

CONVOLUTIONS IN THE SAME DIPLOID AND TETRAPLOID COTTON VARIETIES GROWN AT DIFFERENT AGROCLIMATIC LOCATIONS

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Abstract

In this paper the literature on the origin and growth of characteristic convolution twists on naturally dehydrated cotton fibres is briefly reviewed and discussed. Also presented are the data on average convolutions and convolution angles, in respect of a large number of the same, diploid and tetraploid cotton varieties, grown at different agroclimatic locations in India during 1992, 1994 and 1995 crop years. From the location wise average values of both these parameters for individual cotton varieties, it has been concluded that both, convolutions and convolution angles are genetically determined. Their values between different varieties of cotton differ but within a variety, remain practically invariant with the location of growth of cotton.

Introduction

A cotton fibre is an elongated cylindrical cell from the epidermis of the cotton seed (Balls, 1928; Maursberger, 1954; Cotton Monograph, 1960). In the never-dried state it has been shown to have a circular cross section (Chauhan, et.al. 1981; Peeters, et.al. 1986). However, mature dehydrated cotton hair cells collapse into kidney-bean shaped flat ribbons with characteristic twists along their length, called the "convolutions" (Balls, 1928; Maursberger, 1954; Meredith, 1963). Convolutions have been studied by several workers (Balls, 1922, 1923, 1928; Betrabet, 1967; Betrabet, et.al. 1960, 1964; Balls and Hancock, 1926; Flint, 1950, Meredith, 1951, 1963, 1970; Clegg and Harland, 1924; Datar, et.al. 1973; De Boer, 1977; Denham, 1923; Duckett and Cheng, 1972; Duckett and Goswami, 1979, 1979; Grant and De Gruy, 1972; Hebert, et.al. 1970; Hebert, 1975; Hearle and Sparrow, 1979; Moharir, et.al. 1979, Moharir, 1980) and although they are known to be formed as a result of dehydration of fibres, there is no agreement on the relative roles played by genetic and environmental factors (Betrabet, et.al. 1964; Moharir, et.al. 1979; Moharir, 1980). Both, immature dead and extremely mature cotton fibres have either no convolutions or very few. Only the fibres with average developed secondary wall show a maximum number of convolutions (Tripp and

Giuffria, 1954; Betrabet and Iyengar, 1964). There are fewer convolutions per centimeter on fibres of diploid *Gossypium herbaceum* and *Gossypium arboreum* cotton than on fibres of tetraploid *Gossypium barbadense* and *Gossypium hirsutum* cotton (Betrabet and Iyengar, 1964; Betrabet, et.al. 1973; Datar, et.al. 1973;). Balls (1928) suggested, that the underlying spiral of the cellulose fibrillar elements of the secondary wall causes their formation. However some observations on *Gossypium hirsutum* varieties of cotton (Moharir, et.al. 1979; Moharir, 1980) indicated that convolutions in cotton appear to be related to the diurnal variations in temperature cycles during the desiccation period. Whatever, the cause of origin and formation, it is generally agreed that the convolutions greatly affect many of the physical properties of the cotton fibre and provide the essential inter-fibre grip in yarns.

Chemically, a cotton fibre contains 95-97% pure cellulose (Maursberger, 1954; Warwicker, et.al. 1966, Nevell and Zeronian, 1985) and four distinct polymorphs of cellulose are known (Maursberger, 1954, Warwicker, et.al. 1966, Clark, 1963). A bulk of the cellulose in cotton lays within the secondary diurnal growth layers as crystalline microfibrils that spiral about the axis of the fibre (Balls, 1928, Maursberger, 1954; Cotton Monograph, 1960; Warwicker, et.al. 1966; Hermans, 1946; Preston, 1952, 1974), and this cellulose conforms (Maursberger, 1954; Warwicker, et.al. 1966; Hermans, 1946; Preston, 1952, 1974; Shenouda, 1979; Wellard, 1954; Jones, 1971) to the crystal structure of cellulose-I. Cellulose of the primary wall of developing cotton fibres is also known to be crystalline but its crystal structure conforms to cellulose-IV (Chanzy, et.al. 1978).

Peeters and De Langhe (1986) have shown that the volume density of cellulose in never-dried developing cotton fibres is 0.605 gm/cm³ and that this value is independent of the genetic species of cotton. Electron diffraction studies (Dobb, et.al. 1979) indicate that there are no obvious differences in the nature of the crystallographic units or the supramolecular "crystalline aggregates" of cellulose between cotton species. Even the degree of orientation of crystallites within fibrils does not deviate appreciably from one species of cotton to another (Hebert, et.al. 1973; Iyer, et.al. 1985). The reasons for obvious differences in mechanical properties between varieties have been suggested to be sought, at some higher levels of structural organization (Dobb, et.al. 1979).

There are currently two structural models of cotton; (i) constant spiral angle model and (ii) constant gyre-length model (Meredith, 1963; Duckett and Ramey, 1981; Betrabet, et.al. 1963; Hartshorne, 1959; Morosoff and Ingram, 1970; Stephens, 1978), and there is considerable confusion about the details of the helical disposition of cellulose microfibrils within successive diurnal growth layers (Meredith, 1951; Warwicker, et.al. 1966; Betrabet, et.al. 1963, Morosoff and Ingram, 1970; Anderson

and Kerr, 1938; Hock, 1952; Orr, et.al. 1961; Hebert, 1967; Raes, et.al. 1968; Muhlethaler, 1949; Balls and Hancock, 1922; Flint, 1950; Waterkeyn, et.al. 1975). Meredith (1963) proposed a constant spiral angle in undried-unconvoluted cotton of all the genetic species and some workers support him (Iyer, et.al. 1985 ; Hartshorne, 1959; Morosoff and Ingram, 1970; Stephens, 1978; Hebert, 1967). However several others (Warwicker, et.al. 1966, Duckett and Ramey, 1981; Waterkeyn, et.al. 1975; Iyer, et.al. 1969, 1977; Kalyanaraman, 1978, 1980; Manjunath, 1970) believe that the spiral angle is not necessarily constant. Duckett and Ramey (1981) have shown a rapid decrease in spiral angle in the outermost diurnal layers while the spiral angle of the innermost layers approaches constancy. Duckett and Ramey (1981) also suggest that the extent of transverse shrinkage is an essential factor in the formation of the convolution angle and the transverse shrinkage does not alter the original spiral angle of the fibrils. Spiral orientation measurements, whether they are done by X-rays or by optical techniques as well as the strength of fibres are affected or distorted by the presence of convolutions and shrinkage within individual fibres (Meredith, 1951, 1963; Betrabet, et.al. 1960, 1963, 1964 ;Hebert, et.al. 1970 ;Hebert, 1975 ;Datar, et.al. 1973; Sundaram and Nanjundayya, 1957; Duckett and Tripp, 1967). Hebert et.al. (1987) however demonstrated that, both the X-ray and optical orientation measurement techniques give essentially similar results and they reject the earlier belief (Duckett and Ramey, 1981; Hamza, 1980) that the Becke-line optical microscopic method measures only the refractive index of the outer layers of cotton fibres.

Betrabet and Iyengar (1964) obtained a significant correlation between the convolution angle and strength of fibres and showed that in spite of inter-species differences a common regression line could be fitted. Datar et.al. (1973) however found no significant correlation between the convolution angle and strength in *Gossypium herbaceum* cottons. Duckett and Goswami (1979) showed that the strength of cotton within the same variety depends on the wall thickness and is not correlated with fibre diameter, or number of convolutions. It is generally accepted that the X-ray orientation method gives a value which is composite of fibrillar orientation and convolution angle (Warwicker, et.al. 1966, Moharir, 1987) and yet uncorrected values of X-ray angles (for contribution of convolutions) have shown excellent correlations with mechanical properties of fibres (Warwicker, et.al. 1966; Moharir, 1987; Koch, 1979). Iyer et.al. (1985) attributed many of the differences in orientation factor between cotton varieties in air-dried state, to the presence of convolutions. All these observations suggest that the present understanding about the mechanism of formation of convolutions, the conditions under which they are formed and their effect on the physical and technological properties of fibres is insufficient.

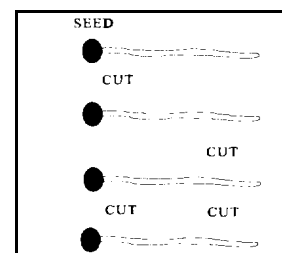
In some interesting observations, on same desiccating fibres for successive eight days, Moharir (1980) observed, that the

first definite convolution twist appears close to the tip of the fibres which progressed with the formation of more convolutions towards the base of the fibres as desiccation proceeds, Figure 1. Similar observations for a period of 25 days were made earlier by Balls and Hancock (1922, 1926). A consequence of such a phenomena implies that there are fewer number of convolutions towards the base of the fibres than in the middle and tip portion. The observations of Seshan (1978) indeed show that the frequency of convolutions decrease from the tip towards the base of the fibres. Perhaps it is because of this difference in convolution frequency along the length of the fibres, that Betrabet et.al. (1960) were compelled to propose measurements of convolutions in the middle portion of fibres.

Moharir and Kiekens (1991) further observed that the average number of convolutions in fibres of *Gossypium hirsutum* variety 278-11 at 10, 20, 34, 55, 80 and 91 days after boll opening, increases exponentially with number of days of desiccation and reaches an asymptotic value after about 35 days. Moharir and Kiekens (1991) also did not observe any variation in the average number of convolutions per centimeter along the fibre length, when fibres from mature cotton bolls(flowered on the same day) were dehydrated at 60° C in an oven and in the laboratory at room temperature after cutting the fibres in three different ways as shown in Figure 2.

This observation suggests that the spiral structure laid down during the secondary wall thickening period and not the temperature of desiccation, plays a deterministic role in the formation of convolutions in agreement with the observations of Balls (1928).

In this investigation, the data on locationwise average values of convolutions and convolution angle measured on the same thirteen cotton varieties grown at four different locations during 1992, 1994 and 1995 crop years are presented and discussed.



Materials and Methods

Same thirteen cotton varieties were grown at four different agroclimatic locations ,Sirs, New Delhi, Nagpur and Coimbatore during 1992, 1994 and 1995 crop years. Matured seed cotton harvested from the field dried bolls from the first picking were ginned and fibres collected. Raw fibres were mounted straight parallel on glass slides with the help of quickfix adhesive and scanned linearly under Carl Zeiss optical microscope and the convolutions physically counted. An average of 160 individual fibres was taken as the representative value for each variety. Likewise , the ribbon width of the fibres was measured while counting the convolutions and an average of 300 such

observations taken along the lengths of fibres. Convolution angles were computed using the Meredith's (1951) formula.

$$\tan q = \frac{p}{2} \left(\frac{D}{C} \right)$$

where D and C are the average values of ribbon width and pitch of the convolutions. The locationwise average values for convolutions and convolution angles for years 1992, 1994 and 1995 crop years are given in Table 1.

Results and Discussion

Analysis of the data on convolutions and convolution angles in respect of the same cotton varieties grown at four different agroclimatic locations and in different crop years indicate that the average value of convolutions per centimeter on fibres of the same variety vary with location of growth of cotton. The range of variation differs from about 7% to as high as 50% and more between varieties. In spite of this, the variation in most of the varieties is not very drastic and the values of convolutions per centimeter length of fibres for widely different locations within a variety are nearly equal or very close to the same value. The same can be described about the values of convolution angles. The situation can be seen in striking contrast from Table-1, column 3, which give the locationwise average values of convolutions for different crop years, irrespective of different number of replications for each location and crop years. These values, nevertheless, very clearly, bring home the fact that convolutions per centimeter for a genetic variety, remains practically invariant over the years, although its individual value for any particular year may vary. Similarly, the convolution angle also remains practically invariant with location and crop year of growth of cotton variety. These observations suggest that both these parameters appear to be genetically determined and are not very drastically influenced by environmental conditions of growth or location. This is an important conclusion and may set to rest the hitherto prevalent controversy over the origin of convolutions being genetic or environmental (Balls, 1928; Clegg and Harland, 1924; Betrabet, 1967; Hearle and Sparrow, 1979). In Table- 2 are presented the correlation coefficients of convolution angle with important orientation parameters only. The actual values of orientation parameters have been described elsewhere (Moharir and Kiekens, 1997). It would be observed from this table that convolution angle correlates very significantly with convolution per centimeter length of fibre, 75% X-ray angle and almost at the same significance levels with the three different measures of true-spiral angles (40%-q), (50%-q) and (a_m -q). Its correlation with relative orientation/crystallinity index w.r.t. Ramie fibres (Moharir and Kiekens, 1997) is also not significant as with the Hermans factor. However the negative sign of both these correlations indicates that increased number of convolutions decrease Hermans factor or the relative orientation w.r.t. ramie values. And since higher values of Hermans factor correspond with higher bundle fibre

tenacity of fibres, it implies that fibres with higher values of Hermans factor or bundle fibre tenacity should have lower values of convolution angle and in turn lower number of convolutions per centimeter of fibre length. This conclusion is in perfect agreement with the findings of Meredith and others (Meredith, 1951, 1963; Betrabet, et.al. 1960, 1963, 1964; Hebert, et.al. 1970; Hebert, 1975; De Boer, 1977; Duckett and Tripp, 1967; Sundaram and Nanjundayya, 1957), who pointed out that increased number of convolutions pull down the strength of fibres and correspond with higher values of X-ray angles (Hebert, et.al. 1970, Hebert, 1975). 75% X-ray angle has been shown by some to be close to the true-spiral angle in cotton (Moharir, 1987). Although 40% and 50% X-ray angles and even average angle of orientation (a_m) show insignificant correlations with convolution angle, its significant correlation with 75% X-ray angle points to the fact that fibres with lower spiral angle are least convoluted.

Since the volume density of cellulose in never-dried cotton fibres and the size of the supramolecular crystalline structural unit of cellulose irrespective of the species and growth conditions have been shown to be invariable (Peeters and De Langhe, 1986; Dobb, et.al. 1979; Hebert, et.al. 1973), the observed differences in convolution number within individual varieties grown at different locations (Table-1) may possibly be occurring as a result of the differences in the rates of cellulose biosynthesis (Marx Figini, 1969; Gipson, 1980; Mergeai, et.al. 1985; Akhmedov and Abdullaev, 1982; Imamliiev, et.al. 1988) and its packing density within the secondary diurnal growth layers of developing cotton fibres. Cellulose biosynthesis, its deposition, extent of cell wall thickness and convolution number induced during dehydration are very much inter-related, and in a very complex way are controlled by several factors such as the genetic (Marx Figini, 1969), the physiological and agroclimatic conditions and the day length (Cotton Monograph, 1960; Gipson, 1980; Stewart, 1980). Moharir and Kiekens (1997) have also shown that the rates of biosynthesis of cellulose within fibres of the same genotypes vary with latitude of the place of growth of cotton. The observations of Duckett and Goswami (1979) that the strength of cotton within the same variety depends on the wall thickness and consequently on the cellulose synthesis and not on fibre diameter or number of convolutions, therefore seems justified. Some workers (Meredith, 1951; Warwicker, et.al. 1966; Betrabet, et.al. 1963) have pointed out that an increase in number of convolutions affects negatively the cellulose crystallite orientation and consequently the strength of fibres. The conclusions of the studies on crystallite orientation reported elsewhere (Moharir and Kiekens, 1997) however point out that there is no significant variation in the average value of orientation within a variety when grown at different agroclimatic locations, although individual values of cellulose crystallite orientation vary between varieties.

In conclusion it may be said that convolutions and their number appear to be genetic in nature and they do not depend upon the orientation but on the cell wall thickness and consequently on rates of cellulose biosynthesis and its deposition within walls of developing cotton fibres.

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Table-1. Locationwise average values of convolutions and convolution angles for all years of crop growth.

S. No.	Cotton variety	Location of growth	Average value	
			Convolutions per cm	Convolution Angle(q) degree
1	2	3	4	
1.	AKH-4	Sirsa	43.86	7.61
	AKH-4	New Delhi	44.36	6.87
	AKH-4	Nagpur	43.83	7.04
	AKH-4	Coimbatore	41.28	7.53
	Std.Deviation		1.39	0.36
2.	AC-738	Sirsa	62.03	11.62
	AC-738	New Delhi	52.57	8.76
	AC-738	Nagpur	51.83	8.80
	AC-738	Coimbatore	58.77	9.60
	Std.Deviation		4.92	1.34
3.	B.N.	Sirsa	61.47	10.88
	B.N.	New Delhi	52.62	8.84
	B.N.	Nagpur	49.81	8.09
	B.N.	Coimbatore	51.99	8.80
	Std.Deviation		5.14	1.20
4.	Y-1	Sirsa	40.61	7.13
	Y-1	New Delhi	40.56	6.70
	Y-1	Nagpur	47.88	7.20
	Y-1	Coimbatore	44.52	7.30
	Std.Deviation		3.52	0.26
5.	Maljari	Sirsa	48.67	8.45
	Maljari	New Delhi	41.00	6.00
	Maljari	Nagpur	43.85	7.63
	Maljari	Coimbatore	43.29	7.26
	Std.Deviation		3.22	1.02

6.	AKA-5	Sirsa	43.67	7.46
	AKA-5	New Delhi	42.20	7.41
	AKA-5	Nagpur	38.43	6.11
	AKA-5	Coimbatore	48.85	8.36
	Std.Deviation		4.31	0.92
7.	LH-900	Sirsa	62.55	10.49
	LH-900	New Delhi	47.11	7.20
	LH-900	Nagpur	56.84	10.62
	LH-900	Coimbatore	52.61	8.23
	Std.Deviation		6.53	1.69
8.	LRA-5166	Sirsa	64.04	9.98
	LRA-5166	New Delhi	56.56	9.03
	LRA-5166	Nagpur	46.39	7.20
	LRA-5166	Coimbatore	55.78	9.97
	Std.Deviation		7.23	1.31
9.	SRT-1 G.Cot-10	Sirsa	-	-
	SRT-1 G.Cot-10	New Delhi	51.11	8.64
	SRT-1 G.Cot-10	Nagpur	49.10	7.37
	SRT-1 G.Cot-10	Coimbatore	52.50	8.36
	Std.Deviation		1.71	0.66
10.	Suvin	Sirsa	-	-
	Suvin	New Delhi	48.96	7.50
	Suvin	Nagpur	44.26	6.40
	Suvin	Coimbatore	52.60	8.35
	Std.Deviation		4.18	0.98
11.	Jyoti	Sirsa	46.93	7.50
	Jyoti	New Delhi	-	-
	Jyoti	Nagpur	-	-
	Jyoti	Coimbatore	45.65	7.21
	Std.Deviation		0.90	0.20
12.	G.Cot-13	Dhandhuka	43.61	6.77
	G.Cot-13	Chharodi	44.99	6.90
	Std.Deviation		0.97	0.09
13.	G.Cot-100	Sirsa	61.36	11.40
	G.Cot-100	New Delhi	-	-
	G.Cot-100	Nagpur	44.44	6.40
	G.Cot-100	Coimbatore	-	-
	Std.Deviation		11.96	3.53

Table-2 Correlations of Convolution Angle with Other Orientation Parameters.

	Convolution Angle(q)	
Convolutions /cm	r = 0.875	p > 0.001
Hermans Factor	r = -0.132	N.S.
Average Angle of Orientation(a _m)	r = 0.198	N.S.
40% X-Ray Angle	r = 0.222	N.S.
50% X-Ray Angle	r = 0.206	N.S.
75% X-Ray Angle	r = 0.312	p > 0.01
(40% - q)(*)	r = -0.436	p > 0.001
True-spiral angle		
(50% - q)(*)	r = -0.481	p > 0.001
True-spiral angle		
(a _m - q)(*)	r = -0.355	p > 0.01
True-spiral angle		
Relative Orientation index w.r.t. Ramie	r = -0.126	N.S.

N.S.: Not Significant (*) For definition see reference Moharir, A.V., et.al., J. Appl. Polymer Sci., 44, 1913 (1992).