True-Spiral Angles in Diploid and Tetraploid Native Cotton Fibers Grown at Different Locations

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ABSTRACT: In this article, data on true-spiral angles in respect to the same 12 cotton varieties grown at different agroclimatic locations and in different crop years in India are presented and discussed. It has been concluded that the values of true-spiral angles are different for different varieties but within a variety remain practically invariant irrespective of the location and environmental conditions of growth. The parameter therefore appears to be genetic in origin. It is believed that this information can be suitably exploited by progressive cotton breeders for evolving high-strength cottons, keeping in view the demand of the modern cotton processing technologies. © 1998 John Wiley & Sons, Inc. J Appl Polym Sci 70: 303–310, 1998

Key words: spiral angle; cotton; locations; variations, genetic

INTRODUCTION

Cotton fiber constitutes about 90–96% pure cellulose and this cellulose, deposited as long microfibrils, is almost wholly crystalline.[1–3] Early studies using optical polarized light microscopy had provided the first approximations about the orientation of the cellulose crystallites to the fiber axis.[1–5] The fibrillar nature of cellulose and its orientation to the fiber axis are very important for understanding the fine structure of cotton and the interfiber differences within and between the species of cotton. The molecular orientation in cotton cellulose is defined by the frequency of the distribution of the angles made by the molecular chains constituting the microfibrils with the fiber axis.[1] The determination of this distribution in the crystalline regions can be made by the X-ray diffraction technique. An average angle of orientation for spiraling fibrils can be obtained from which the "degree of orientation" can be calculated. Since the meridional (020) and (040) reflections are generally very weak to allow measurement of the diffracted intensity with reasonable accuracy along them, calculations are therefore conventionally made on the basis of measurements of the azimuthal variation of intensity along the strong (002) "equatorial" arc from cotton.

Clark[6] and Sisson and Clark[7] suggested and elaborated on the use of X-rays for the measurement of orientation. Sisson[8] not only described the physical meaning of the orientation by X-rays but also suggested the possibility of varying spiral angle in the diurnal growth layers of native cotton fibers. Meredith[9] proposed a constant spiral angle of undried cotton in all the genetic varieties and the issue has still not been settled as many workers believe that the spiral angle need not be constant for all genetic varieties of cotton.[10–25] Sisson[8] introduced and defined for the first time the 40% X-ray angle as the half-width of the azimulthal scan around the (002) equatorial arc in degrees of the X-ray diagram at 40% of the maximum intensity. It is also referred to as the

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Table I Data on X-ray Studies on Cotton Fibers: True-spiral Angles

Sample No.	Cotton Variety 1	Year of Growth 2	Location of Growth 3	True-spiral Angles (40% - θ) 4 (a)	(50% - θ) 4 (b)	(α_m - θ) 4 (c)
1	AKH-4	1992	Sirsa	22.39	18.64	27.79 (L)
2	AKH-4	1992	Nagpur	20.72	16.72	29.82
3	AKH-4	1992	Coimbatore	20.97	16.47	27.80
4	AKH-4	1994	Sirsa	21.38	17.38	30.18 (H)
5	AKH-4	1994	Nagpur	23.20	19.20	29.06
6	AKH-4	1995	New Delhi	18.13 (L)	15.13 (L)	28.93
7	AKH-4	1995	Nagpur	24.20 (H)	20.20 (H)	29.20
8	**Range of variation within variety (H - L)**			6.07°	5.07°	2.39°
9	**Average within variety**			21.57°	17.67°	28.96°
10	**Standard deviation**			1.97	1.76	0.91
11	AC-738	1994	Sirsa	16.38	13.38	24.58(L)
12	AC-738	1994	New Delhi	23.38 (H)	19.28 (H)	28.18
13	AC-738	1994	Nagpur	16.20 (L)	12.20 (L)	27.20
14	AC-738 (R-I)	1994	Nagpur	21.20	16.20	26.20
15	AC-738 (R-II)	1994	Nagpur	19.20	14.20	25.10
16	AC-738	1995	New Delhi	17.20	14.20	27.20
17	AC-738	1995	Nagpur	19.20	15.20	29.60 (H)
18	AC-738 (S)	1995	Coimbatore	19.40	16.40	27.20
19	**Range of variation within variety (H - L)**			7.18°	7.08°	5.02°
20	**Average within variety**			19.02°	15.13°	26.90°
21	**Standard deviation**			2.45	2.18	1.62
22	B.N.	1992	Sirsa	20.62	17.62	23.60(L)
23	B.N.	1992	Nagpur	18.10	15.10	28.00
24	B.N.	1992	Coimbatore	21.62	17.12	28.00
25	B.N.	1994	Sirsa	16.12	13.12	24.52
26	B.N.	1994	New Delhi	14.82 (L)	10.82 (L)	26.42
27	B.N.	1994	Nagpur	21.00	18.00	—
28	B.N.	1995	New Delhi	20.49	15.49	26.79
29	B.N.	1995	Nagpur	23.00 (H)	18.00 (H)	29.60 (H)
30	B.N. (S)	1995	Coimbatore	18.48	14.48	26.08
31	**Range of variation within variety (H - L)**			8.20°	7.18°	6.00°
32	**Average within variety**			19.36°	15.52°	26.66°
33	**Standard deviation**			2.68	2.46	1.95
34	Y-1	1994	Sirsa	17.87	14.37	27.57
35	Y-1	1994	New Delhi	18.30	14.30	27.80
36	Y-1	1995	Nagpur	20.80 (H)	16.80 (H)	29.10 (H)
37	Y-1 (S)	1995	Coimbatore	16.70 (L)	12.70 (L)	27.30 (L)
38	**Range of variation within variety (H - L)**			4.10°	4.10°	1.80°
39	**Average within variety**			18.41°	14.54°	27.94°
40	**Standard deviation**			1.73	1.69	0.80
41	Maljari	1992	Sirsa	21.55	18.30(H)	29.48
42	Maljari	1992	Nagpur	16.94 (L)	13.44 (L)	35.74 (H)
43	Maljari	1992	Coimbatore	21.99 (H)	14.12	28.90
44	Maljari	1994	Sirsa	20.55	16.55	26.25 (L)
45	Maljari (R-I)	1994	Nagpur	18.30	15.30	30.50
46	Maljari (R-II)	1994	Nagpur	21.30	16.30	29.30
47	Maljari	1995	Nagpur	21.30	17.30	28.60
48	Maljari (S)	1995	Coimbatore	19.30	16.30	28.00
49	**Range of varioation within variety (H - L)**			5.05°	4.86°	9.49°
50	**Average Within variety**			20.15°	15.95°	29.59°
51	**Standard deviation**			1.80	1.60	2.77

Table I *Continued*

				True-spiral Angles		
Sample No.	Cotton Variety 1	Year of Growth 2	Location of Growth 3	(40% - θ) 4 (a)	(50% - θ) 4 (b)	(α_m - θ) 4 (c)
52	AKA-5	1992	Sirsa	25.54(H)	21.04 (H)	29.59
53	AKA-5	1992	Nagpur	19.58	15.58	31.38 (H)
54	AKA-5	1992	Coimbatore	24.14	19.64	30.14
55	AKA-5	1994	Sirsa	20.22	17.72	26.92 (L)
56	AKA-5	1995	New Delhi	15.59 (L)	12.59 (L)	27.19
57	AKA-5 (S)	1995	Coimbatore	16.64	12.64	27.24
58	**Range of variation within variety (H - L)**			5.32°	8.45°	4.46°
59	**Average within variety**			20.28°	16.53°	28.74°
60	**Standard deviation**			3.95	3.55	1.88
61	LH-900	1992	Sirsa	19.42(H)	14.92 (H)	25.08
62	LH-900	1992	Coimbatore	17.20	13.35	25.28
63	LH-900	1994	Sirsa	13.60 (L)	9.60 (L)	21.60 (L)
64	LH-900	1994	Nagpur	19.38	14.38	26.18
65	LH-900	1995	Coimbatore	17.82	14.80	27.50 (H)
66	**Range of variation within variety (H - L)**			5.82°	5.32°	5.90°
67	**Average within variety**			17.48°	13.41°	25.12°
68	**Standard deviation**			2.38	2.22	2.20
69	LRA-5166	1992	Sirsa	21.52(H)	17.77	24.50
70	LRA-5166	1992	Coimbatore	18.35	14.97	25.96
71	LRA-5166	1994	Sirsa	16.02(L)	12.02 (L)	20.82 (L)
72	LRA-5166	1994	New Delhi	18.10	15.10	26.40
73	LRA-5166 (R-I)	1994	Nagpur	16.10	12.10	24.50
74	LRA-5166 (R-II)	1994	Nagpur	17.10	13.10	24.40
75	LRA-5166 (R-III)	1994	Nagpur	18.10	15.10	25.10
76	LRA-5166	1995	New Delhi	18.84	15.84	26.94
77	LRA-5166	1995	Nagpur	20.80	17.80 (H)	24.70
78	LRA-5166 (S)	1995	Coimbatore	20.80	17.80	28.30 (H)
79	**Range of variation within variety (H - L)**			5.50°	5,78°	7.48°
80	**Average within variety**			18.57°	15.16°	25.16°
81	**Standard deviation**			1.94	2.23	2.00
82	SRT-1, G. Cot-10	1992	Sirsa	20.07	16.32	28.88
83	SRT-1, G. Cot-10	1992	Coimbatore	20.82	17.07	27.90
84	SRT-1, G. Cot-10	1994	New Delhi	16.82 (L)	13.82 (L)	27.12 (L)
85	SRT-1, G. Cot-10	1995	New Delhi	17.90	14.90	27.60
86	SRT-1, G. Cot-10	1995	Nagpur	22.60 (H)	16.60 (H)	29.60 (H)
87	**Range of variation within variety (H - L)**			5.78°	4.78°	2.48°
88	**Average within variety**			19,64°	15.74°	28.22°
89	**Standard deviation**			2.31	1.34	1.00
90	Suvin	1992	Coimbatore	17.60	14.10	27.30
91	Suvin	1995	New Delhi	16.50	12.50 (L)	27.00 (L)
92	Suvin	1995	Nagpur	18.60 (H)	15.60 (H)	27.10
93	**RAnge of variation within variety (H - L)**			2.10°	3.10°	0.20°
94	**Average within variety**			17.56°	14.06°	27.13°
95	**Standard deviation**			1.05	1.55	0.15
96	Jyoti	1994	Sirsa	19.50(H)	15.50 (H)	28.30 (H)
97	Jyoti (S)	1995	Coimbatore	17.79 (L)	14.79 (L)	26.49 (L)

Table I *Continued*

				True-spiral Angles		
Sample No.	Cotton Variety 1	Year of Growth 2	Location of Growth 3	(40% - θ) 4 (a)	(50% - θ) 4 (b)	(α_m - θ) 4 (c)
98	Jyoti (R)	1995	Coimbatore	17.90	14.79	28.10
99	**Range of variation within variety (H - L)**			1.71°	0.71°	1.81°
100	**Average variety**			18.39°	15.02°	27.63°
101	**Standard deviation**			0.96	0.41	0.99
102	G. Cot-13	1994	Dhandhuka	20.23	16.23	28.43(H)
103	G. Cot-13	1994	Chharodi	21.10 (H)	17.10 (H)	28.23
104	G. Cot-13	1995	Dhandhuka	20.23 (L)	16.23 (L)	19.63 (L)
105	**Range of variation within variety (H - L)**			0.87°	0.87°	8.80°
106	**Average within variety**			20.52°	16.52°	25.43°
107	**Standard deviation**			0.50	0.50	5.00

H: highest value within variety; (H - L): range of variation; L: lowest value within variety; S: summer-grown crop at Coimbatore; R: regular winter crop at Coimbatore.

X-ray angle. Subsequent workers have found it convenient to define the orientation in terms of 40, 50, or 75% X-ray angles and several improvements in the methods of the measurement of X-ray angles were suggested by Creely et al.,[26] who also suggested that a 40% X-ray angle has no advantage over a 50% X-ray angle and the latter is not only easier to use but can also find some theoretical justification for its use as the half-width of a spectral line intensity peak in spectroscopy. The choice of 40, and 75% X-ray angles is therefore purely arbitrary. Subsequent workers have almost all used the 50% X-ray angle in preference to the 40% X-ray angle.[27–36] A general mathematical relation of the orientation of units of cellulose in a fiber for both optical and X-rays has been worked out,[29,37,38] but the analysis proposed by De Luca and Orr[39] is considered an advance in that it rightly emphasized the complicated nature of the X-ray angle and it is felt that there is still need to extend the work to clarify this subject. It is generally accepted that the X-ray orientation method gives a value which is a composite of the true fibrillar orientation and convolution angle.[28] Meredith[9,40,41] eliminated the effect of convolution by subtracting the convolution angle (θ) from the value of the 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 subtraction 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.[42] Moharir[43] and Moharir et al.[44,45] proposed and used this argument in calculating at least three different close measures of the true-spiral angle in *Gossypium hirsutum* and *Gossypium arboreum* cotton. Also, while doing so, they emphatically determined the choice of the average angle of orientation (α_m) derived from the Hermans crystallite orientation factor (*f*) to be the best index of spirality for computing the true-spiral angle in cotton. In this report, the data on true-spiral angles in respect of the same cotton varieties grown at different agroclimatic locations in India are presented and discussed.

MATERIALS AND METHODS

Cotton Varieties and Convolution Angle Measurement

The same 12 cotton varieties were grown in different crop years and at locations spread over between 11°00' north to 29°11' north latitudes in India. Field-dried seed cotton from individual locations of growth were collected and ginned on a Cotton Technological Research Laboratory model laboratory gin. The fibers separated were individually mounted straight on glass slides with the help of a quick-fix adhesive. The fibers were scanned linearly using a Carl Zeiss optical micro-

Table II Locationwise Average Values of True-spiral Angles for all Crop Years

Sample No.	Cotton Variety	Location Growth	Average Value of True-spiral Angle (°)		
			(40% - θ)	(50% - θ)	(α_m - θ)
	1	2	3	4	5
1	AKH-4	Sirsa	21.88	18.01	28.98
2	AKH-4	New Delhi	18.13	15.13	28.93
3	AKH-4	Nagpur	22.70	18.70	29.36
4	AKH-4	Coimbatore	20.97	16.47	27.80
5	AC-738	Sirsa	16.38	13.38	24.58
6	AC-738	New Delhi	20.29	16.74	27.69
7	AC-738	Nagpur	18.95	15.45	27.02
8	AC-738	Coimbatore	19.40	16.40	27.20
9	B.N.	Sirsa	18.37	15.37	24.06
10	B.N.	New Delhi	17.65	13.15	26.60
11	B.N.	Nagpur	20.70	17.03	28.80
12	B.N.	Coimbatore	20.05	15.80	27.04
13	Y-1	Sirsa	17.87	14.37	27.57
14	Y-1	New Delhi	18.30	14.30	27.80
15	Y-1	Nagpur	20.80	16.80	29.10
16	Y-1	Coimbatore	16.70	12.70	27.30
17	Maljari	Sirsa	21.05	17.42	27.86
18	Maljari	Nagpur	19.46	15.58	31.03
19	Maljari	Coimbatore	20.64	15.21	28.45
20	AKA-5	Sirsa	22.88	19.38	28.25
21	AKA-5	New Delhi	15.59	12.59	27.19
22	AKA-5	Nagpur	19.58	15.58	31.38
23	AKA-5	Coimbatore	20.39	16.14	28.69
24	LH-900	Sirsa	16.51	12.26	23.34
25	LH-900	Nagpur	19.38	14.38	26.18
26	LH-900	Coimbatore	17.51	14.07	26.39
27	LRA-5166	Sirsa	18.77	14.89	22.66
28	LRA-5166	New Delhi	18.47	15.47	26.67
29	LRA-5166	Nagpur	18.00	14.52	24.67
30	LRA-5166	Coimbatore	18.35	14.97	25.96
31	SRT-1 G. Cot10	Sirsa	20.07	16.32	28.88
32	SRT-1 G. Cot10	New Delhi	17.36	14.36	27.35
33	SRT-1 G. Cot10	Nagpur	22.60	16.60	29.60
34	SRT-1 G. Cot10	Coimbatore	20.82	17.07	27.90
35	Suvin	New Delhi	16.50	12.50	27.00
36	Suvin	Nagpur	18.60	15.60	27.10
37	Suvin	Coimbatore	17.60	14.10	27.30
38	Jyoti	Sirsa	19.50	15.50	28.30
39	Jyoti	Coimbatore	17.84	14.79	27.29
40	G. Cot13	Chharodi	21.10	17.10	28.23
41	G. Cot13	Dhandhuka	20.23	16.23	24.03

scope and the number of convolution twists along the length of the fibers were physically counted. Likewise, the ribbon width of the cotton fibers along the length was measured and an average of over 300 observations was recorded. The values of the convolution angles (θ) in degrees were computed for each cotton cultivar using Meredith's formula.[41,46]

Table III Correlations of the Three Close Measures of True-spiral Angles with Bundle Fiber Tenacity

Measurements	True Spiral Angles		
	(40% - θ)	(50% - θ)	(α_m - θ)
Hermans factor	$\gamma = -0.314$ $P > 0.01$	$\gamma = -0.341$ $P > 0.01$	$\gamma = -0.370$ $P > 0.01$
Average angle of orientation (α_m)	$\gamma = 0.325$ $P > 0.01$	$\gamma = 0.238$ $P > 0.05$	$\gamma = 0.318$ $P > 0.01$
40% X-ray angle	$\gamma = 0.709$ $P > 0.001$	$\gamma = 0.653$ $P > 0.001$	$\gamma = 0.061$ N.S.
50% X-ray angle	$\gamma = 0.418$ $P > 0.001$	$\gamma = 0.623$ $P > 0.001$	$\gamma = 0.011$ *N.S.*
75% X-ray angle	$\gamma = 0.583$ $P > 0.001$	$\gamma = 0.612$ $P > 0.001$	$\gamma = 0.087$ N.S.
Bundle fiber tenacity	$\gamma = -0.348$ $P > 0.01$	$\gamma = -0.295$ $P > 0.05$	$\gamma = -0.144$ N.S.

P: probability; N.S.: not significant; γ: correlation coefficient.

Measurement of 40 and 50% X-ray Angles

X-ray azimuthal scans from a well-parallelled bundle of cotton fibers along the strong equatorial (002) reflections were normalized, and from the normalized plots of these diffracted X-ray intensities, the angles corresponding to the decrease of the maximum intensity to 40 and 50% of its value were read as the 40 and 50% X-ray angles.

Measurement of the Average Angle of Orientation (α_m)

The values of the average angle of orientation (α_m) in respect to the cotton varieties were derived from the values of $\overline{\sin^2\alpha_m}$ computed for the determination of the Hermans crystallite orientation factor following the graphical integration procedure due to Hermans.[3]

Measures of True-spiral Angles

Three different close measures of the true spiral angles were computed in respect to the cotton varieties studied, following the logic of Iyer et al.[42] by subtracting the values of the convolution angle (θ) from the values of the 40 and 50% X-ray angles and the average angle of orientation (α_m) as suggested earlier by Moharir[43] and Moharir et al.[44,45] The data on the three close measures of the true-spiral angles are given in Table I. In Table II are given the locationwise average values of the true-spiral angles for individual cotton varieties for all crop years and replications. Table III gives the computed correlation coeffcients of the bundle fiber tenacity of the cotton varieties with the three close measures of the true-spiral angles.

RESULTS AND DISCUSSION

It can be observed from Table I columns 4a, 4b, and 4c that the range of variation in the values of the true-spiral angle within individual cotton varieties, grown at different locations and in different crop seasons, is generally maximum for the true-spiral angle (40% - θ) and least for (α_m - θ). Also, all the three different measures of the true-spiral angles vary not only within the individual variety grown at different locations but also between different varieties. From the locationwise average values of the true-spiral angles (irrespective of the number of replicates) given in Table II, it could be observed that there is definitely no pattern of variation in the values of all three measures of the true-spiral angle with the locations of the growth of the cotton varieties, when the locations are spread over between 11°00' north to 29°10' north latitudes in India. Moreover, the values of all three measures of the true-spiral angles, particularly (40% - θ) and (α_m - θ), within a variety are nearly the same irrespective of the location of the growth of cotton. This would be seen in sharper focus from the values for varieties

AKH-4, Maljari, LRA-5166, and SRT-1 G. cot 10. However, the values of the spiral angles vary between varieties although the variation is very narrow. Variety LRA-5166 shows practically uniform values for both (40% - θ) and (50% - θ) for all locations. It may also be mentioned here that this variety also showed an almost uniform rate for cellulose synthesis at different locations.[47] No wonder that the LRA-5166 variety is being regarded by cotton breeders and agronomists as highly adaptable to various locations in India.

Lower values of the spiral angle correspond to increased orientation of the cellulose crystallites to the fiber axis and, consequently, to higher strength of the fibers. Comparing the correlation coefficients of the three different close measures of the true-spiral angles with the bundle fiber tenacity of the fibers and other orientation parameters (Table III) reveals that the true-spiral angle (α_m - θ) correlates best with the Hermans crystallite orientation factor and the average angle orientation and (α_m), as compared to the other measures of true-spiral angle (40% - θ) and (50% - θ). (α_m - θ) also does not significantly correlate with the 40, 50, and 75% X-ray angles, whereas the correlations of the other two measures of the true-spiral angles, (40% - θ) and (50% - θ), are very significant with the 40, 50, and 75% X-ray angles, and with bundle fiber tenacity. The correlations of (α_m - θ) with bundle fiber tenacity are, however, surprisingly nonsignificant, because in earlier studies that were reported on a large number of cotton varieties of *G. hirsutum* and *G. arboreum* species[44,45], this parameter had shown the best correlations with the bundle tenacity. Nevertheless, the correlations of the Hermans crystallite orientation factor and the average angle of orientation (α_m) are uniformly significant with all the orientation parameters and with bundle fiber tenacity.

It may thus be concluded that whereas the values of true-spiral angles are different for different varieties they are practically invariant within a variety irrespective of the location of the growth of cotton. Therefore, the parameters seem to be genetic in their origin and are not dependent on environmental conditions of growth. This result can be profitably exploited by progressive cotton breeders in breeding newer varieties with increased strength of the fibers, keeping in view the demand of the new spinning technology for the increased strength of cotton fibers for efficient production.[47]

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