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Study of Cotton Matured Fibre Quality and the Super-Molecular Structure in Upland Cotton RILs

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Abstract
A RIL(recombinant inbred lines) population with 196 $F_{6:9}$ lines was developed from an F2 population of upland cotton (Gossypium hirsutum L.) cross of sGK9708×0-153. sGK9708 is a commercial transgenic variety with Bt+CpTI genes resistant to budworm and 0-153 with high fibre quality. Five materials with high fibre strength and five materials with low fibre strength from the recombinant inbred lines were researched [1]. Ten materials of super-molecular structure and fibre quality were studied by X-ray diffraction and the HVI900 technique. The results indicated that cotton matured fibre quality should mainly depend on the decrease in the orientational parameter in the crystalline section, especially the orientational separate and orientational distribution angles. The correlation of fibre maturity, linear density and the fibre super-molecular structure is an innovation in the study. Studies on the correlation of cotton fibre quality and the fibre super-molecular structure provide a scientific basis for the improvement cotton fibre quality.

Key words: *upland cotton, recombinant inbred lines, fibre super-molecular structure, fibre quality.*

Introduction

Cotton fibre quality is influenced by many factors. Fibre strength and linear density are affected by the fibre super-molecular structure, which is an important internal factor. The results indicated that the strength of cotton matured fibre is influenced by the thickening model of the secondary walls of the fibre, the fibre's ultrastructure, the fibre's morphology, its construction and composition [2 - 10]. The microstructure determines the macroscopic quality and can be used to provide a foundation for superior or inferior macroscopic quality. The difference in the cotton fibre quality trait was controlled mainly by the parameter of orientation [11 - 13]. The crystalline grain size grows and the parameters of orientation gradually decrease in the fibre development, but they vary among different varieties [14].

Fibre strength is an important quality index, having an important influence on the textile industry. It is a very important study field in how to improve fibre strength further. It has already been probed from three perspectives—cotton breeding, development and cultivation. On the basis of this, further exploration of the interior mechanism of the strength of cotton matured fibre was made, having an important meaning for improving fibre strength. Therefore this paper studied cotton matured fibre quality and its super-molecular structure by using upland cotton RILs.

Materials and methods

Materials

The experiment was carried out at the Cotton Research Institute, Chinese Academy of Agricultural Sciences, from 2010 - 2011. A RIL population with 196 $F_{6:9}$ lines was developed from an F_2 population of upland cotton (*Gossypium hirsutum* L.) cross of sGK9708×0-153. sGK9708 is a commercial transgenic variety with *Bt+CpTI* genes resistant to budworm and 0 - 153, with high fibre quality. Five materials with high fibre strength (69262, 69272, 69328, 69327, 69307) and five materials with low fibre strength (69312, 69404, 69305, 69412, 69362) from the recombinant inbred lines were researched. The line length was 5 meters and the line width 0.8 meters, with two lines in each material (total 20 lines).

Sampling method

The flower of the same day was marked every other week. The three hanging flower dates were July 19, July 26 and August 2, respectively. Cotton fibre was harvested at the wadding stage, and for three batch samples and a compound sample, the fibre super-molecular structure and fibre quality were measured.

Determination methods of the fibre quality

The cotton fibre quality was measured by HVI900 (HVI (high volume instrument) series, namely, the large capacity fibre testing system) and WIRA (WIRA cotton fibre fineness and maturity electronic tester). The traits tested include fibre strength, the fibre length, fibre micronaire, elongation, uniformity, fibre linear density and fibre maturity.

Determination methods of the fibre super-molecular structure

The cotton fibre super-molecular structure parameter includes the crystallinity, crystalline grain size, the orientational parameter and so on, measured at TianJin Polytechnic University.

Crystallinity

There is a crystalline region and amorphous region in cotton fibre. The percentage of the crystalline region in every fibre is the crystallinity. To cut (fibre) into powder, it is pressed into the sample tablet. Data of $2\theta = 5 - 60°$ was collected and corrected by an X-Diffraction instrument, and afterwards with Ruland method calibration, the crystalline and amorphous regions were differentiated and the crystallinity calculated [15, 16].

Crystalline grain size

An equator atlas of 002 diffraction was collected and corrected by the X-Diffraction instrument with the symmetry refection method, and the crystalline grain

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size was obtained with the Scherrer formula [16, 17].

Orientational parameter

The strength value at the azimuth of the 002 diffraction apex was collected by the X-Diffraction meter using a FS-3 fibre affix. After deducting sundry scatter, the total oriental index ψ was taken as the half value of the half width in the half height. Angles φ and α were obtained from the corrected data based on the method of Deluca [18] and Orr [19]. Angle ψ was the sum of angles φ and α.

Data statistics and analysis

Data statistics and analysis make use of Microsoft Excel 2003, SPSS11.5, MATLAB6.5 software and the Test of Analytical Data with Duncan's SSR. The correlation coefficient (r) of fibre quality and the fibre super-molecular structure was estimated with the MINQUE(1) method for the different anthesis date samples [20 - 23].

Results and analysis

Differences in cotton fibre quality in the different anthesis date samples fibre strength

As shown in ***Figure 1***, the fibre strength of the five materials with high fibre strength is between 30.5 cN/tex and 33.5 cN/tex and that of the five materials with low fibre strength is between 23.5 cN/tex and 29.2 cN/tex, which is a significant difference. The fibre strength had no significant difference for the different anthesis date samples; this trend was in accordance with the compound sample.

Cotton fibre length

As shown in ***Figure 2***, the fibre length of the five materials with high fibre strength is between 27.38 mm and 33.12 mm and that of the five materials with low fibre strength is between 23.89 mm and 28.82 mm, which is a significant difference. The fibre length had no significant difference for the different anthesis date samples; this trend was in accordance with the compound sample.

Cotton fibre micronaire

As shown in ***Figure 3***, the fibre micronaire of the five materials with high fibre strength is between 2.5 and 4.17 and that of the five materials with low fibre strength is between 3.47 and 5.39, being a significant difference. The fibre micronaire had no significant variation in the different anthesis date samples, and the trend was in accordance with the compound sample.

Fibre linear density

As shown in ***Figure 4***, the fibre linear density of the five materials with high fibre strength is between 107.0 mtex and

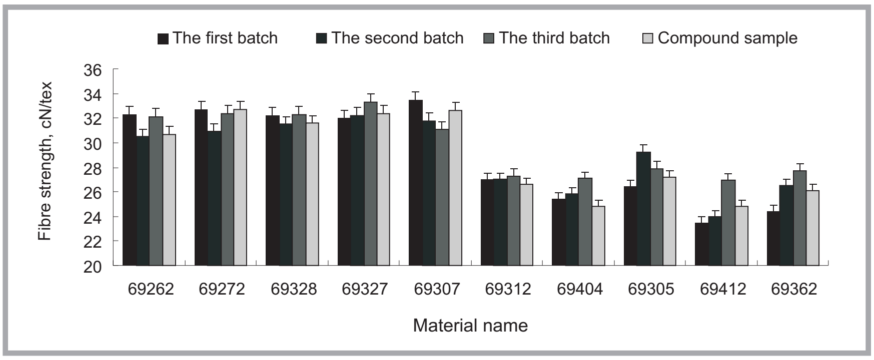

Figure 1. *Differences in cotton fibre strength in the different samples.*

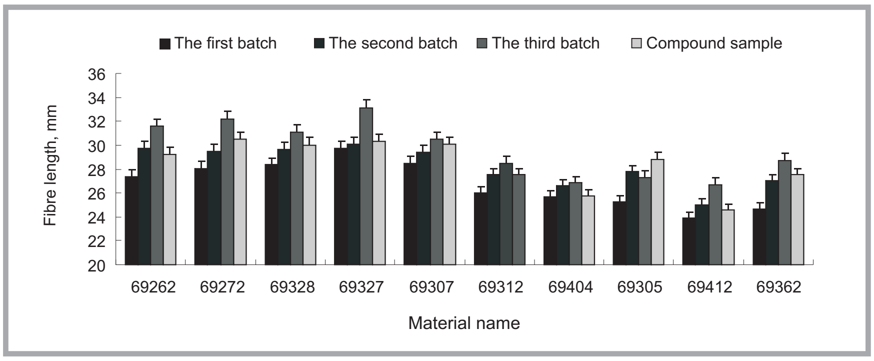

Figure 2. *Differences in cotton fibre length in the different samples.*

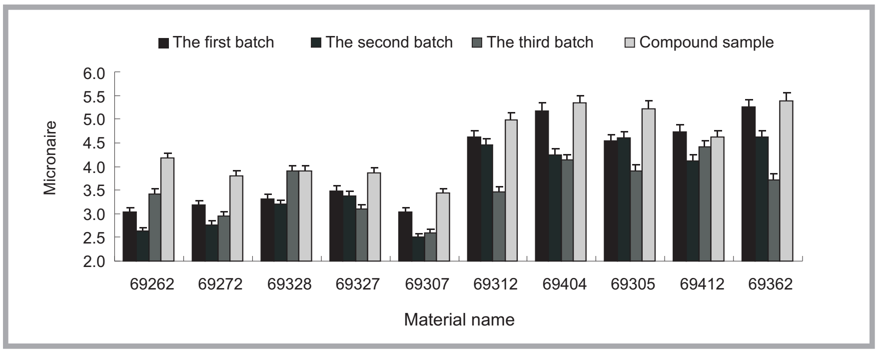

Figure 3. *Differences in cotton fibre micronaire in the different samples.*

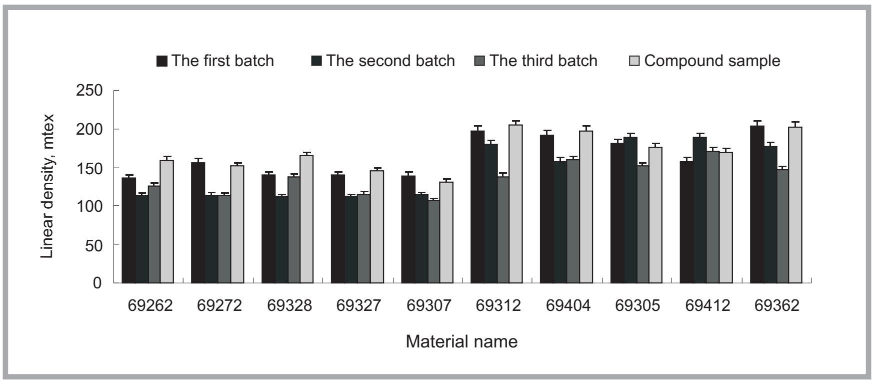

Figure 4. *Differences in cotton fibre linear density in the various samples.*

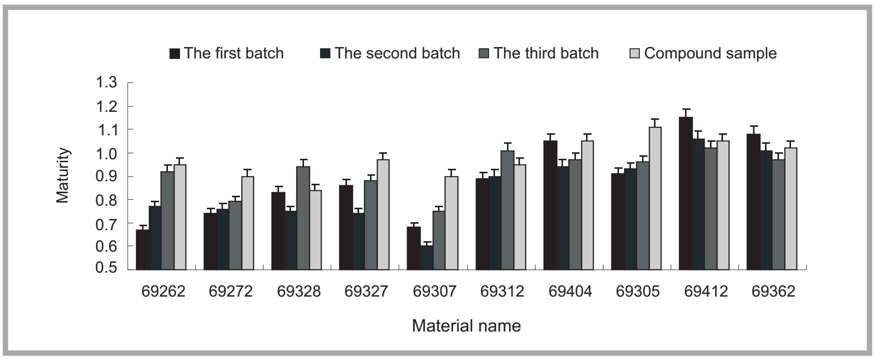

Figure 5. *Differences in cotton fibre maturity in the various samples.*

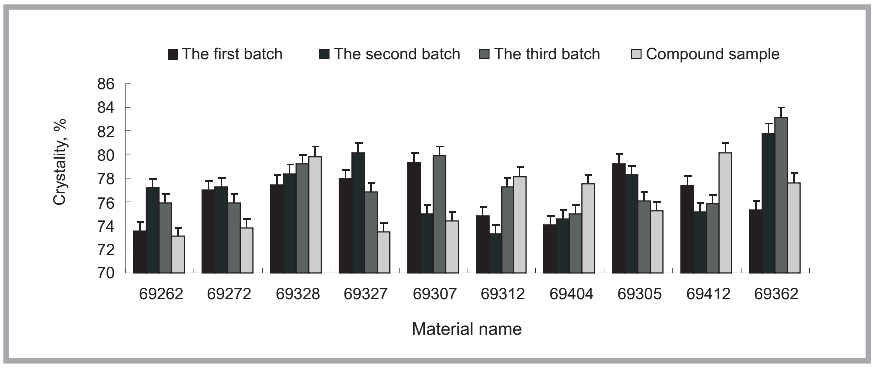

Figure 6. *Differences in cotton fibre crystallinity in the different samples.*

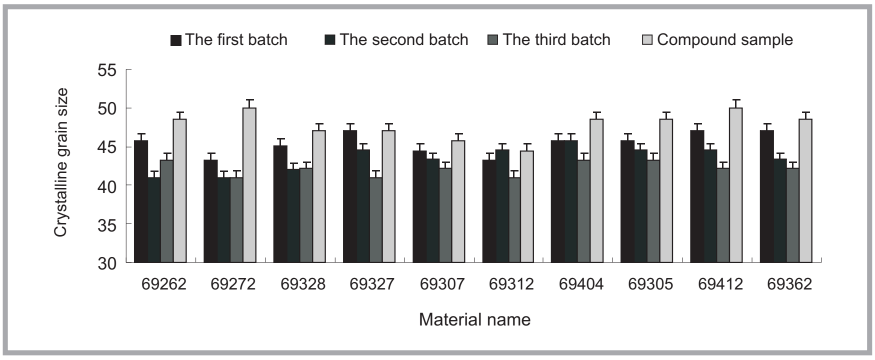

Figure 7. *Differences in cotton fibre crystalline grain size in the various samples.*

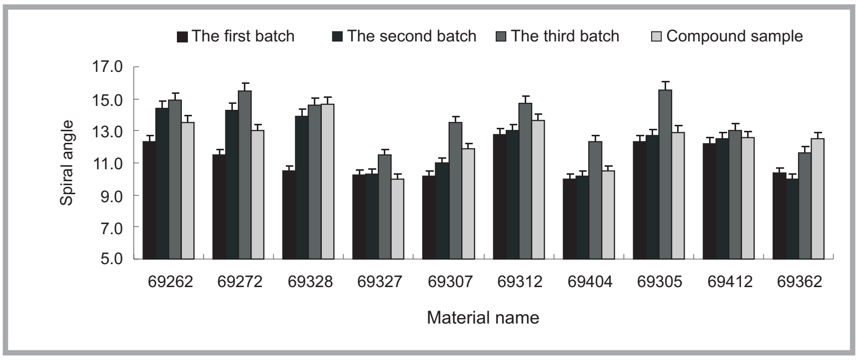

Figure 8. *Differences in the cotton fibre spiral angle in the various samples.*

164.9 mtex and that of the five materials with low fibre strength is between 138.2 mtex and 204.5 mtex, which is a significant difference. The fibre linear density had no significant variation in the different anthesis date samples, and the trend was in accordance with the compound sample.

Fibre maturity

As shown in ***Figure 5***, the fibre maturity of the five materials with high fibre strength is between 0.6 and 0.97 and that of the five materials with low fibre strength is between 0.89 and 1.15, which is a significant difference. The fibre maturity had no significant variation in the different anthesis date samples, and the trend was in accordance with the compound sample.

Through analysis, the trend of fibre quality was found to be in accordance with the compound sample in the different anthesis date samples. Moreover they are representative.

Differences in cotton fibre super-molecular structure in the various anthesis date samples

Crystallinity

As shown in ***Figure 6***, the fibre crystallinity of the five materials with high fibre strength is between 73.1% and 80.2% and that of the five materials with low fibre strength is between 73.3% and 83.2%, which is not a significant difference. The fibre crystallinity had no significant difference in the various anthesis date samples; the trend was in accordance with the compound sample.

Crystalline grain size

As shown in ***Figure 7***, the fibre crystalline grain size of the five materials with high fibre strength is between 41 Å and 50 Å and that of the five materials with low fibre strength is between 41 Å and 50 Å, being of no significant difference. The fibre crystalline grain size had no significant difference in the various anthesis date samples, and the trend was in accordance with the compound sample.

Spiral angle

As shown in ***Figure 8***, the fibre spiral angle of the five materials with high fibre strength is between 10 and 15.5 °C and that of the five materials with low fibre strength is between 10 and 15.6 °C, which is not a significant difference. The fibre spiral angle had no significant difference in the various anthesis date samples, and the trend was in accordance with the compound sample.

The orientational separate angle

As shown in ***Figure 9***, the fibre orientational separate angle of the five materials with high fibre strength is between 23.0 and 26.8 °C and the fibre orientational separate angle of the five materials with low fibre strength is between 25.0 and 29.1°C, which is not a significant difference. The fibre orientational separate angle had no significant difference in the various anthesis date samples, and the trend was in accordance with the compound sample.

The orientational distribution angle

As shown in ***Figure 10***, the fibre orientational distribution angle of the five materials with high fibre strength is between 28.0 and 32.8 °C and that of the five materials with low fibre strength is between 29.1 and 34.3 °C, which is not a significant difference. The fibre orientational distribution angle had no significant difference in the various anthesis date samples, and the trend was in accordance with the compound sample.

Through analysis, the trend of its super-molecular structure was found to be in accordance with the compound sample of the different anthesis date samples. Moreover they are representative.

Correlation between fibre strength and quality characters with the super-molecular structure in the different anthesis date samples

As shown in ***Table 1***, the fibre strength had a positive correlation with the fibre length in the different anthesis date samples (correlation coefficient is 0.929** ~ 0.973**), and a negative correlation with the fibre micronaire (correlation coefficient: -0.963** ~ -0.654*), fibre line density (correlation coefficient: -0.845** ~ -0.782**), fibre maturity (correlation coefficient: -0.924** ~ -0.697*), orientational separate angle (correlation coefficient: -0.906** ~ -0.749*) and orientational distribution angle (correlation coefficient: -0.791** ~ -0.574), but no correlation with the crystallinity, crystalline grain size and spiral angle.

As shown in ***Table 2***, the fibre length had a negative correlation with the fibre micronaire in the different anthesis date samples (correlation coefficient: -0.848** ~ -0.697*), a negative correlation with the fibre line density (correlation coefficient: -0.882** ~ -0.646*), fibre maturity (correlation coefficient: -0.896** ~ -0.639*), orientational separate angle (correlation coefficient: -0.888** ~ -0.668*) and orientational distribution angle (correlation coefficient: -0.769** ~ -0.541), but no correlation with the crystallinity, crystalline grain size and spiral angle.

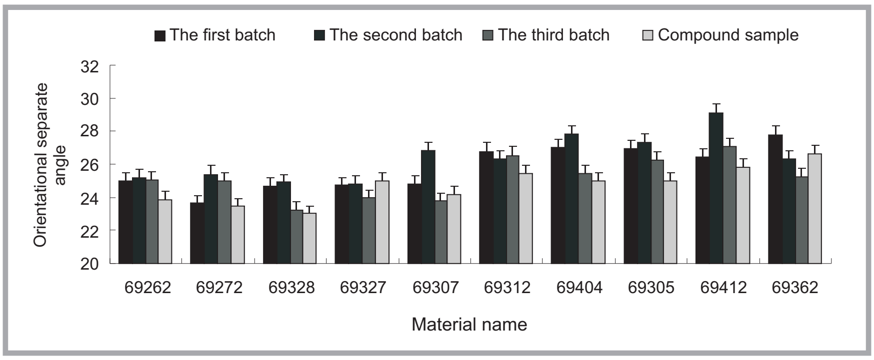

Figure 9. *Differences in the orientational separate angle in the various samples.*

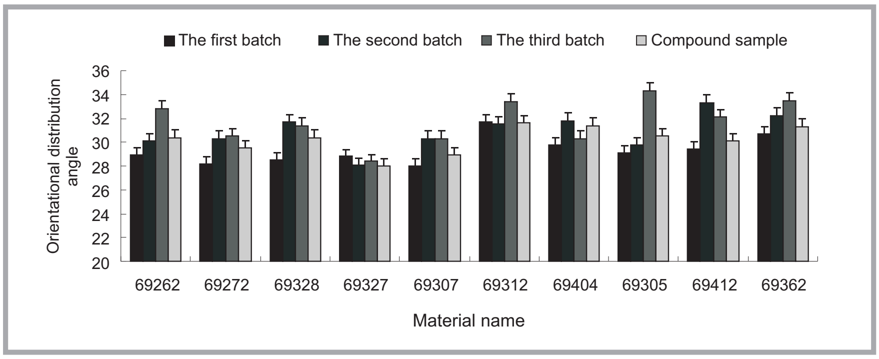

Figure 10. *Differences in the orientational distribution angle in the various samples.*

Table 1. *Correlation between fibre strength and quality characteristics with the super-molecular structure in the different samples: I: The first batch; II: The second batch; III: The third batch; IV: Compound sample; FS - fibre strength, FL - fibre length, MV - micronaire, LD - fibre line density, M - fibre maturity, Cry - crystallinity, CGS - crystalline grain size, φ - spiral angle, α - orientational separate angle, ψ - orientational distribution angle. ** Correlation is significant at the 0.01 level.* Correlation is significant at the 0.05 level.*

	FL	MV	LD	M	Cry	CGS	φ	A	ψ
I	0.935**	-0.963**	-0.782**	-0.924**	0.247	-0.424	-0.219	-0.906**	-0.695*
II	0.973**	-0.743*	-0.845**	-0.912**	0.309	-0.544	0.244	-0.792**	-0.791**
III	0.964**	-0.654*	-0.819**	-0.697*	-0.001	-0.302	0.158	-0.793**	-0.574
IV	0.929**	-0.905**	-0.830**	-0.760*	-0.629	-0.188	0.076	-0.749*	-0.743*

Table 2. *Correlation between the fibre length and quality characteristics with the super-molecular structure in the different samples.*

	FS	MV	LD	M	Cry	CGS	φ	A	ψ
I	0.935**	-0.848**	-0.709*	-0.776**	0.268	-0.289	-0.387	-0.841**	-0.605
II	0.973**	-0.755*	-0.882**	-0.896**	0.297	-0.613	0.287	-0.888**	-0.769**
III	0.964**	-0.735*	-0.873**	-0.670*	0.095	-0.467	0.084	-0.731*	-0.541
IV	0.929**	-0.697*	-0.646*	-0.639*	-0.665*	-0.258	0.142	-0.668*	-0.584

Table 3. *Correlation between micronaire and quality characters with its super-molecular structure in the different samples.*

	FS	FL	LD	M	Cry	CGS	φ	α	ψ
I	-0.963**	-0.848**	0.887**	0.901**	-0.303	0.360	0.056	0.935**	0.758*
II	-0.743*	-0.755*	0.914**	0.862**	0.050	0.705*	-0.382	0.518	0.422
III	-0.654*	-0.735*	0.966**	0.870**	-0.206	0.465	-0.112	0.528	0.424
IV	-0.905**	-0.697*	0.913**	0.774**	0.429	0.149	-0.064	0.715*	0.797**

As shown in ***Table 3***, the fibre micronaire had a positive correlation with the fibre linear density in the different anthesis date samples (correlation coefficient: 0.887** ~ 0.966**), with the fibre maturity (correlation coefficient: 0.774** ~ 0.901**), orientational separate angle (correlation coefficient: 0.518 ~ 0.935**), and orientational distribution angle (correlation coefficient: 0.422 ~ 0.797**), but no cor-

Table 4. Correlation between the linear density and quality characteristics with the super-molecular structure in the different samples.

	FS	FL	MV	M	Cry	CGS	φ	α	ψ
I	-0.782**	-0.709*	0.887**	0.637*	-0.364	-0.007	0.105	0.846**	0.825**
II	-0.845**	-0.882**	0.914**	0.889**	-0.157	0.626	-0.228	0.736*	0.553
III	-0.819**	-0.873**	0.966**	0.864**	-0.165	0.448	-0.163	0.666*	0.479
IV	-0.830**	-0.646*	0.913**	0.467	0.577	-0.035	0.124	0.602	0.906**

Table 5. Correlation between the maturity and quality characteristics with the super-molecular structure in the different samples.

	FS	FL	MV	LD	Cry	CGS	φ	α	ψ
I	-0.924**	-0.776**	0.901**	0.637*	-0.147	0.567	-0.039	0.766**	0.555
II	-0.912**	-0.896**	0.862**	0.889**	0.018	0.486	-0.185	0.641*	0.644*
III	-0.697*	-0.670*	0.870**	0.864**	-0.108	0.258	-0.138	0.632*	0.562
IV	-0.760*	-0.639*	0.774**	0.467	0.105	0.379	-0.394	0.712*	0.311

relation with the crystallinity, crystalline grain size and spiral angle.

As shown in ***Table 4***, the fibre linear density had a positive correlation with the fibre maturity in the different anthesis date samples (correlation coefficient: 0.467 ~ 0.889**) as well as with the orientational separate angle (correlation coefficient: 0.602 ~ 0.846**) and orientational distribution angle (correlation coefficient: 0.479 ~ 0.906**), but had no correlation with the crystallinity, crystalline grain size and spiral angle.

As shown in ***Table 5***, the fibre maturity had a positive correlation with the orientational separate angle in the different anthesis date samples (correlation coefficient is 0.632* ~ 0.766**)as well as with the orientational distribution angle (correlation coefficient is 0.311 ~ 0.644*), but had no correlation with the crystallinity, crystalline grain size and spiral angle.

The results showed that the fibre strength had a positive correlation with the fibre length in the different anthesis date samples, and a negative correlation with the fibre micronaire, line density, maturity, orientational separate angle, orientational distribution angle, but had no correlation with the crystallinity, crystalline grain size and spiral angle. This shows that the higher the fibre strength, the longer the fibre length, and the smaller the value of the fibre micronaire, linear density, maturity, orientational separate angle and orientational distribution angle. The fibre length had a negative correlation with the fibre micronaire, linear density, maturity, orientational separate angle and orientational distribution angle, but had no correlation with the crystallinity, crystalline grain size and spiral angle. This shows that the longer the fibre length, the smaller the value of the fibre micronaire, linear density, maturity orientational separate angle and orientational distribution angle. The fibre micronaire had a positive correlation with the fibre linear density, maturity, orientational separate angle and orientational distribution angle, but had no correlation with the crystallinity, crystalline grain size and spiral angle. This shows that the smaller the value of the fibre micronaire, the smaller the value of the linear density, maturity, orientational separate angle and orientational distribution angle. The fibre linear density had a positive correlation with the maturity, orientational separate angle and orientational distribution angle, but had no correlation with the crystallinity, crystalline grain size and spiral angle. This shows that the smaller the value of the fibre linear density, the smaller the value of the maturity, orientational separate angle and orientational distribution angle. The fibre maturity had a positive correlation with the orientational separate angle and orientational distribution angle, but had no correlation with the crystallinity, crystalline grain size and spiral angle. This shows that the smaller the value of fibre maturity, the smaller the value of the orientational distribution angle and orientational separate angle.

Discussion

The results showed that the fibre strength is between 30.5 cN/tex and 33.5 cN/tex, the fibre length between 27.38 mm and 33.12 mm, the fibre micronaire between 2.5 and 4.17, the fibre linear density between 107.0 mtex and 164.9 mtex, the fibre maturity between 0.60 and 0.97, the crystallinity between 73.1% and 80.2%, the crystalline grain size between 41 and 50 Å, the spiral angle between 10 and 15.5, the orientational separate angle between 23.0 and 26.8, and that the orientational distribution angle is between 28.0 and 32.8 in the five materials of high fibre strength.

The fibre strength is between 23.5 cN/tex and 29.2 cN/tex, the fibre length between 23.89 mm and 28.82 mm, the fibre micronaire between 3.47 and 5.39, the fibre linear density between 138.2 mtex and 204.5 mtex, the fibre maturity between 0.89 and 1.15, the crystallinity between 73.3% and 83.2%, the crystalline grain size between 41 and 50 Å, the spiral angle between 10 and 15.6, the orientational separate angle between 25.0 and 29.1, and the orientational distribution angle is between 29.1 and 34.3 in the five materials of low fibre strength.

The fibre strength and length are higher in the five materials with high fibre strength than in those with low fibre strength, being a reasonable difference. The fibre micronaire, fibre linear density, fibre maturity, orientational separate angle and orientational distribution angle are lower in the five materials with high fibre strength than in those with low fibre strength, but the difference is reasonable. Contrarily the crystallinity, crystalline grain size and spiral angle do not show reasonable variation between the five materials with high fibre strength and those with low fibre strength.

The results showed that the cotton fibre quality and fibre super-molecular structure did not have a reasonable difference in the various flowering dates.

The results indicated that the strength of cotton matured fibre had a positive correlation with the fibre length but a negative correlation with the fibre micronaire, line density and maturity. This shows that the higher the fibre strength, the longer the fibre length, and the smaller the value of the fibre micronaire, linear density and maturity. These results are in accordance with the research results reported. The fibre length had a negative correlation with the fibre micronaire, linear density and maturity. This shows that the longer the fibre length, the smaller the value of the fibre micronaire, linear density and maturity. The fibre maturity and linear density had a positive correlation with the fibre micronaire, which shows that the smaller the value of the fibre micronaire, the smaller that of the linear density and maturity. The fibre linear density had a positive correlation with the maturity, which shows that the smaller the value of the fibre linear density, the smaller the value of maturity.

Crystallinity does not show a reasonable difference in the various materials. The results indicated that the cotton matured fibre quality should not depend on the size of the crystallinity, especially the fibre strength. The results are in accordance with the research results reported.

The crystalline grain size is a stable trait of the fibre structure, but showed no reasonable difference in the various materials and had no correlation with the fibre strength, length, micronaire, linear density and maturity. The results indicated that the cotton matured fibre strength should not depend on the size of the crystalline grain size.

The cotton matured fibre quality should mainly depend on the decrease in the orientational parameter in the crystalline section, especially the orientational separate angle and orientational distribution angle. The results are very important for the theory and practice of cotton breeding. The spiral angle showed no correlation with the fibre strength, length, micronaire, maturity and linear density from the correlation analysis. Moreover the spiral angle showed no influence on the fibre quality.

Conclusions

The results obtained from the study lead to the following conclusions:

1) The cotton fibre quality and fibre super-molecular structure did not have a sensible difference for the various flowering dates.
2) The cotton matured fibre quality should not depend on the size of crystallinity.
3) The cotton matured fibre strength should not depend on the crystalline grain size.
4) The cotton matured fibre quality should mainly depend on the decrease in the orientational parameter in the crystalline section, especially the orientational separate angle and orientational distribution angle, but it had no correlation with the spiral angle. This shows that the smaller the value of the orientational separate angle and orientational distribution angle, the higher the fibre strength, the longer the fibre length, the smaller the value of the fibre micronaire, linear density and maturity, and the better the fibre quality.
5) The new points of the research:
   1. material innovation taking advantage of upland cotton $F_{6:9}$ recombinant inbred lines as study objects;
   2. the research content - the relationship between the linear density, maturity and fibre super-molecular structure was researched;
   3. the cotton matured fibre quality should mainly depend on the decrease in the orientational separate angle and orientational distribution angle, but had no correlation with the spiral angle.

Acknowledgements

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