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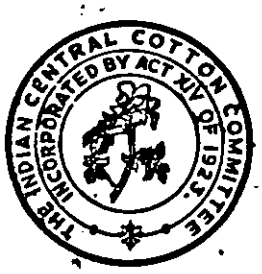

ESTIMATION OF WAX CONTENT AND FEEL OF A COTTON FROM ITS PHYSICAL CHARACTERS

By

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CONTENTS

Estimation of Wax Con of a Cotton from its Phy rs

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I. Introduction

THE classification of cotton into different grades is made by the hand and eye estimation of its grade and staple, the former taking into account the amount of trash, leaf and seed-bits, colour and ginning irregularities, and the latter including the staple length, strength, uniformity of staple, drag and silkiness or feel. Though the complete process is accomplished in one operation with remarkable rapidity by the grader, yet it is subjected to serious personal errors, which can at best be minimized by long experience. The grader's estimation is thus an art and constant endeavour is being made by the textile research workers to replace it by objective and reproducible tests, which might help the breeder in evolving new strains, if they are unsuitable for commercial purposes due to their comparative slowness.

Amongst the characteristics of staple, scientific methods have been evolved to measure average length, strength, fineness, drag or clinging power and rigidity, but no work appears to have been done so far to connect feel with any physical character of cotton. Ahmad and Sen[1] have, however, established a relation between wax-content and grader's estimation of feel. The present work is an attempt to correlate wax-content with some physical characters of cotton.

For the sake of clarity, this paper will be divided into two parts: (i) Relationship between wax-content and physical characters of a cotton, and (ii) Relationship between the grader's estimation of feel and physical characters of a cotton.

II. Part I—Relationship between Wax-content and Physical Characters of a Cotton

(i) *General*

Although minute quantities of wax are present in a cotton, the amount ranging from 0.2 to 0.6 per cent., its importance is felt in the physical and chemical processing of cotton during its conversion from fibre to fabric. Fargher and his associates[2,3,4] have carried out exhaustive work not only on the quantity and nature of wax, but also on the efficiency of various organic solvents in extracting it. The exact location of wax in a cotton fibre is, however, not yet definitely known, but the available literature bears evidence to the fact that it is a surface constituent. Fargher and his collaborators[5] found that "there was no evidence of relatively large amount of wax and resin, which are protected from the attack by their position within the hairs." Denham[6], Anderson and Kerr[7], Levin[8] and Osborne[9] G.G. observed that though the structure of the cuticle and the primary wall of mature fibres is not precisely known the cuticle contains wax, most of the pectic substances and some mineral material. Recent observations of Hock, Ramsay and Harris[10] on transverse sections of cotton hairs revealed the presence of non-cellulosic material only in the periphery and the lumen of the hair.

Studies of Compton[11], and Compton and Haver[12] showed that there was a rapid accumulation of wax during the period of elongation of the primary wall. X-ray work[13, 14] on this subject lends further support to this finding. There are, therefore, sufficient grounds to assume that the wax is mainly on the fibre surface and may, in some measure, be related to the surface area.

The next step is to calculate the surface area of a known quantity of cotton. For this purpose it is necessary to know the average shape of cross-section of a fibre, which exhibits considerable variation from fibre to fibre due to its dependence upon the original cell diameter, the amount of secondary thickening, and the degree of collapse due to desiccation. Peirce[15], Balls[16], and Schwarz and Schapiro[17] have, however, shown that the nearest approximation would be a rectangle with semi-circular caps at the two ends. This shape will be assumed for calculating the surface area of fibre.

(ii) *Calculation of the surface area per gram of cotton*

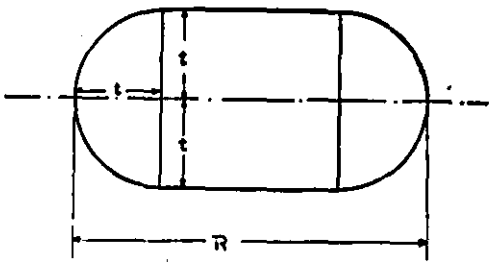


Fig. 1 :· CROSS-SECTION OF A RAW-FIBRE

Fig. 1 represents the transverse section of a cotton fibre. Let R=Ribbon-width, t=Wall-thickness, and f=fibre-weight per unit length. Then the perimeter, P=2 (R+1.1416t); surface area per fibre of average length, l=P×l. Since in one gram of cotton, there are N fibres=$\frac{1}{lf}$, the surface area per gram,

$$S = P \times l \times N = \frac{P}{f}$$

$$= 2\frac{R}{f}\left(1 + 1.1416\frac{t}{R}\right) \quad .. \quad (1)$$

Further simplification of equation (I) may be effected by assuming the perimeter of hairs in the three maturity groups to be nearly the same. Peirce and Lord[18a] have made a statement to this effect and, moreover, the mean swollen hair diameters[18b] of the three maturity groups have been observed to be nearly coincident.

Let f_N be the weight per unit length of a mature hair, and P_N its perimeter

$$f_N = (2Rt - 0.8584\,t^2)\,\rho$$

Substituting $\frac{t}{R} = 0.3$* for raw mature hairs and

$\rho = 1.51$ (apparent specific volume being 0.66 c.c. per gram)

$R = 1.125\sqrt{f_N}$

$\therefore P_N = 2.685$ R, and

$$S = 3.02\frac{\sqrt{f_N}}{f} \quad .. \quad (2)$$

Furthermore, if only a rough estimate of 'S' is required equation (2) may be simplified by assuming $f_N = f$, then

$$S = 3.02\frac{1}{\sqrt{f}} \quad .. \quad .. \quad .. \quad (3)$$

Peirce and Lord[19] have recently derived an equation for surface per gram similar to that of equation (2) from slightly different considerations, when, however, their equation is converted into the same form as the present one, a small difference of 0.44 occurs in the constant, on the righthand side of the equation (2), which could be ascribed to the following two reasons: (1) their calculations are based on the empirical relationships between fibre weight per unit length, immaturity and the degree of thickening. As the constants are derived from the regression equations slight variation is to be expected apart from the fact that the correlation between immaturity and fibre-weight has a small dispersion due to the maturity grouping being only a rough classification, and (2) slight variability in the mean value of $\frac{t}{R}$ of the mature group and the apparent specific volume of cotton are bound to alter the constant in equation (2). It should, however, be remarked that whatever be the value of the constant, the correlation coefficient between wax-content and surface per gram or the root-weight per unit length is not affected.

(iii) *Material and Methods*

The material used in this investigation consisted of standard Indian cottons of three seasons, 1932-33, 1937-38, and 1938-39, the other details regarding them will be found in the Technological Reports on Standard Indian Cottons[20], 1940.

The methods adopted in determining fibre-weight per unit length, ribbon-width, maturity count and wax-content of cotton have been described in the various Indian Central Cotton Committee Technological Bulletins[21, 22].

(iv) *Results*

The data pertaining to the same material as was used by Ahmad and Sen [1] along with those of the standard Indian cottons of the 1932-33 season are given in Table I, while those of the standard Indian cottons of 1937-38, and 1938-39 seasons are embodied in Table II.

As complete results of standard Indian cottons of 1932-33 season were not

* This value is likely to be slightly different for different cottons (author's work to be published).

TABLE I

No.	Cotton	Ribbon width 10^{-3} inch (R)	Fibre weight per inch 10^{-6} oz. (f)	$\frac{R}{f}$	Wax-content (experimental) % (w)	Percentage difference between "$\frac{R}{f}$" and "w" calculated on "w"
1	Jayawant	0.70	0.199	0.352	0.393	— 10.5
2	Gadag I	0.63	0.134	0.470	0.423	+ 11.1
3	Surat 1027 A.L.F. ..	0.74	0.190	0.389	0.375	+ 3.7
4	Wagad 8	0.82	0.240	0.342	0.343	— 0.4
5	P. A. 4F	0.74	0.143	0.517	0.448	+ 15.2
6	P. A. 289F	0.60	0.114	0.526	0.510	+ 2.9
7	Mollisoni	0.78	0.274	0.285	0.312	— 8.6
8	A. 19	0.79	0.290	0.272	0.230	+ 18.2
9	C. 402	0.69	0.195	0.354	0.381	— 7.1
10	C. A. 9	0.62	0.134	0.463	0.407	+ 13.5
11	Verum 262 (Nag.) ..	0.63	0.180	0.350	0.382	— 8.4
12	Do. (Akola) ..	0.62	0.163	0.380	0.345	+ 10.0
13	Umri Bani	0.65	0.175	0.371	0.357	+ 4.2
14	Co. 2	0.68	0.123	0.553	0.503	+ 10.0
15	Nandyal 14	0.67	0.156	0.429	0.334	+ 28.4
16	Hagari 1	0.70	0.175	0.400	0.271	+ 47.5
17	Hagari 25	0.74	0.170	0.435	0.275	+ 58.2
18	Karunganni C7	0.69	0.167	0.413	0.387	+ 6.4
19*	Kampala	0.62	0.133	0.466	0.544	— 14.3
20	Navsari	0.69	0.163	0.417	0.457	— 8.9
21	Palej	0.72	0.198	0.364	0.405	— 10.0
22	Dholeras	0.73	0.193	0.378	0.387	— 2.3
23	Kumpta	0.69	0.181	0.381	0.359	+ 6.1
24	P. Desi	0.80	0.268	0.299	0.385	— 22.3
25	P. American	0.73	0.160	0.456	0.468	— 2.6
26	Berar	0.75	0.228	0.329	0.330	+ 0.3

* *N.B.*—Nos. 1 to 18 are Standard Indian Cottons of 1932-33 season and Nos. 19 to 26 are those which are mentioned in Table I of Indian Central Cotton Committee Technological Bulletin Series B, No. 18, by Ahmad, N. and Sen, D. L.

available they have not been used in further calculations. The values calculated from the basic data given in Table II are entered in Table III. The correlation coefficients and the regression equations are given in Table IV, and the values are also plotted in Figs. 2, 3 and 4 with the respective regression lines.

(v) *Discussion*

The first and foremost interesting point that emerges from a study of Tables I and III, is a fairly close agreement between the experimental wax-content and "$\frac{R}{f}$" Values (expressed in English units). It will, however, be seen that there is a wide divergence between these two values in some cottons, as for example, in A 19, Nandyal 14, Hagari I, and Hagari 25 of 1932-33 season (Table I), and Jayawant (1937-38 and 1938-39), A. 19 (1937-38), Verum 262 (Nagpur) (1937-38); Nandyal 14 (1938-39), Hagari 1 (1937-38), Karungani (1937-38 and 1938-39), and Koilpatti (1937-38). The cause of the abnormal behaviour of these cottons requires further study.

The values of wax-content calculated from each factor $\frac{R}{f}$, $3.02\ \frac{\sqrt{f_N}}{f}$ and $\frac{1}{\sqrt{f}}$ are entered in columns 8, 9 and 10 respectively of Table III. The mean percentage differences between the experimental and calculated values are 15.2 per cent., 15.2 per cent. and 17.0 per cent. respectively for the above-mentioned factors. There is practically no difference between the first two factors, but $\frac{1}{\sqrt{f}}$ yields slightly more divergent values than the remaining two.

The correlation coefficients given in Table IV are self-explanatory; it will be

TABLE II

Cotton	Season	Ribbon width 10^{-3} cms. (R)	Swollen Hair diameter (10^{-3} cms.) (D)	Fibre weight per cm. (10^{-6} gms.) (f)	Maturity count % M—I	Experimental wax content % (w)
1	2	3	4	5	6	7
Jayawant ..	1937-38	1.80	2.54	2.17	67 — 14	0.243
	1938-39	1.83	2.46	2.20	73 — 8	0.255
Gadag I	1937-38	1.70	1.96	1.58	71 — 11	0.413
	1938-39	1.68	2.06	1.65	73 — 8	0.524
Surat 1027 A.L.F.	1937-38	1.96	2.87	1.73	46 — 27	0.445
	1938-39	1.90	2.79	2.19	63 — 20	0.345
Wagad 8 ..	1937-38	2.11	3.02	2.36	57 — 25	0.374
	1938-39	2.31	3.23	3.02	47 — 28	0.324
Sind Sudhar ..	1937-38	1.55	1.85	1.45	73 — 12	0.580
	1938-39	1.65	1.98	1.45	54 — 23	0.640
Sind N. R. ..	1937-38	1.93	2.92	3.07	86 — 5	0.236
	1938-39	2.18	3.02	3.11	76 — 12	0.298
P.A. 4F	1937-38	1.90	2.36	1.65	39 — 37	0.506
	1938-39	2.06	2.44	1.57	32 — 51	0.681
P.A. 289F ..	1937-38	1.60	2.01	1.28	55 — 23	0.620
	1938-39	1.57	1.96	1.25	42 — 29	0.586
Mollisoni ..	1937-38	1.96	2.72	2.56	80 — 8	0.257
	1938-39	2.18	2.64	2.94	86 — 4	0.291
Aligarh A. 19 ..	1937-38	2.08	2.87	3.15	88 — 6	0.192
	1938-39	2.03	2.92	3.13	88 — 6	0.226
C. 402 (U.P.) ..	1937-38	1.75	2.51	2.22	81 — 10	0.336
	1938-39	1.75	2.57	1.99	64 — 17	0.386
Verum 262 (Nag.)	1937-38	1.83	2.26	2.00	75 — 11	0.277
	1938-39	1.98	2.26	1.74	63 — 17	0.455
Verum 262 (Akola)	1937-38	1.85	2.29	1.70	68 — 15	0.430
	1938-39	1.80	2.34	1.96	66 — 16	0.326
Verum 434 (Akola)	1937-38	1.80	2.34	1.89	62 — 19	0.366
	1938-39	1.80	2.34	2.26	77 — 8	0.248
Late Verum (Nag.)	1937-38	1.70	2.41	1.93	73 — 15	0.317
	1938-39	1.98	2.39	1.99	62 — 18	0.432
Umri Bani ..	1937-38	1.90	2.31	1.94	69 — 13	0.443
	1938-39	1.83	2.39	1.94	66 — 17	0.479
Cambodia Co. 2	1937-38	1.83	2.29	1.67	48 — 34	0.529
	1938-39	1.96	2.34	1.65	61 — 20	0.503
Nandyal 14 ..	1937-38	1.85	2.39	1.91	78 — 13	0.303
	1938-39	1.85	2.49	2.03	76 — 13	0.297
Hagari I	1937-38	1.90	2.41	2.01	72 — 8	0.278
	1938-39	1.85	2.39	2.15	76 — 8	0.324
Karunganni C7 ..	1937-38	1.85	2.51	2.01	72 — 14	0.279
	1938-39	1.96	2.49	2.06	63 — 20	0.227
Koilpatti I ..	1937-38	1.85	2.44	2.02	71 — 18	0.286
	1938-39	1.93	2.44	1.78	54 — 29	0.426

seen that the correlation coefficient between wax-content and $\frac{R}{f}$ or $3.02\ \frac{\sqrt{f}N}{f}$ is practically the same. Either of these two factors will, therefore, account for about 74.75 per cent. of the variation in wax-content between cottons; while $\frac{1}{\sqrt{f}}$ can account for only about 67 per cent. of the variation. This point can be clearly seen in Figs. 2, 3 and 4. The lack of greater strength of association between the experimental and the calculated wax-contents may partly be ascribed to the slight variations in the coating and the density of wax between cottons, as well as to the imperfection in the calculation of the surface area. These points could only be clarified by further experimentation.

Furthermore, it was thought that $\frac{D}{f}$ would have the same correlation with

Fig 2

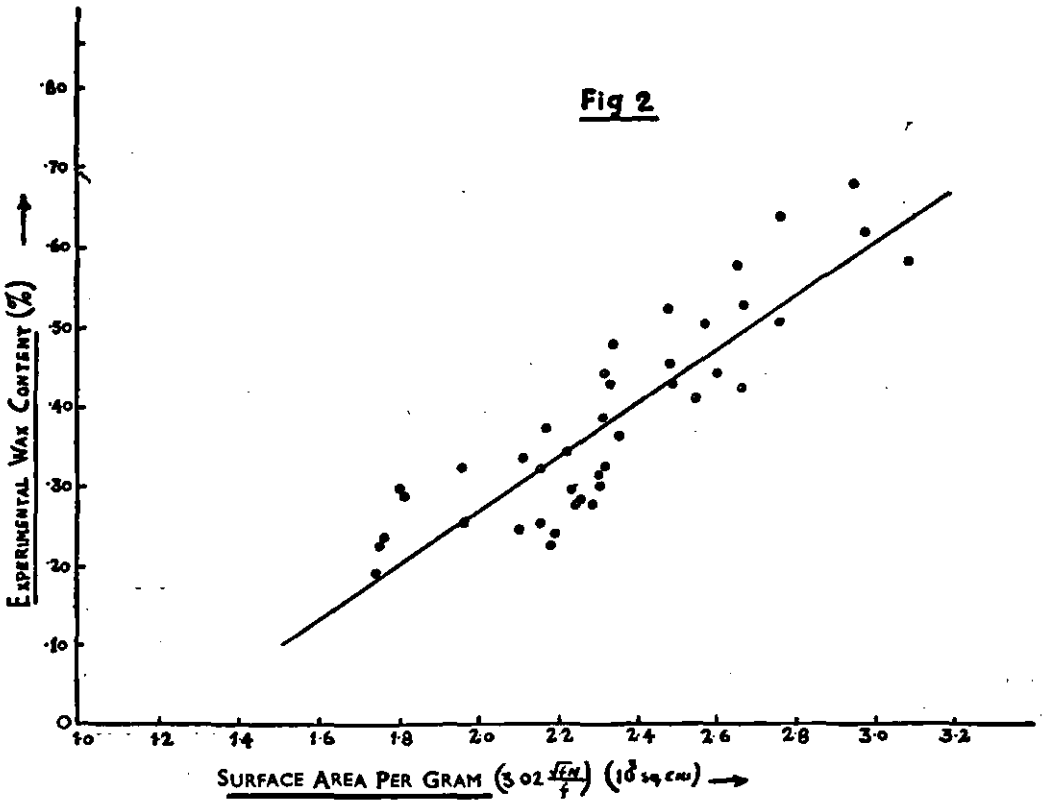

EXPERIMENTAL WAX CONTENT (%)
·80
·70
·60
·50
·40
·30
·20
·10
0
1·0
1·2
1·4
1·6
1·8
2·0
2·2
2·4
2·6
2·8
3·0
3·2
SURFACE AREA PER GRAM (3·02 √(LN)/f) (10³ sq cms)

FIG. 3

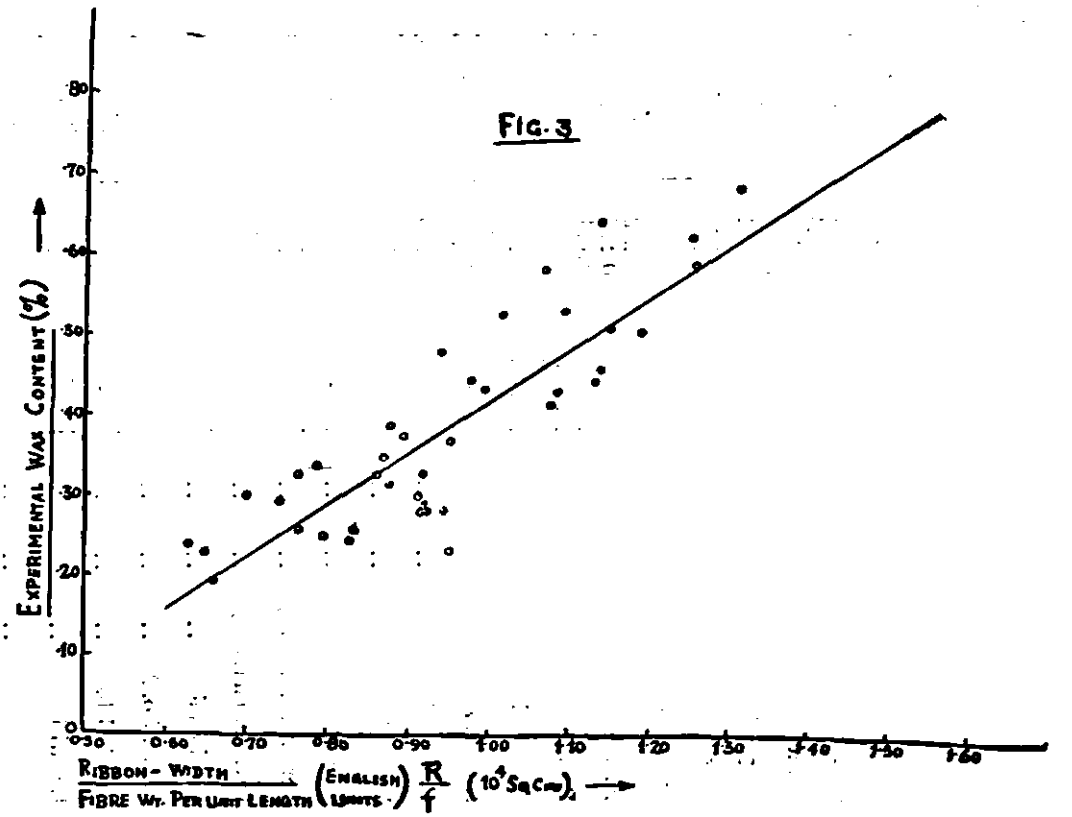

EXPERIMENTAL WAX CONTENT (%)
80
70
60
50
40
30
20
10
0
0·50
0·60
0·70
0·80
0·90
1·00
1·10
1·20
1·30
1·40
1·50
1·60
RIBBON-WIDTH / FIBRE WT. PER UNIT LENGTH (ENGLISH UNITS) R/f (10³ Sq Cms)

TABLE III

Calculated values, derived from the data given in Table II

Cotton	Season	Experimental wax content % (w)	R/f		Surface per gram (S)	$\frac{1}{\sqrt{f}}$	Calculated values of wax content from the respective equations		
			In English units (10^4)	In metric units (10^3)	$3.02\frac{\sqrt{f_N}}{f}$ 10^3 sq.cm.	(10^3 sq.cm)	R/f 10^3 sq.cm.	$3.02\frac{\sqrt{f_N}}{f}$ 10^3 sq. cm.	$\frac{1}{\sqrt{f}}$ 10^3 sq.cm.
Jayawant	1937-38	0.243	0.364	0.829	2.19	0.679	0.304	0.337	0.339
	1938-39	0.255	0.365	0.832	2.15	0.674	0.306	0.323	0.333
Gadag I	1937-38	0.413	0.472	1.076	2.54	0.796	0.462	0.456	0.488
	1938-39	0.524	0.446	1.018	2.47	0.778	0.425	0.432	0.465
Surat 1027 A.L.F.	1937-38	0.445	0.497	1.138	2.59	0.760	0.498	0.473	0.442
	1938-39	0.345	0.381	0.868	2.22	0.676	0.329	0.347	0.335
Wagad 8	1937-38	0.374	0.393	0.894	2.17	0.651	0.345	0.330	0.303
	1938-39	0.324	0.337	0.765	1.96	0.575	0.263	0.259	0.207
Sind Sudhar	1937-38	0.580	0.473	1.069	2.64	0.830	0.458	0.490	0.531
	1938-39	0.640	0.500	1.138	2.75	0.830	0.502	0.528	0.531
Sind N.R.	1937-38	0.236	0.278	0.629	1.76	0.571	0.176	0.191	0.202
	1938-39	0.298	0.307	0.701	1.80	0.567	0.222	0.204	0.197
P.A. 4F	1937-38	0.506	0.507	1.152	2.75	0.778	0.511	0.528	0.465
	1938-39	0.681	0.574	1.312	2.93	0.798	0.613	0.589	0.491
P.A. 289F	1937-38	0.620	0.548	1.250	2.96	0.884	0.573	0.599	0.600
	1938-39	0.586	0.554	1.256	3.07	0.894	0.577	0.636	0.613
Mollisoni	1937-38	0.257	0.335	0.766	1.97	0.625	0.263	0.262	0.270
	1938-39	0.291	0.326	0.741	1.81	0.583	0.247	0.208	0.217
Aligarh A. 19	1937-38	0.192	0.291	0.660	1.74	0.563	0.195	0.184	0.191
	1938-39	0.226	0.285	0.649	1.75	0.565	0.188	0.187	0.194
C. 402 (U.P.)	1937-38	0.366	0.347	0.788	2.11	0.671	0.277	0.310	0.329
	1938-39	0.386	0.388	0.879	2.31	0.709	0.336	0.378	0.377
Verum 262 (Nag.)	1937-38	0.277	0.402	0.915	2.24	0.707	0.359	0.354	0.375
	1938-39	0.455	0.500	1.138	2.47	0.758	0.502	0.432	0.440
Verum 262 (Akola)	1937-38	0.430	0.480	1.088	2.48	0.767	0.470	0.436	0.451
	1938-39	0.326	0.406	0.918	2.31	0.714	0.361	0.378	0.384
Verum 434 (Akola)	1937-38	0.366	0.420	0.952	2.35	0.727	0.383	0.391	0.400
	1938-39	0.248	0.351	0.796	2.10	0.665	0.283	0.306	0.321
Late Verum (Nag.)	1937-38	0.317	0.387	0.881	2.30	0.720	0.337	0.374	0.391
	1938-39	0.432	0.438	0.995	2.32	0.709	0.410	0.381	0.377
Umri Bani	1937-38	0.443	0.431	0.979	2.31	0.718	0.400	0.378	0.389
	1938-39	0.479	0.414	0.943	2.33	0.718	0.377	0.385	0.389
Camb. Co. 2	1937-38	0.529	0.480	1.096	2.66	0.774	0.475	0.497	0.460
	1938-39	0.503	0.520	1.188	2.56	0.778	0.534	0.463	0.465
Nandyal 14	1937-38	0.303	0.427	0.969	2.30	0.724	0.393	0.374	0.396
	1938-39	0.297	0.403	0.911	2.23	0.702	0.356	0.351	0.368
Hagari 1	1937-38	0.278	0.414	0.945	2.24	0.705	0.378	0.354	0.372
	1938-39	0.324	0.380	0.860	2.15	0.682	0.324	0.323	0.343
Karunganni	1937-38	0.279	0.406	0.920	2.28	0.705	0.362	0.368	0.372
	1938-39	0.227	0.414	0.951	2.18	0.697	0.382	0.334	0.362
Koilpatti I	1937-38	0.286	0.403	0.916	2.25	0.704	0.359	0.357	0.3[illegible]
	1938-39	0.426	0.478	1.084	2.65	0.750	0.467	0.493	0.430

wax-content as $\frac{R}{f}$ because the ratio $\frac{D}{R}$ has been shown[23] to be nearly constant for all cottons. This, however, was not the case; the correlation coefficient (0.77) being lower than the other. This adverse effect on the correlation coefficient may perhaps be due to the dispersion in the values of the ratio $\frac{D}{R}$ of different cottons, which range from 1.1 to 1.5.

In order to investigate whether the actual value of surface area per gram, $S=2\frac{R}{f}(1+1.1416\ t/R)$, would enhance the correlation coefficient, measurements of t/R were done on six cottons given in Table I, three of which had shown considerable divergence between R/f and experimental wax-content and three had good agreement. Barritt's method[24] was employed to determine the wall-thickness, " t ". The results are given in the following Table IV (a).

It will be seen from these results that the inclusion of t/R in the formula does not yield a better relation between the surface area per gram and the wax content.

TABLE IV

Correlation Coefficients

Correlation between the following pairs	Correlation coefficient
W and R/f	0.856
W and $3.02\sqrt{f_N}/f$	0.869
W and $1/\sqrt{f}$	0.818
W and D/f	0.772

In Table IV, W=Wax-content (%), R=Ribbon-width, f=fibre weight per cm., f_N=Normal hair weight* (calculated according to the old formula of Peirce and Lord), and D=swollen hair diameter.

Regression equations:—

$$W\quad 0.3402\times 3.02\frac{\sqrt{f_N}}{f}-0.4081 \quad (1)$$

$$W=0.6406\times\frac{R}{f}-0.2273 \quad .. \quad (2)$$

$$W=1.2731\times\frac{1}{\sqrt{f}}-0.5253 \quad .. \quad (3)$$

Equations (1), (2) and (3) are plotted in Figs. 2, 3 and 4 respectively.

Since the relationship between the wax-content and fineness of cotton had been theoretically worked out and experimentally verified on a large number of cottons, Nickerson, Fontaine and Leape[25] have made an empirical statement to the same effect in a recent paper thus corroborating the author's findings.

(vi) *Probable thickness of wax layer on a cotton fibre*

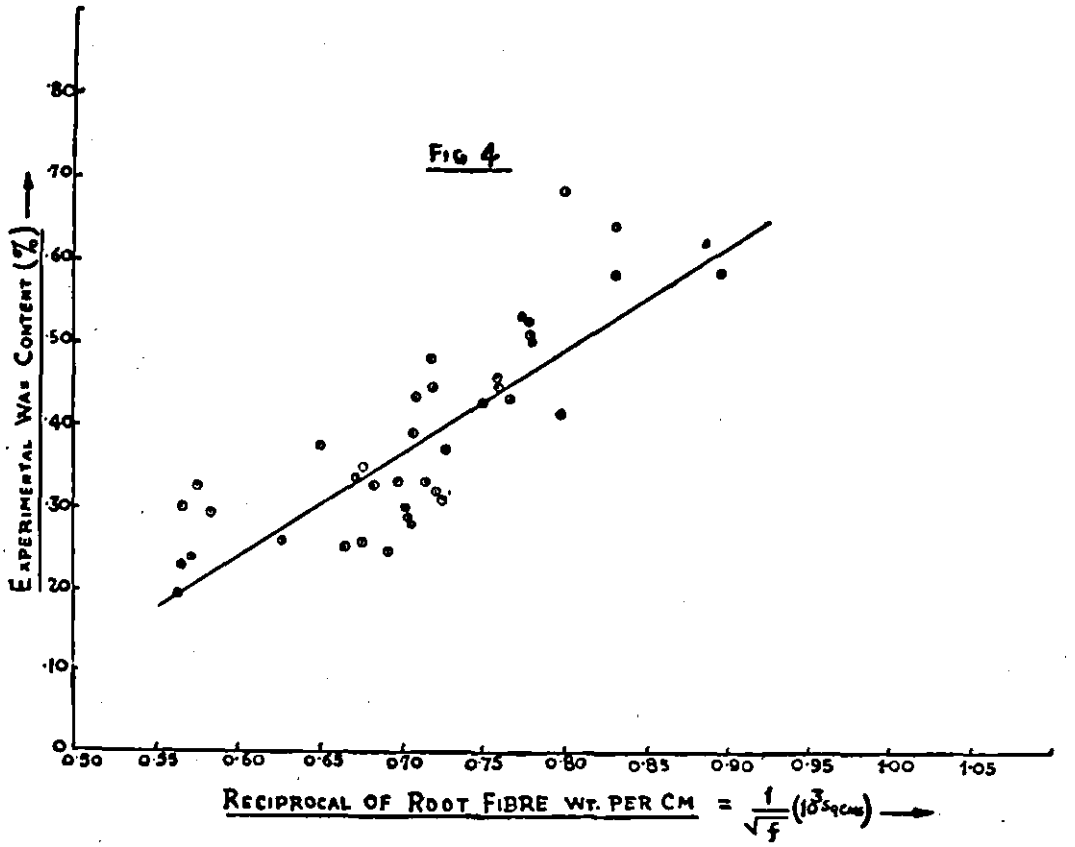
Since the experimental wax-content is shown to be highly correlated with the surface area per gram of cotton, it follows that the thickness of wax-layer should approximately be the same for all cottons. Its value is obtained by dividing the experimental wax-content (calculated on the weight of cotton at 70 per cent. R.H.) by surface area and the mean density of cotton wax (0.989 gms. per c.c.). Using the surface areas calculated from equations (1) and (2) the thickness works out to be 1.48×10^{-6} cm. and 1.50×10^{-6} cm. respectively. The remarkable agreement between these two values is noteworthy.

The factors involved in the calculation of the thickness of wax being slightly variable, its value should be taken as approximate. Assuming that the wax is coated only on the fibre surface it can account for about 0.01 to 0.03 of the

*This was also calculated using Peirce and Lord's new formula, and the correlation coefficient calculated between this and the wax-content was 0.874, indicating no significant difference between the two correlation coefficients.

TABLE IV (a)

Standard Indian cottons of 1932-33 season	R/f	t/R	R/f (1+1.1416 t/R)	Exptl. wax content %
Hagari 25	0.435	0.227	0.548	0.275
Hagari 1	0.400	0.228	0.504	0.271
Nandyal 14	0.429	0.245	0.549	0.334
Umri Bani	0.371	0.213	0.401	0.357
P. A. 289F	0.526	0.155	0.619	0.510
Wagad 8	0.342	0.178	0.411	0.343



thickness of the primary wall, which is known to be of the order of 0.25—0.50μ[7, 19]. At the present stage of our knowledge it would be premature to speculate as to whether wax is located at the surface as a homogeneous layer or the whole primary wall is impregnated with it. Nevertheless, the present work has shown that both the distribution and the coating of wax is nearly the same for all cottons.

Indirect evidence in support of the above statement could be cited from the work of Navkal and Turner[26], who found that clinging power divided by the square root of fibre weight per unit length (i.e., approximate surface area) showed very little variation between cottons, the coefficient of variation being 10 per cent. Subsequently Sen and Ahmad[27] determined the clinging power using single hairs with a different type of apparatus; the clinging power per unit surface calculated from their data also has a tendency to lie close to each other for all cottons. Recent findings of the author (unpublished) have also corroborated these observations. It thus appears probable that the variation of clinging power among cottons could be ascribed mainly to such characters as convolutions, surface corrugations, and intrinsic fineness and not to the differential distribution of wax. Incidentally the present findings yield an answer to Peirce's query[18b], namely, "Another question was to what extent a high wax-content due to a heavier coating of wax per unit surface of cotton and to what extent was it due to the geometrical features of the cotton itself, the way in which the wax was distributed on the surface, and the rate of surface to weight?"

It might be suggested here that since most of the pectic substances are contained in the cuticle the same type of relationship between the pectic content and the surface area per gram of a cotton as exists between wax-content and the latter property might be established. For this purpose it would be necessary to determine the pectic content, the ribbon-width, fibre-weight per unit length and maturity and to work out the exact relationships between these characters.

III. Part II—Relationship Between Grader's Estimation of Feel and the Physical Characters of Cotton

(i) *General*

As has already been mentioned before, there can be no rigid definition of feel on account of its qualitative nature. To quote one of the few definitions that are available in the literature, Brown[28] states under silkiness or fineness that "it is a desirable quality in cotton that is to be used in making a fine fabric. Such feel feels very soft and smooth. As a rule the fibres are long and of small diameter." This definition is at best vague and fails to convey a clear mental picture of this property. When a grader pulls a mass of cotton between his fingers he gets an impression of feel which is highly dependent upon the weather conditions and the amount of light incident on the sample. Though it has been admitted that he is able to classify cottons fairly accurately due to his uncanny sense of perception yet personal errors are bound to creep in. These considerations show that the method proposed by Ahmad and Sen for assessing the feel of cotton by its wax-content is a real advance in this direction. The present work has, however, revealed that since wax-content is highly correlated with certain physical characters of cotton, the latter factors are the primary determinants of feel.

(ii) *Results*

In the foregoing part three relationships have been established between experimental wax-content (W) and each of the factors, R/f, $\sqrt{f_N}/f$ and $1/\sqrt{f}$. It is, therefore, clear that among the fibre properties, viz., Ribbon-width, maturity count and fibre-weight per unit length, one of the first two in combination with the third or in the extreme case where the immaturity is low the third property alone would serve as a fairly good index of feel.

In order to test whether the proposed criterion of feel holds good in practical grading, samples of standard Indian cottons of 1938-39 season were sent to three expert graders, designated here as A, B and C, who were asked to give their estimates in accordance with the commercial practice. These results are embodied in Table V along with those predicted by experimental wax-content according to the Ahmad-Sen classification and also according to R/f (English units). Corresponding scales for $\sqrt{f_N}/f$ and f (based on $1/\sqrt{f}$) are also given in Table VI.

(iii) *Discussion*

It will be seen from Table V that considerable divergence exists between the estimates of the three graders themselves, for example, Co. 2 has been classified as "roughish," "very silky" and "slightly coarse" by the graders A, B and C respectively, other glaring instances being Sind Sudhar and Jayawant. It should be remarked that while a fair degree of agreement is noticeable in the remaining cottons, grader C has shown a slight tendency to overestimate in comparison with A and B. These observations suffice to show that both the method and the phraseology employed by different graders require to be standardized.

Furthermore, it is interesting to note that the feel estimates derived from the experimental wax-content and R/f according to the Ahmad-Sen scale are in good agreement with grader's valuation, the exceptions being Jayawant, Gadag, Surat 1027 A.L.F., Verum 262 (Akola), Umri Bani, Co. 2 (440), Sind Sudhar and Karunganni. Amongst these the cottons marked with an asterisk yield better agreement when predicted by R/f than by wax-content.

In Part I, it has been stipulated that all cottons have almost the same thickness of wax which is mainly a surface constituent. A logical conclusion that could be drawn from this statement would be that if wax is the primary determinant of feel all cottons should possess the same feel; this is obviously not true. The question next arises as to which are the factors that contribute to feel. The present study has shown that fineness stands first in importance, wax, surface structure, etc., playing a secondary role. The following experiment was carried out in support of the above conclusion. Two cottons A and B, A being much finer than B, were dewaxed and designated 'A" and 'B" respectively. It was observed that while 'A" and 'B" felt slightly harsher than A and B respectively due to dewaxing, the initial difference in feel between the two cottons persisted even after dewaxing.

Additional evidence in support of the above thesis could be cited by the fact

TABLE V

"Feel" estimation of standard Indian Cottons of 1938-39 *Season*

Cotton	Experimental wax-content (%)	$\frac{R}{f}$ (in English units)	Graders' estimation of feel			Estimation of feel according to Ahmad-Sen scale of wax-content	Estimation of feel according to R/f (in English units) (Present method)
			Grader A	Grader B	Grader C		
Jayawant	0.225	0.365	Slightly roughish	Fairly silky	Silkish but hard	Rough	Rough
Gadag I	0.524	0.446	Very slightly roughish	Poor	Little coarse	Very silky	Silky
Surat 1027 A.L.F. ..	0.345	0.381	Slightly silky	Fairly silky	Silky	Roughish	Roughish
Wagad 8	0.324	0.337	Roughish	Very rough	Rough	Roughish	Rough
Sind Sudhar ..	0.640	0.500	Slightly roughish	Silky	Very silky	Very silky	Very silky
Sind N.R.	0.298	0.307	Very roughish	Very rough	Rough	Rough	Rough
P.A. 4F	0.681	0.574	Slightly silky	Fairly silky and soft	Soft and silky	Very silky	Very silky
P.A. 289F	0.586	0.554	Slightly silky	Silky	Soft and silky	Very silky	Very silky
Mollisoni	0.291	0.326	Roughish	Rough	Rough	Rough	Rough
A. 19	0.226	0.285	Very roughish	Very rough	Rough	Rough	Rough
C. 402 (U.P.) ..	0.386	0.388	Very slightly roughish	Rather rough	Roughish	Slightly silky	Roughish
Verum 262 (Nag.) ..	0.455	0.500	Somewhat silky	Fairly silky	Silkish	Silky	Very silky
Verum 262 (Akola)..	0.326	0.406	Slightly silky	Fairly silky	Silky	Roughish	Slightly silky
Verum 434 (Akola)..	0.248	0.351	Slightly roughish	Roughish	Slightly roughish	Rough	Rough
Late Verum (Nag.) ..	0.432	0.438	Somewhat silky	Fairly silky	Silky	Silky	Slightly silky
Umri Bani	0.479	0.414	Slightly roughish	Somewhat rough	Silkish but hard	Silky	Slightly silky
Cambodia Co. 2 ..	0.503	0.520	Roughish	Very silky	Slightly coarse	Very silky	Very silky
Nandyal 14	0.297	0.403	Very slightly roughish	Rather rough	Slightly coarse but silkish	Rough	Slightly silky
Hagari 1	0.324	0.380	Very slightly roughish	Slightly roughish	Slightly coarse	Roughish	Roughish
Karunganni C. 7 ..	0.227	0.414	Very slightly silky	Fairly silky	Silky	Rough	Slightly silky
Kollpatti	0.426	0.478	Somewhat silky	Fairly silky	Silky	Silky	Very silky

TABLE VI

Scales of different factors for estimating "Feel"

Feel	Experimental wax-content (%) (Ahmad-Sen scale)	$\frac{R}{f}$		$\frac{\sqrt{f_N}}{f}$	$\frac{1}{\sqrt{f}}$	"f" (Fibre weight per cm.; 10^{-6} gm.)
		English units	Metric units			
Very silky ..	Above 0.500	Above 0.480	Above 1.085	Above 0.855	Above 0.775	Below 1.65
Silky	0.425-0.500	0.440-0.480	1.000-1.085	0.800-0.855	0.735-0.775	1.65-1.85
Slightly silky ..	0.350-0.425	0.400-0.440	0.915-1.000	0.745-0.800	0.695-0.735	1.85-2.10
Roughish ..	0.300-0.350	0.375-0.400	0.860-0.915	0.710-0.745	0.670-0.695	2.10-2.25
Rough	Below 0.300	Below 0.375	Below 0.860	Below 0.710	Below 0.670	Above 2.25

N.B.—In this table R=Ribbon-width, f_N=Fibre weight per cm. of a mature fibre, and f=average fibre weight per cm. (10^{-6} gm.) except when $\frac{R}{f}$ is expressed in English units in Col. 3.

that the fibre weight per unit length and fibre rigidity are highly correlated. Turner and Venkataraman[29] found that the total correlation coefficient between these two properties was +0.81 for the 95 Standard Indian Cottons of series I and +0.69 for 45 cottons of series II, while the partial correlation coefficients of the fourth order, eliminating the influence of fibre-length, fibre-width, fibre-strength, and convolutions per inch were as high as +0.53 and +0.59 respectively for the two series. Thus fibre-rigidity which has a definite influence on the feel of cotton bears a strong relation with fibre-weight per unit length or fineness.

In addition to the cottons mentioned in Table V a larger number of cottons belonging to different varieties and different strains in the same variety has been studied in regard to the relation between fibre weight per unit length and grader's estimate of feel. One outstanding conclusion, which emerged from this study, was that, generally speaking, cottons which possessed low fibre weight per unit length were classed as "silky," while those with high fibre weight per unit length as "rough." A note of warning should, however, be sounded that some glaring exceptions did occur. Nevertheless, the breeder can actually weed out useless strains without much risk by employing the criterion $\frac{\sqrt{f_N}}{f}$ or f, the former being better than the latter. The ratio, $\frac{\sqrt{f_N}}{f}$, indicates that mature cottons will have a harsh feel, while the immature ones will feel soft.

It, therefore, appears that from the feel point of view immature cottons are better, but immaturity has detrimental effect on the spinning and the dyeing processes. Consequently, particular attention must be directed towards evolving strains which have at least normal maturity with low fibre weight per unit length or small original cell diameter, in other words, greater importance must be attached to intrinsic fineness.

In conclusion, it may be stated here that in the early stages of the evolution of a new strain, fibre weight per unit length and maturity, which could be determined quickly, would serve to give a fairly good estimate of feel. Wax-content, the determination of which is much more laborious and time-absorbing, may at best be used as an additional criterion of judging feel. Recently Sullivan and Hertel[30] have proposed an air-flow method of measuring surface per gram of cotton fibres and claim it to be quick and accurate. If that is so, it may serve as a useful measure of feel.

IV. Conclusions

The following conclusions are deduced from the results of the present investigation:—

(1) Wax-content of a cotton is highly correlated with the surface area per gram, which, in turn, is a function of the ratio, $\frac{\text{Ribbon-width}}{\text{Fibre-weight per unit length}}$ or the reciprocal of the square root of fibre weight per unit length.

(2) The ratio, $\frac{\text{Ribbon-width}}{\text{Fibre-weight per unit length}}$ expressed in English units directly gives the experimental value of wax-content of a cotton, the calculated value being in close agreement with the experimental value in the majority of cases.

(3) It is deduced that the coating of wax is nearly the same for all cottons and its distribution on the fibre surface is fairly uniform.

(4) "Feel" of a cotton, as ordinarily estimated by an expert grader, is related primarily to the fibre-weight per unit length or to the ratio of ribbon-width to the fibre weight per unit length.

(5) Scales of fibre-weight per unit length, and the ratio of the ribbon-width to the fibre-weight per unit length for classifying cotton into different grades of "feel" are given for the first time.

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