NOTES

True Spiral Angle in Cotton of *Gossypium arboreum*

INTRODUCTION

The measure of spiral orientation by X-rays or optical techniques and the strength of cotton fibers are believed to be affected or distorted by the presence of convolutions and the shrinkage within individual fibers.[1-6] It is generally accepted that the X-ray orientation method gives a value that is a composite of true fibrillar orientation and convolution angle.[2,6-10] Meredith[7,8,11] eliminated the effect of convolution by substracting the convolution angle (θ) from the value of spiral angle (ϕ) calculated with the help of the refractive index. The difference gave the measure of the true spiral angle in cotton. However, since the X-ray angle is closely related to the angle of spirality (ϕ) and the values of the two are numerically very close, the substraction of the convolution angle (θ) from the X-ray angles would also yield a close measure of the true spiral angle. This argument has been previously used to calculate true spiral angles in solvent-exchanged never-dried cotton by Iyer et al.[1] Moharir et al.[12] used this argument in calculating at least three different close measures of the true spiral angle in *Gossypium hirsutum* cotton. The lower spiral angle is known to correspond to increased orientation of cellulose crystallites to the fiber axis and, consequently, to higher tenacity.[2,5,6,10,13,14] A comparison of correlations of various measures of true spiral angles with single fiber and bundle tenacity by Moharir et al.[12] indicated that the average angle of orientation (α_m) is the best measure of spirality for computing the true spiral angle in cotton, rather than the 40 or 50% X-ray angles, and also to characterize cotton fibers for strength. In this short note, spiral angle data on 24 varieties of yet another commercial species of cotton, namely, *Gossypium arboreum,* are presented and discussed.

EXPERIMENTAL

The 24 varieties of *Gossypium arboreum* listed in Table I were grown on the same farm at Sirsa, Haryana, India. Methods of purification of fibers and characterization along with extensive data on these varieties have been published elsewhere.[14-16] Only the data on convolution angles and the spiral angles are being presented here.

The Hermans crystallite orientation factors were computed following the graphical integration procedure due to Hermans.[10,14,17] The X-ray angles were measured from the normalized X-ray intensity distribution curves along the 002 reflections recorded on a Joyce Loebl microdensitometer from flat-plate X-ray Laue patterns of cotton fiber bundles. From the values of the Hermans orientation factor, the average angle of orientation (α_m) was computed. The number of convolutions per unit length of cotton fibers and the ribbon widths were measured on a Carl Zeiss optical microscope and the convolution angles were determined using Meredith's expression.[11,18] Three different close measures of the true spiral angle were computed by subtracting the values of the convolution angle (θ) from the values of the average angle of orientation (α_m) and the 40 and 50% X-ray angles. The correlations of various true spiral angle measures and other orientation parameters such as the Hermans factor, α_m, and 40 and 50% X-ray angles with fiber bundle tenacity (measured by Pressley strength tester) were computed and are reported in Table II.

DISCUSSION

It may be observed from Table I that the values of the Hermans factor within the varieties vary from the lowest 0.331 to the highest 0.671 within a range of 0.340. Correspondingly, the values of the average angle of orientation (α_m) vary from 27.9° to 41.9°. The 40 and 50% X-ray angles vary from 29.0° to 40.5° and from 24.0° to 36.0°, respectively. The number of convolutions per millimeter vary from 2.16 to 4.78 and convolution angles vary from 4.9° to 10.4°. The average value of the true spiral angles deduced from (α_m) and 40% X-ray angles are close to each other, whereas the average value of true spiral angles deduced from 50% X-ray angles is marginally lower. Similarly, the range of variation of true spiral angles from 40 and 50% X-ray angles is almost similar, but this range is marginally higher in true spiral angles deduced from (α_m). The lowest values of true spiral angles deduced from (α_m) and 40% X-ray angles are, however, the same within the varieties studied.

Correlations of bundle tenacity with various orientation parameters and true spiral angles (Table II) indicate that the Hermans factor (α_m) and 50% X-ray angles are better

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Table I Orientation, True Spiral Angle, Convolutions, and Bundle Tenacity Data of *Gossypium arboreum* Cotton

Sample No.	Cotton Variety	Hermans Factor (f)	Average Angle of Orientation α_m (°)	X-Ray Angles (°) 40% (A)	X-Ray Angles (°) 50% (B)	Convolution Angle (°) θ	Convolutions/mm	True Spiral Angles (°) ($\alpha_m - \theta$)	True Spiral Angles (°) ($A - \theta$)	True Spiral Angles (°) ($B - \theta$)	Bundle Tenacity N/tex
1	G-27	0.555	33.0	33.0	28.5	8.2	3.45	24.8	24.8	20.3	0.31
2	Shyamli	0.432	37.9	34.0	31.5	6.9	3.38	31.0	27.1	24.6	0.27 (L)
3	CJ-73	0.671 (H)	27.9 (L)	31.0	26.0	5.1	2.43	22.8 (L)	25.9	20.9	0.34 (H)
4	Daulat	0.417	38.5	33.0	30.0	9.0	3.89	29.5	24.0	21.0	0.30
5	Y-1	0.496	35.4	36.0	32.5	7.2	3.15	28.2	28.2	25.3	0.28
6	905	0.466	36.6	31.5	28.5	4.9 (L)	2.16 (L)	31.7	26.6	23.6	0.29
7	AKH-4	0.537	33.7	32.0	28.0	5.7	2.54	28.0	26.3	22.3	0.34 (H)
8	Virnar	0.534	33.8	35.0	31.5	6.9	2.91	26.9	28.1	24.6	0.30
9	G-27 × CJ-73	0.435	37.8	33.0	30.0	5.9	2.87	31.9	27.1	24.1	0.28
10	G-27 × 1946	0.416	38.6	40.5 (H)	36.0 (H)	7.3	3.62	31.3	33.2 (H)	28.7 (H)	0.27 (L)
11	G-27 × Daulat	0.438	37.7	34.0	30.0	9.3	4.43	28.4	24.7	20.7	0.29
12	G-27 × Y-1	0.331 (L)	41.9 (H)	37.0	31.0	6.4	2.95	35.5 (H)	30.6	24.6	0.27 (L)
13	G-27 × 905	0.531	34.0	29.0 (L)	24.0 (L)	6.2	2.86	27.8	22.8 (L)	17.8 (L)	0.33
14	G-27 × AKH-4	0.496	35.4	36.5	32.5	10.4 (H)	4.09	25.0	26.1	22.1	0.30
15	G-27 × 875	0.451	37.2	32.5	29.0	5.1	2.63	32.1	27.4	23.9	0.30
16	G-27 × 877	0.639	29.3	33.5	29.0	6.3	2.93	23.0	27.2	22.7	0.33
17	Shyamli × 1946	0.595	31.3	33.0	29.0	7.6	3.21	23.7	25.4	21.4	0.32
18	Shyamli × Daulat	0.467	36.5	33.0	30.0	10.2	4.78 (H)	26.3	22.8 (L)	19.8	0.29
19	Shyamli × Y-1	0.482	35.9	33.8	30.0	6.7	2.94	29.2	27.1	23.3	0.31
20	Shyamli × 905	0.448	37.3	37.0	32.5	6.5	3.09	30.8	30.5	26.0	0.29
21	Shyamli × AKH-4	0.575	34.6	34.0	29.5	7.2	3.19	27.4	26.8	21.8	0.30
22	Shyamli × Virnar	0.439	37.7	33.5	28.5	7.9	3.36	29.8	25.6	20.6	0.29
23	Shyamli × 875	0.585	31.7	31.3	27.5	6.2	2.90	25.5	25.1	21.3	0.32
24	Shyamli × 877	0.513	34.7	35.0	30.0	8.6	3.59	26.1	26.4	21.4	0.29
	Average values	0.497	35.35	33.83	29.77	7.15	3.22	28.19	26.65	22.61	0.31
	Range within the varieties (H–L)	0.340	13.5	11.5	12.0	5.5	2.62	12.7	10.4	10.9	0.07

(H): highest value; (L): lowest value.

Table II Correlations of Bundle Tenacity with Various Orientation Parameters and True Spiral Angle Measures in *Gossypium arboreum*

	Herman Factors (f)	Average Angle of Orientation (α_m) (°)	X-ray Angles (°) 40% (A)	X-ray Angles (°) 50% (B)	True Spiral Angles (°) ($\alpha_m - \theta$)	True Spiral Angles (°) ($A - \theta$)	True Spiral Angles (°) ($B - \theta$)
r	.806	− .825	− .655	− .721	− .686	− .480	− .561
P	> .001	> .001	> .01	> .001	> .001	> .05	> .01

α_m = average angle of orientation; A = 40% X-ray angle; B = 50% X-ray angle; θ = convolution angle; P = probability.

correlated with bundle tenacity with equal probability levels. The correlation value for the 50% X-ray angle is marginally lower. It may be curiously noted that from among the three true spiral angle measures the true spiral angle deduced from (α_m) correlates best with a 0.1% confidence level with bundle tenacity. The correlations of the other two true spiral angle measures with bundle tenacity are also significant but with a lower confidence level.

Recently, Iyer et al.[1] showed a constancy of spiral angle in solvent-exchanged never-dried cotton irrespective of species and attributed many of the differences in orientation factor between cotton varieties in the air-dried state to the presence of convolutions. This conclusion has been critically contested by Moharir.[19] Duckett and Goswami[4] suggest that the extent of transverse shrinkage is an essential factor in the formation of the convolution angle but has no influence on the spiral angle of the cellulose fibrils. Electron diffraction studies[20] indicate that there are no basic differences between orientation of cellulose crystallites and the size of the crystallographic units of cellulose in cotton of different varieties and species. The reasons for apparent differences in cotton varieties is suggested to be sought in some higher order of structural organization.[20] Whereas the range of variation in the true spiral angle deduced from 40 and 50% X-ray angles in tetraploid *Gossypium hirsutum* cotton[12] was observed to be 22.7° and 21.7°, respectively, this range of variation in respect to *Gossypium arboreum* cotton (Table I, three columns under True Spiral Angles subhead and the bottom row) is merely 10.4° and 10.9°, respectively. Apparently, the variation in the true spiral angle in diploid *Gossypium arboreum* species of cotton is about 50% less than in tetraploid cotton. This perhaps explains the reason why the Hermans factor and 40 and 50% X-ray angles in diploid species of cotton gave equally significant correlations[14-16,21] with bundle tenacity and not so significantly in the tetraploid cottons of *Gossypium hirsutum* and *Gossypium barbadense*.[14,22] On the other hand, the Hermans factor and the average angle of orientation (α_m) and also the true spiral angle deduced from (α_m) have consistently shown very high significant correlations with bundle tenacity[10,12,14-16,21,22] earlier and in *Gossypium arboreum* cotton (Table II). The lowest value of true spiral angle deduced from (α_m) very faithfully corresponds to the highest bundle tenacity value of the fibers (Table I, last four columns, sample nos. 3 and 13), which is, however, not the case with true spiral angles deduced from 40 and 50% X-ray angles.

It may thus be concluded from this that the true spiral angles in diploid *Gossypium arboreum* cotton vary within a narrow range but are not constant within species. Further, the average angle of orientation (α_m) measures the true spirality in cotton more faithfully than do the arbitrary 40 or 50% X-ray angles. This is evident from the correlations of true spiral angle deduced from (α_m) with bundle tenacity and with other orientation parameters

Table III Correlations among Various Orientation Parameters and True Spiral Angles

	Hermans Factor	Average Angle of Orientation (α_m)	40% X-ray Angle (A)	50% X-ray Angle (B)	($\alpha_m - \theta$)	($A - \theta$)	($B - \theta$)
Hermans factor	1	−0.986	−0.462	−0.514	−0.880	−0.341	−0.398
Average angle of orientation α_m		1.000	+0.468	+0.517	0.884	0.336	0.389
40% X-ray angle (A)			1.000	0.935	0.316	0.795	0.746
50% X-ray angle (B)				1.000	0.347	0.713	0.796
($\alpha_m - \theta$)					1.000	0.489	0.524
($A - \theta$)						1.000	0.930
($B - \theta$)							1.000

(Table III) in comparison to the corresponding correlations for the true spiral angles deduced from 40 and 50% X-ray angles.

References

1. P. Bhama Iyer, K. R. Krishna Iyer, and N. B. Patil, *J. Appl. Polym. Sci.,* **30,** 435 (1985).
2. J. O. Warwicker, R. Jeffries, R. L. Colbran, and R. N. Robinson, Pamphlet No. 93, Shirley Institute, Manchester, U.K., 1966.
3. K. L. Datar, S. M. Betrabet, and V. Sundaram, *Text. Res. J.,* **43,** 718 (1973).
4. K. E. Duckett and B. C. Goswami, in *Cotton in a Competitive World,* P. W. Harrison, Ed., The Textile Institute, Manchester, U.K., 1979; *Text. Res. J.,* **49,** 368 (1979).
5. S. M. Betrabet and R. L. N. Iyengar, *Text. Res. J.,* **34,** 36 (1964).
6. Fiber Tables according to P. A. Koch, *Cotton-1989,* Institut für Textiltechnik der Rheinisch Westfalischen Technischen Hochschule, Aachen, Germany.
7. R. Meredith, *J. Text. Inst.,* **37,** T-205 (1946).
8. R. Meredith, *Br. J. Appl. Phys.,* **4,** 369 (1953).
9. J. J. Hebert, *Text. Res. J.,* **37,** 57 (1967).
10. V. B. Gupta, A. V. Moharir, and B. C. Panda, in *Cotton in a Competitive World,* P. W. Harrison, Ed., The Textile Institute, Manchester, U.K., 1979, p. 83.
11. R. Meredith, *J. Text. Inst.,* **42,** T-291 (1951).
12. A. V. Moharir, J. Louwagie, L. Van Langenhove, and P. Kiekens, *J. Appl. Polym. Sci.,* **44,** 1913 (1992).
13. R. T. O. Connors, Ed., *Instrumental Analysis of Cotton Cellulose and Modified Cotton Cellulose,* Marcel Dekker, New York, 1972.
14. A. V. Moharir, *Indian J. Text. Res.,* **12,** 106 (1987).
15. K. M. Vijayraghavan, A. V. Moharir, B. C. Panda, K. C. Nagpal, D. K. Suri, and V. B. Gupta, *J. Text. Inst.,* **74,** 38 (1983).
16. A. V. Moharir, K. M. Vijayraghavan, B. C. Panda, and V. B. Gupta, *Text. Res. J.,* **52,** 756 (1982); also in *Proc. Internat. Conf. on Cotton Test,* Faserinstitut, Bremen West Germany, 1982.
17. P. H. Hermans, *Physics and Chemistry of Cellulose Fibres,* Elsevier, New York, 1949.
18. V. Sundaram and R. L. N. Iyeagar, Eds., *Hand-Book of Methods of Tests for Cotton Fibres, Yarns, and Fabrics,* Cotton Technological Research Laboratory, I.C.A.R., Bombay, India, 1968.
19. A. V. Moharir, *J. Appl. Polym. Sci.,* **44,** 1121 (1992).
20. J. J. Hebert, E. K. Boylston, and D. P. Thibodeaux, *Text. Res. J.,* **57,** 742 (1987).
21. A. V. Moharir, K. M. Vijayraghavan, B. C. Panda, D. K. Suri, and K. C. Nagpal, *Indian J. Text. Res.,* **11,** 117 (1986).
22. A. V. Moharir, K. M. Vijayraghavan, B. C. Panda, D. K. Suri, and K. C. Nagpal, *Indian J. Text. Res.,* **11,** 82 (1986).

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