoint of textile industry, as these traits are associated with reduced manufacturing waste, nep and ends down during the yarn production, along with improved yarn appearance and strength.

Fibre fineness, a genetic characteristic, is an important cotton quality parameter next to fibre length
innovative breeding techniques on which it may be classified as soft and silky or coarse and harsh. This also contributes to yarn strength and spinnability, particularly for open end spinning systems. Fibre fineness recorded in terms of micronaire value (MV) is used in conjunction with other fibre properties, such as fibre strength and fibre length, to produce a yarn of certain diameter and to achieve consistency in performance of a group of cottons during yarn manufacturing process. The improved arboreum varieties show significant improvement in fibre fineness with mean micronaire values in the range of 4.5-4.9, as compared to 7.0 recorded for conventional arboreum cotton RG-8. Duncan's multiple range test reveals that all the improved G. arboreum genotypes, except PA-255, show significantly higher micronaire values as compared to conventional hirsutum cotton genotypes. Increased levels of fibre fineness promote fibre-to-fibre cooperation in the yarn, permitting less yarn twist, which translates in to a gain in productivity for the textile manufacturer. A high micronaire value (>5.0) is an indication of coarseness in the fibre and may not spin efficiently in to finer count yarns, whereas very low micronaire value (<3.5) cottons are usually termed as immature that can cause neps and dye defects. Infact, very low micronaire value (<3.5) cottons are found to be comparable with those recorded for G. hirsutum cotton varieties, in general.

3.1.2 Fibre Maturity

Fibre maturity is an important physiological property of cotton, the knowledge of which is equally important to the cotton breeder, technologist and processing chemist. Cellulose is the element of the fibre that is dyed in the textile dyeing process and the more the cellulose present, the better is the dye uptake. Most of the textile processing operations like carding, drawing, combing, spinning, dyeing and printing are sensitive to cotton fibre attributes which are conceptually related to fibre development or maturity. The mature fibres generally exhibit greater strength and thus reduce fibre breakage during mechanical processing. Moreover, mature fibres are charaterized by lower neps formation propensity during opening and cleaning and by adequate dye absorption in the fabric finishing process.

The contribution of fibre elongation to the spinning and textile performance is well documented and reported to be highly significant, as it is associated with improved yarn quality of open-end spun yarn, considering the yarn evenness, strength, and reduced hairiness and ability to withstand the demands of weaving. The elongation values (measured on HVI) recorded for improved G. arboreum strains are found to be in the range of 4.0 –5.6% for the strain DLSA-17 recording highest value of 5.6%. But for the genotype Jawahar Tapati (4.0%), all the improved G. arboreum varieties show significantly higher values for elongation as compared to the conventional G. arboreum variety RG-8 (3.9%). At the same time these values are found to be comparable with those recorded for G. hirsutum cotton varieties, in general. The improvement in fibre strength and elongation should be a relatively straightforward goal for cotton breeder.
percentage (obtained by direct method), the values obtained for improved *G. arboreum* strains are significantly lower (75-82%) than the value recorded for conventional *arboreum* strain RG-8 (85%) but markedly higher as compared to the conventional *hirsutum* varieties (69-73%).

### 3.1.3 AFIS Fibre Properties

The results of analysis of variance and comparison of mean values reveal (Table 1) that the improved *G. arboreum* cottons have recorded significantly higher values for fineness and length related parameters as compared to conventional *arboreum* cotton (RG-8). The SFC (w) (percentage of fibres by weight having length less than 12.7mm) values (5.9-17.7%) recorded for improved *arboreum* varieties are found to be significantly lower as compared to that obtained for *arboreum* strain RG-8 (22.3%). The higher values for conventional *G. arboreum* strain may be due to the fact that it is a short stapled cotton and hence a good number of fibres may be falling in the vicinity of defined length (<12.7 mm) for short fibre content. Also, but for the strain DLSA-17 (17.7%), the SFC (w) values obtained for the improved *G. arboreum* strains are lower than that for the *G. hirsutum* strains studied. With respect to SFC (n) (percentage of fibres by number having length less than 12.7 mm), the values recorded for improved *G. arboreum* cotton are in the range of 22.0-46.4%, and except for the strain DLSA-17 the improved *G. arboreum* varieties show lower values as compared to the *G. hirsutum* cotton LRA-5166 and the *G. arboreum* cotton RG-8. With regards to IFC (immature fibre content), the analysis of comparison of means indicates that barring the improved *G. arboreum* strain DLSA-17, the IFC values recorded by other improved *G. arboreum* varieties lie in between the values recorded for conventional *G. arboreum* and conventional *G. hirsutum* varieties and have a significant difference. Improved *G. arboreum* varieties, in general, show numerically lower values (0.90-0.95) for maturity ratio (MR) as compared to conventional *G. arboreum* RG-8 (0.95); however these values are found to be significantly higher than the values obtained for the *G. hirsutum* cotton LRA-5166 (0.87).

Improved *G. arboreum* strains show significantly lower values for seed coat neps (SCN (µm))—by size...
and SCN (cnt/g–by number) as compared to conventional G. arboreum and conventional G. hirsutum strains. The improved G. arboreum strain PA-255 shows lowest value (1 cnt/g). The results are fully endorsed by the findings of Vizia et al.27, who reported that the G. arboreum cotton has the low propensity to shed seed coat during ginning and seed coat bits are extremely smaller in size and very few in number unlike other cotton varieties and hybrids. In textile industry, the seed coat trash is considered as a major drawback and leads to about 50% of yarn imperfections.

In this regard the performance of improved G. arboreum cotton could be considered as an important step forward. Duncan's multiple range tests reveal that the improved arboreum strains record significantly lower values for nep size (632-681 µm) as compared to those obtained for conventional G. hirsutum strains (774-850 µm) and conventional arboreum strain RG-8 (747µm) as well. With regards to nep count, the improved G. arboreum varieties show significantly lower values (73-138 cnt/g) as compared to G. hirsutum strain LRA-5166 (163 cnt/g).

3.2 Morphological and Structural Properties

3.2.1 Morphological Features

The morphological properties determined in terms of convolution frequency, convolution angle, reversal frequency as well as wall thickness and ribbon width of the fibre after swelling with 18% caustic soda are presented in Table 2. Analysis of variance and comparison of mean values reveal that the improved arboreum varieties are characterized by the presence of significantly higher number of convolutions (35-44/ cm) in comparison to the conventional arboreum cotton RG-8 (23.1/cm), whereas these values are significantly lower in comparison to the hirsutum cotton (59-62/cm). Similar trends are observed with respect to convolution angle with the improved arboreum varieties, recording significantly higher values for convolution angle (3.6°–4.8°) as compared to arboreum cotton RG-8 (3.1°), whereas these values are significantly lower in comparison to hirsutum cottons (5.6°–6.3°).

These results help to infer that the improvement in physical quality parameters has not altered much the basic characteristics of the species G. arboreum, which is generally identified with lower number of convolutions as compared to the cotton belonging to other species.18,29. It is generally believed that convolutions greatly affect many of the physical properties of cotton fibre, and their number and distribution are two additional factors that affect the fibre strength and its measurement. Convolutions are considered necessary for spinning cotton as they provide the essential inter-fibre grip in addition to establishing appropriate packing of fibres in yarn, thereby giving better cover in cloth.30–32 Among the improved arboreum cotton strains evaluated, the reversal frequency varies from 8.4/cm to 11.2/cm, which is significantly lower than that recorded for hirsutum strains (16.7-23.8/cm) but markedly higher than that obtained for the conventional arboreum variety RG-8 (5.1/cm.).

Wall thickness and ribbon width are the indices of fineness of a cotton fibre and usually regarded as characteristic of individual variety. Conventional arboreum RG-8 recorded the highest ribbon width (23.4 µm) and is one of the coarsest cultivars grown in India. Analysis of the data reveals that though the improved arboreum cotton shows significantly lower values for wall thickness and ribbon width in comparison to conventional arboreum (RG-8), but the values are on higher side in comparison to hirsutum cotton strains, in general. The linear density values (176-197 m.tex), obtained for improved arboreum

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Wall thickness, µm</th>
<th>Ribbon width, µm</th>
<th>Convolution angle (°), deg</th>
<th>Reversal frequency/cm</th>
<th>Convolution frequency/cm</th>
<th>Linear density m.tex</th>
</tr>
</thead>
<tbody>
<tr>
<td>RG</td>
<td>10.3d</td>
<td>23.4f</td>
<td>3.1a</td>
<td>5.1a</td>
<td>23.1a</td>
<td>297</td>
</tr>
<tr>
<td>PA</td>
<td>6.4c</td>
<td>16.7b</td>
<td>3.8b</td>
<td>9.9d</td>
<td>39.5d</td>
<td>176bc</td>
</tr>
<tr>
<td>DL</td>
<td>6.3c</td>
<td>17.9d</td>
<td>3.6b</td>
<td>8.4b</td>
<td>34.9b</td>
<td>197d</td>
</tr>
<tr>
<td>MD</td>
<td>6.5c</td>
<td>18.2df</td>
<td>3.8b</td>
<td>8.9c</td>
<td>36.4c</td>
<td>186cd</td>
</tr>
<tr>
<td>JT</td>
<td>5.4b</td>
<td>15.8a</td>
<td>4.5c</td>
<td>11.2e</td>
<td>43.9e</td>
<td>189d</td>
</tr>
<tr>
<td>BN</td>
<td>4.5a</td>
<td>17.3c</td>
<td>5.6d</td>
<td>23.8g</td>
<td>58.8f</td>
<td>169ab</td>
</tr>
<tr>
<td>LR</td>
<td>5.5b</td>
<td>18.6e</td>
<td>6.3e</td>
<td>16.7f</td>
<td>61.5g</td>
<td>161a</td>
</tr>
</tbody>
</table>

Any two mean values not sharing ‘a’ letter in common (a,b,c,d,e,f,g) differ significantly at 0.05 level of probability (Duncan’s multiple range test).
strains, are although significantly higher than the *hirsutum* strains (161-169 m.tex), but registered a marked improvement in comparison to conventional *arboreum* RG-8 (297 m.tex).

### 3.2.2 Structural Features

#### 3.2.2.1 Fibre Cross-sectional Parameters

The fibres cross-sectional parameters recorded are presented in Table 3, giving the averages as well as the coefficient of variation evaluated for individual variety. The improved *arboreum* PA-255 and conventional *arboreum* RG-8 show highest value (0.78) for circularity, thus inferring that the fibre is more circular as compared to other strains analysed in the present study. With respect to the area of cross-section and perimeter the improved *arboreum* strains PA-255 and DLSA-17 show values comparable to that of *hirsutum* varieties, whereas other strains have shown higher values. The area of cross-section recorded for improved *arboreum* cotton strains is found to be in the range of 144-158µm², though these values are higher than those recorded for *hirsutum* cotton strains (136-139 µm²) but at the same time the values are almost 50% lower than the values recorded for conventional *arboreum* RG-8 (279 µm²). However, among all the strains evaluated the area of cross-section of conventional *arboreum* RG-8 shows highest variability with a CV of 40%. With regards to the degree of thickening, the value recorded for improved *arboreum* DLSA-17 exhibits large variation with a CV of 30%. The area of cross-section and the degree of thickening of *hirsutum* strain LRA-5166 shows less variability with CV of 29% and 16% respectively.

Cotton fibre perimeter is usually considered to be a varietal characteristic of individual strain and primarily has genetic bearings. The perimeter CV% values recorded for the population of individual fibres for all the strains, irrespective of the species, ranges from 15% to 21%. These CV% values for perimeter are found to be lower as compared to those observed for the area of cross-section (29-40%) and circularity (16-30%). The CV% values obtained indicate that in comparison to other structural parameters, fibre perimeter shows least variation. Pierce and Lord have confirmed that the cell wall diameter as well as its perimeter are fixed early in the growth cycle and mainly remain as genetic characters. Sreenivasan *et al.* while monitoring the structural and other properties of developing cotton fibre at very close intervals starting from 18th day after flowering, have categorically stated that the perimeter of cross-section remains almost constant, thereby proving that with the growing age there is very little change in the outer tubular dimension of fibre. In another study, Hussain *et al.* also have recorded similar results and concluded that for a given variety the cross-sectional perimeter remains fairly constant irrespective of the degree of maturation, and this constancy of perimeter for a given variety leads to a significant relationship between the micronaire value and the degree of thickening. Thus, the results obtained in the present study may again be interpreted to suggest that the perimeter of cotton fibre is of genetic origin and is a varietal characteristic, which remains constant as compared to other structural parameters.

The CV% recorded for cross-sectional area is higher than that of the fibre perimeter. Usually the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RG</th>
<th>PA</th>
<th>DL</th>
<th>MD</th>
<th>JT</th>
<th>B N</th>
<th>LR</th>
</tr>
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<tbody>
<tr>
<td>Area of cross-section, µm²</td>
<td>279</td>
<td>144</td>
<td>145</td>
<td>158</td>
<td>153</td>
<td>136</td>
<td>139</td>
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<td></td>
<td>(40)</td>
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<td>(37)</td>
<td>(31)</td>
<td>(39)</td>
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<td>(29)</td>
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<td>Perimeter, µm</td>
<td>66</td>
<td>43</td>
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<td>55</td>
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<td>45</td>
<td>49</td>
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<tr>
<td></td>
<td>(19)</td>
<td>(18)</td>
<td>(21)</td>
<td>(15)</td>
<td>(20)</td>
<td>(19)</td>
<td>(15)</td>
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<tr>
<td>Degree of thickening (θ)</td>
<td>0.78</td>
<td>0.77</td>
<td>0.61</td>
<td>0.65</td>
<td>0.77</td>
<td>0.59</td>
<td>0.73</td>
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<tr>
<td></td>
<td>(17)</td>
<td>(17)</td>
<td>(30)</td>
<td>(26)</td>
<td>(20)</td>
<td>(27)</td>
<td>(16)</td>
</tr>
<tr>
<td>Circularity (Shape factor)</td>
<td>0.78</td>
<td>0.78</td>
<td>0.61</td>
<td>0.67</td>
<td>0.77</td>
<td>0.61</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>(16)</td>
<td>(16)</td>
<td>(30)</td>
<td>(26)</td>
<td>(20)</td>
<td>(27)</td>
<td>(17)</td>
</tr>
<tr>
<td>Wall area (A-A²), µm²</td>
<td>276</td>
<td>142</td>
<td>135</td>
<td>156</td>
<td>152</td>
<td>131</td>
<td>136</td>
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<tr>
<td></td>
<td>(40)</td>
<td>(37)</td>
<td>(36)</td>
<td>(31)</td>
<td>(39)</td>
<td>(35)</td>
<td>(29)</td>
</tr>
<tr>
<td>50 % X-ray angle, deg</td>
<td>24.8</td>
<td>26.6</td>
<td>24.0</td>
<td>24.0</td>
<td>22.9</td>
<td>21.4</td>
<td>27.8</td>
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<tr>
<td>Herman's factor/ f(x)</td>
<td>0.66</td>
<td>0.71</td>
<td>0.69</td>
<td>0.67</td>
<td>0.71</td>
<td>0.75</td>
<td>0.66</td>
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<tr>
<td>Crystallinity index, %</td>
<td>81</td>
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<td>80</td>
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<tr>
<td>Crystallite size, Å</td>
<td>43</td>
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</tbody>
</table>

Values in parentheses are CV%.
CV% for cross-section is reported to be on the higher side as a consequence of the fact that the fibre of a given perimeter could assume different cross-sectional areas, thus there can be larger variations in cross-section. Numerically also, attempts have been made to show that for a given shape the CV% for area of cross-section (A) will be higher than that of the perimeter (P).

Since \( \varepsilon = 4\pi A/P^2 \) or \( A = (\varepsilon / 4\pi) P^2 \), the (\( \varepsilon / 4\pi \)) can be taken as constant for a fibre or we can express \( \Delta A/A = 2\Delta P/P \).

Thus, the variation in CV% for cross-section would be double to that of perimeter (P), this appears true for the strains evaluated under the present study. Therefore, the high variation in area of cross-section could be attributed to the nature of relationship between area of cross-section and perimeter.

The degree of thickening is usually considered as the fundamental measure of the maturity of cotton fibre. The value obtained for shape factor appears to be directly proportional to degree of thickening not only with the numerical value but also with respect to CV% variation. The improved *arboreum* cotton PA-255 shows lowest (43μm) value for fibre perimeter, thus indicating that the fibre is comparatively finer in the group. Coupled with this high degree of thickening (0.77), higher values for circularity one of the highest in the group, elaborate the fact that this fibre could be spun to a good and uniform, fairly, fault free yarn of medium count.

3.2.2.2 Fibrillar Orientation, Crystallinity Index and Crystallite Size

In general, the average values of Herman’s factor and 50% X-ray angle recorded (Table 3) for improved *arboreum* cotton strains are found to be comparable to those recorded for conventional *arboreum* and *hirsutum* cotton varieties. The 50% X-ray angle recorded for improved *arboreum* is in the range of 22.9°-26.6° with the strain PA-255 recording highest value (26.6°), whereas Herman’s orientation factor varies from 0.67 to 0.71. Crystallinity and crystallite size are regarded to be associated with the rigidity of the fibre and higher values for these characteristics will mean the loss of flexibility in the fibre. Up to certain limit, crystallinity contributes to the tenacity of the fibre but beyond that it affects the pliability (flexibility). Earlier studies have shown that the crystallinity index has inherent variability (error) in repeated measurement of the order of ±2.5%. Keeping this in view, it can be concluded that both the improved *arboreum* and conventional *hirsutum* cotton strains possess similar values for crystallinity index, whereas the conventional *arboreum* recorded marginally higher values. With respect to crystallite size the values recorded for improved *arboreum*, conventional *arboreum* and *hirsutum* strains are found to be comparable.

3.3 Mechanical Properties

3.3.1 Fibre (Bundle) Mechanical Properties (Stelometer)

The mechanical properties are summarized in Table 4. The statistical analysis of variance and comparison of individual means for various tensile properties reveal that the difference between improved *arboreum* cotton strains and conventional *arboreum* cotton (RG-8) is highly significant. The improved *arboreum* cotton strains, in general, are at par with the *hirsutum* strain BN, with respect to almost all the mechanical parameters evaluated; however, the *hirsutum* strain LRA-5166 shows markedly superior values.

The strength uniformity ratio (SUR), toughness and stiffness values recorded for *hirsutum* strain LRA-5166 are of special interest. This strain recorded significantly higher values for SUR and toughness as compared to improved *arboreum* cotton strains, indicating that in the case of LRA-5166 the fibre is structurally more uniform thus giving uniform distribution of strength along the length of the fibre.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RG</th>
<th>PA</th>
<th>DL</th>
<th>MD</th>
<th>JT</th>
<th>BN</th>
<th>LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity at 0 gauge, g/tex</td>
<td>38.6a</td>
<td>50.2d</td>
<td>50.7de</td>
<td>51.1e</td>
<td>50.4d</td>
<td>48.6c</td>
<td>47.6b</td>
</tr>
<tr>
<td>Tenacity at 3.2 mm gauge, g/tex</td>
<td>15.8a</td>
<td>22.7d</td>
<td>21.8c</td>
<td>21.7c</td>
<td>22.7d</td>
<td>20.5b</td>
<td>22.3cd</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>4.5bc</td>
<td>4.3b</td>
<td>4.7c</td>
<td>4.3b</td>
<td>4.0a</td>
<td>4.7c</td>
<td>5.5d</td>
</tr>
<tr>
<td>Strength uniformity ratio</td>
<td>0.41a</td>
<td>0.45c</td>
<td>0.43b</td>
<td>0.42b</td>
<td>0.45c</td>
<td>0.42ab</td>
<td>0.47d</td>
</tr>
<tr>
<td>Stiffness</td>
<td>3.5a</td>
<td>5.3d</td>
<td>4.6c</td>
<td>5.0d</td>
<td>5.8e</td>
<td>4.4c</td>
<td>4.1b</td>
</tr>
<tr>
<td>Toughness (Rupture)</td>
<td>36a</td>
<td>49cd</td>
<td>51d</td>
<td>47bc</td>
<td>45b</td>
<td>48bc</td>
<td>61e</td>
</tr>
</tbody>
</table>

Any two mean values not sharing ‘a’ letter (a,b,c,d,e) in common differ significantly at 0.05 level of probability (Duncan’s multiple range test).
and will result in better yarn tenacity. Higher values for toughness indicate better abrasion resistance and ability of a material to absorb the stress, when it is strained. With regards to stiffness, all the improved *arboreum* cultivars but for the strain DLSA-17, show significantly higher values as compared to the *hirsutum* strains. Conventional *arboreum* cotton RG-8 shows significantly lower values for fibre toughness and stiffness, mainly because of poor bundle tenacity.

3.3.2 Single Fibre Mechanical Properties (Instron Tensile Tester)

Single fibre tensile properties are critical to the processing efficiency of cotton fibres into products and the quality of these products. The breaking strength of individual cotton fibres is considered to be the most important factor in determining the strength of the yarn spun from those fibres. Also, the shift in spinning technology has placed an added emphasis on individual fibre strength as these new technologies produce yarns of lower strength. Table 5 shows that the breaking load values for improved *G. arboreum* cotton strains are at par with those obtained for conventional *G. arboreum* cotton (RG-8), one of the shortest and coarsest varieties. The improved *G. arboreum* cotton PA-255 shows highest value for breaking load (5.9 gf) and it is found to be noticeably higher in comparison to the values obtained for *G. hirsutum* strains (3.6-4.9 gf). The higher values for breaking load signify the sturdiness of the fibre and should be able to sustain the wear and tear commendably as compared to the one with low breaking load. With respect to work of rupture, the improved *G. arboreum* cotton strains record higher values (2.3-3.2 gf-mm) as compared to conventional *hirsutum* cotton varieties (1.3-2.4 gf-mm). The sturdiness measured in terms of breaking load seems to be the contributing factor for the higher work of rupture.

Several studies in the past have clearly shown that rather than the fibre strength, fibre elongation influences the performance of the yarn, and single fibre elongation is considered essential to decide upon the yarn parameters. Patil and Sundaram inferred that for getting good yarn properties, particularly for blended yarn, cotton used for blending should have good fibre strength and extensibility. The single fibre breaking elongation recorded for improved *G. arboreum* strains, in general, is found to be lower than the conventional *G. arboreum* cotton RG-8, except for the improved *G. arboreum* strain DLSA-17 which recorded the highest value (10.1%), at par with the value recorded for *G. hirsutum* strain LRA-5166 (9.9%). Here, it is worth mentioning that while developing the strain DLSA-17, the *hirsutum* gene has been utilized (introgression of *hirsutum* and *arboreum* species), that is known to provide fibres with better elongation.

Young’s modulus of a fibre is a measure of its ability to resist deformation within the elastic limits and a higher value for this measure is indicative of better recovery character in the elastic range. It plays an important role in determining tensile as well as compressional properties of fibre, which, in turn, influences the tensile properties of yarn and fabrics, particularly the low stress mechanical properties. The data presented (Table 5) reveals that all the improved *G. arboreum* strains, except DLSA-17, show higher Young’s modulus in comparison to conventional *G. hirsutum* strains, thus suggesting that for inducing same amount of strain, fibre obtained from improved *arboreum*, needs higher deforming force. The tenacity values recorded for improved *G. arboreum* varieties are in the range of 25.3–33.5 g/tex, with the strain PA-255 recording highest value (33.5 g/tex). In the case of conventional *G. hirsutum* strains, the range is 21.3–30.4 g/tex, whereas the conventional *G. arboreum* cotton (RG-8) records lowest value (19.2g/tex). The comparatively higher single fibre tenacity for improved *arboreum* varieties is a noteworthy character.

### Table 5—Single fibre mechanical properties

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Load at maximum</th>
<th>Elongation %</th>
<th>Work of rupture</th>
<th>Young’s modulus g/den</th>
<th>Tenacity g/tex</th>
</tr>
</thead>
<tbody>
<tr>
<td>RG</td>
<td>5.7(45)</td>
<td>9.1(47)</td>
<td>2.7(85)</td>
<td>865(61)</td>
<td>19.2</td>
</tr>
<tr>
<td>PA</td>
<td>5.9(45)</td>
<td>8.3(48)</td>
<td>3.2(81)</td>
<td>965(60)</td>
<td>33.5</td>
</tr>
<tr>
<td>DL</td>
<td>5.6(51)</td>
<td>10.1(41)</td>
<td>3.0(82)</td>
<td>715(42)</td>
<td>28.4</td>
</tr>
<tr>
<td>MLD</td>
<td>4.7(47)</td>
<td>8.1(52)</td>
<td>2.3(86)</td>
<td>917(62)</td>
<td>25.3</td>
</tr>
<tr>
<td>JT</td>
<td>5.5(47)</td>
<td>8.5(44)</td>
<td>2.6(70)</td>
<td>966(61)</td>
<td>29.1</td>
</tr>
<tr>
<td>BN</td>
<td>3.6(46)</td>
<td>7.3(44)</td>
<td>1.3(69)</td>
<td>751(73)</td>
<td>21.3</td>
</tr>
<tr>
<td>LR</td>
<td>4.9(37)</td>
<td>9.9(58)</td>
<td>2.4(69)</td>
<td>749(60)</td>
<td>30.4</td>
</tr>
</tbody>
</table>

Values in parentheses are CV% .

4 Conclusion

4.1 The performance of improved *G. arboreum* cultivars is found to be significantly superior as compared to the conventional *G. arboreum* cotton RG-8 and with respect to most of the parameters evaluated it was at par with that of the conventional *G. hirsutum* strains.
4.2 Improved *G. arboreum* strains perform significantly better than the conventional *G. hirsutum* cultivars with respect to fibre maturity, seed coat nepes and fibre nepes.

4.3 Improved *G. arboreum* varieties show significantly lower values for fibre morphological parameters, viz. convolution and reversal frequency, convolution angle, as compared to *G. hirsutum* varieties.

4.4 Despite of the fact that other physical parameters are similar, improved *G. arboreum* varieties show significantly higher values for wall thickness (a measure of cotton fibre maturity) as compared to *G. hirsutum* varieties, thus suggesting that the improved *G. arboreum* varieties, even after attaining significant improvement in physical quality parameters, continue to produce mature and less convoluted fibres, a typical characteristic of the species.

References


