SAWTRI
SPECIAL PUBLICATION

Textiles: Some Technical Information and Data V: Cotton

by

L. Hunter

SOUTH AFRICAN
WOOL AND TEXTILE RESEARCH
INSTITUTE OF THE CSIR

P.O. BOX 1124
PORT ELIZABETH
REPUBLIC OF SOUTH AFRICA

WOL. 54

ISBN 0 7988 1548 5

December, 1980

CONTENTS

1. Introduction 1
2. General 1
3. Cotton Growing 14
4. Fibre Structure 25
5. Composition of Cotton 30
6. Cotton Wax 35
7. Picking and Ginning 39
8. Delinting Cotton Seed 46
9. Cotton Grade 47
10. Cotton Damage 50
11. Sticky Cotton 53
12. Fibre Length Characteristics 54
13. Micronaire 60
14. Fibre Maturity 65
15. Fibre Fineness 80
16. Summary of Relationships Involving Maturity and Fineness 82
17. Structural Reversals and Fibre Convolutions 84
18. Fibre Dimensional Proportions 87
19. Fibre Strength 96
20. Some Effects of Mercerisation 101
21. Fibre Elongation 103
22. Stiffness and Compressional Properties 104
23. Fibre Friction 105
24. General Fibre Properties 108
25. Trash and Non-Lint Content 114
26. Cotton Dust and Byssinosis 118
27. General Particle Characteristics 122
28. Waste During Processing 124
29. Effect of Processing on Fibre Properties 129
30. Neps 131
31. Carding and Neps 135
32. Effect of Fibre Properties on Yarn Properties 139
33. Fibre Quality Index 150
34. Yarn Faults and Spinning End Breakages 155
35. Yarn Linear Density Variation 156

References 157

TEXTILES : SOME TECHNICAL INFORMATION AND DATA
PART V : COTTON

by L. HUNTER

INTRODUCTION

The main objective of this series of publications has been to collect, compile and collate technical information and data on textiles considered to be useful to the textile industry and researcher alike. In many cases such data and information are not readily available.

As in Parts I to IV of this series, the information, in many cases, has been reproduced in the original words and form. The author does not claim originality nor does he guarantee the accuracy of all the data. Part II of this series contains general fibre properties, including those of cotton.

GENERAL

The history of textile apparel starts with cotton[1]. Remnants of cotton fabrics from the year 5 800 B.C. were discovered in a cave near Tehuacan, Mexico. The oldest remnants of cotton in the "Old World" were found in Pakistan, China and India[1]. It was only around the year 1 000 A.D. that Saracens, Arabs and the Crusaders brought cotton to Europe[1].

Outside of the areas of cotton cultivation, people had some very strange ideas about where it came from. For example Herodot, a Greek, wrote about a curious race of "plant sheep", the fleece-carrying trees[1]. Eventually the botanical facts became known and understood: Cotton is obtained from a malvaceous plant called Gossypium and can be more correctly described as a hair rather than a fibre[20]. There are more than 300 known species of cotton — some are small bushes, some taller shrubs and some are tree-like[1], it being suggested that the curtailment of the secondary deposition of cellulose, so that a lumen remains, is the essential difference between cultivated and wild cotton species[2]. American Upland type cottons account for about 85% of the world crop[4].

Cotton, although the most important fibre raw material of the present, for a long time played a very unimportant role compared to linen, wool and silk[1]. At the beginning of the 17th century, cotton was planted in North America in large quantities using Indian seed. Prior to mechanisation, harvesting and manufacturing processes involved very hard manual labour. A full day's work by a labourer separating the seed hairs from the seed itself yielded only half a kilogram! In 1871, the first Cotton Exchange was opened in New Orleans. Barely 30 years later cotton reigned over the textile world. The market share of cotton at that time was 80%; today it is less than 50%.

TABLE I

COTTON CULTIVATION IN AFRICA[4]

Year	Area (in 1 000 ha)	Seed cotton		Ginned raw cotton (Fibre percentage in raw cotton)	Production (in million kg)
		Yield (in million kg)	Yield (in kg/ha)		
1946/1947	400	60	150	28%	16,8
1976/1977	870	610 000	700	38%	230 000
INCREASE	x 2,2	x10	x4,7	+10%	x13,7

It has been stated[20a] that South African farmers should get a seed cotton yield of 2 500 kg/ha or more under irrigation.

Picking the "white gold" by hand still offers an advantage in quality, compared to machine harvesting. The pickers select only the fully ripe, radiantly white fibre bundles, while the machine harvests a whole field at the same time, including both ripe and unripe cotton. The most important quality feature, apart from purity, is fibre length, which ranges between 10 and 50 millimetre, Egypt and the Sudan producing extra long qualities. Today cotton is planted in about 70 countries on a total of about 31,6 million hectares — and in spite of man-made fibres, it remains the most processed and the most highly used textile fibre.

Japan is the world's largest cotton buyer, taking nearly 20% of the total, followed by China, South Korea, France, West Germany and Italy[3].

The United States Department of Agriculture (USDA) estimated the world annual cotton production during 1979/80 at about 64 million bales ($1{,}41 \times 10^{10}$ kg) of which the U.S. produced about 14 million bales (on 14 million acres). Australia's annual production is about 60 million kilograms and so is South Africa's.

Table 1 reflects the development of cotton cultivation in the African countries. In Table 1 "seed cotton" means the product of the cotton plant, i.e.

TABLE 2

WORLD COTTON PRODUCTION IN MILLIONS OF BALES[5]

	1977/1978	1978/1979	1979/1980
Argentina	1,0	0,7	1,0
Brazil	2,2	2,6	2,8
China	9,2	9,8	10,2
Egypt	1,8	1,9	1,7
India	5,5	6,1	5,9
Mexico	1,6	1,5	1,7
Iran	0,8	0,6	0,6
Pakistan	2,5	2,3	2,5
Peru	0,3	0,3	0,3
Sudan	0,8	0,6	0,8
Colombia	0,6	0,4	0,5
Turkey	2,7	2,4	2,3
U.S.A.	14,5	10,9	14,2
U.S.S.R.	12,8	12,3	12,8
Others	7,3	7,4	6,5
TOTAL	63,6	59,8	63,8

TABLE 3

ESTIMATED PRODUCTION OF COTTON* BY STAPLE LENGTH
1976/77 THROUGH 1978/79
(1 000 BALES OF 478 POUNDS)[6]

COUNTRY	SHORT (Under 20,5 mm)			MEDIUM (20,6 to 25,5 mm)			MEDIUM-LONG (26 to 28 mm)			LONG (28,5 to 33,5 mm)			EXTRA-LONG (35 mm and over)		
	1976/77	1977/78	1978/79	1976/77	1977/78	1978/79	1976/77	1977/78	1978/79	1976/77	1977/78	1978/79	1976/77	1977/78	1978/79
NORTH AMERICA															
Costa Rica	—	—	—	—	—	—	8	30	15	—	—	—	—	—	—
El Salvador	—	—	—	16	91	—	225	219	280	80	55	50	—	—	—
Guatemala	—	—	—	20	20	—	605	620	665	10	10	10	—	—	—
Honduras	—	—	—	—	—	—	32	53	37	—	—	—	—	—	—
Mexico	2	4	—	50	81	70	956	1 481	1 430	37	61	70	—	—	—
Nicaragua	—	—	—	4	7	5	546	557	510	—	1	—	—	—	—
United States	1	—	1	2 526	4 086	2 741	6 538	8 302	6 700	1 219	1 520	1 016	64	112	93
Others	—	—	—	—	—	—	20	20	20	—	—	—	1	1	1
SOUTH AMERICA															
Argentina	—	—	—	615	785	575	170	265	175	—	—	—	—	—	—
Bolivia	—	—	—	—	—	—	70	80	65	—	—	—	—	—	—
Brazil	—	—	—	375	275	200	2 078	1 780	2 250	115	145	150	—	—	—
Colombia	—	—	—	—	—	—	608	565	320	77	80	55	—	—	—
Ecuador	—	—	—	—	—	—	28	48	48	20	—	—	—	—	—
Paraguay	—	—	—	—	—	—	294	300	292	6	75	33	—	—	—
Peru	—	—	—	—	—	—	2	3	5	190	235	260	138	92	115
Venezuela	—	—	—	—	—	—	51	57	85	42	40	75	—	—	—
Others	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—
WESTERN EUROPE															
Greece	—	—	—	4	—	—	380	491	542	163	214	153	—	—	—
Italy	—	—	—	3	3	2	—	—	—	—	—	—	—	—	—
Spain	—	—	—	—	5	5	85	94	60	90	116	80	—	—	—
Yugoslavia	—	—	—	1	1	1	7	4	4	—	—	—	—	—	—
EASTERN EUROPE															
Albania	—	—	—	35	35	30	—	—	—	—	—	—	—	—	—
Bulgaria	—	—	—	40	20	25	—	—	—	—	—	—	—	—	—
USSR	—	—	—	—	—	—	10 000	10 300	9 850	1 685	1 900	1 800	365	550	750
ASIA AND OCEANIA															
Afghanistan	—	—	—	30	20	20	220	200	200	—	—	—	—	—	—

Australia	—	—	—	4	1	—	118	183	227	8	21	25	—	—	—
Burma	10	10	10	20	25	25	20	30	30	—	—	—	—	—	—
India	1 100	1 200	1 250	2 700	3 100	3 350	250	330	500	400	450	500	500	500	450
Iran	12	10	5	—	—	—	168	210	275	540	600	420	—	—	—
Iraq	—	—	—	25	20	20	25	20	30	—	—	—	—	—	—
Israel	—	—	—	—	—	—	182	201	245	55	50	110	10	14	15
Korea, Rep.	—	—	—	7	5	5	4	3	2	—	—	—	—	—	—
Pakistan	180	153	200	1 587	2 217	1 810	121	130	125	42	50	20	—	—	—
Syria	—	—	—	2	6	5	714	683	650	4	1	5	—	—	—
Thailand	—	—	—	—	—	—	—	—	—	125	75	130	—	—	—
Turkey	—	—	—	10	—	—	1 960	2 250	1 840	220	400	460	—	—	—
Yemen, P.D.R.	—	—	—	—	—	—	—	8	5	—	—	—	20	12	7
Yemen, Arab Rep.	—	—	—	—	—	—	35	40	40	—	—	—	—	—	—
Others	10	10	10	10	9	10	10	10	11	3	5	5	—	—	—
AFRICA															
Angola	—	—	—	—	—	—	60	55	60	—	—	—	—	—	—
Benin	—	—	—	10	5	5	25	20	30	—	—	—	—	—	—
Cameroon, U.R.	—	—	—	25	20	20	60	50	80	—	—	—	—	—	—
Central Afr. Emp.	—	—	—	—	—	—	70	50	60	—	—	—	—	—	—
Chad	—	—	—	30	27	27	195	160	150	20	23	23	—	—	—
Egypt	—	—	—	—	—	—	—	—	—	1 123	1 176	1 359	706	662	663
Ethiopia	—	—	—	—	—	—	50	60	30	50	30	80	—	—	—
Ivory Coast	—	—	—	2	1	5	130	169	202	10	20	23	—	—	—
Kenya	—	—	—	—	—	—	14	15	25	14	15	25	—	—	—
Madagascar	—	—	—	5	5	5	50	55	55	5	5	—	—	—	—
Malawi	—	—	—	—	—	—	25	18	—	10	20	40	—	—	—
Mali	—	—	—	15	10	—	195	185	220	—	—	—	—	—	—
Morocco	—	—	—	—	—	—	—	—	—	—	—	—	21	27	18
Mozambique	—	—	—	4	6	—	50	70	80	1	9	20	—	—	—
Niger	—	—	—	—	—	—	12	6	7	—	—	—	—	—	—
Nigeria	—	—	—	250	115	10	130	55	100	—	—	60	—	—	—
Senegal	—	—	—	—	—	—	77	63	55	—	—	—	—	—	—
South Africa	—	—	—	1	—	—	130	192	195	33	48	50	—	—	—
Sudan	—	—	—	25	20	20	260	375	289	35	35	1	405	445	265
Tanzania	—	—	—	25	11	—	217	175	182	68	46	78	—	—	—
Togo	—	—	—	2	2	—	11	8	20	—	—	—	—	—	—
Uganda	—	—	—	—	—	—	40	60	50	25	30	20	—	—	—
Upper Volta	—	—	—	28	15	20	65	45	80	—	—	—	—	—	—
Zaire	—	—	—	—	—	—	50	37	37	5	5	—	—	—	—
Zambia	—	—	—	—	—	—	3	13	18	—	—	—	—	—	—
Zimbabwe (Rhodesia)	—	—	—	—	—	—	150	150	140	—	—	—	—	—	—
Others	—	—	—	—	—	—	32	30	28	—	—	—	1	2	3

*To convert to kg multiply by $2{,}17 \times 10^5$

TABLE 4

PROPORTION OF COTTON IRRIGATED, MACHINE PICKED, AND ROLLER GINNED[6]

Country	Proportion of cotton acreage under irrigation	Proportion of crop machine picked	Proportion of crop roller ginned
Afghanistan*	100	NA	NA
Algeria (1973)	65	0	76
Angola (1968)	0	0	0
Argentina	10	3	0
Australia	99	100	0
Bolivia	0	0	0
Brazil	0	3	0
Burma	26	0	NA
Burundi*	NA	0	NA
Cameroon*	0	0	0
Central African Rep.	0	0	0
Chad	0	0	0
China (Taiwan)*	90	0	100
Colombia*	15	0	0
Costa Rica*	0	15	0
Cuba (1973)	0	0	0
Cyprus*	100	0	NA
Dahomey*	0	0	0
Dominican Republic*	0	0	0
Ecuador	10	0	0
El Salvador	0	0	0
Egypt	100	0	100
Greece	97	NA	NA
Guatemala	0	10	0
Honduras	0	0	0
India	25	0	98
Iran	90	1	0
Iraq	100	10	0
Israel	90	100	75
Italy*	20	15	0
Ivory Coast	0	0	0
Kenya	1	0	100

Country	Proportion of cotton acreage under irrigation	Proportion of crop machine picked	Proportion of crop roller ginned
Korea Rep.	0	0	0
Malagasy (1968)	50	0	0
Malawi	0	0	0
Mali	0	0	0
Mexico	84	5	0
Morocco	100	0	100
Mozambique*	0	0	0
Nicaragua	0	3	0
Niger	9	0	0
Nigeria	0	0	0
Pakistan	90	0	15
Paraguay*	0	0	100
Peru	98	0	35
Senegal	0	0	0
South Africa	65	20	0
Spain	98	3	8
Sudan	85	0	70-75
Syria	97	0	7
Tanzania	0	0	90
Thailand	10	0	95
Togo	0	0	0
Turkey (Average)	84	0	74
Uganda	0	0	0
USSR	100	85	100
United States	33	89	1
Upper Volta	0	0	0
Uruguay*	0	0	0
Venezuela*	5	20	0
West Indies	0	0	100
Zaire*	0	1	0
Zambia*	0	0	100
Zimbabwe (Rhodesia)	80 est.	0	0

Source: ICAC Cotton Production Survey, 1979

*Cotton International Survey NA: Not Available

TABLE 5

WORLD PRODUCTION OF CERTAIN TEXTILE FIBRES[7]

Thousand Metric Tons* & Per cent

TYPE OF FIBRE	1971	1972	1973	1974	1975	1976	1977	1978
Rayon + Acetate								
Filament	1 401	1 342	1 363	1 302	1 136	1 188	1 167	1 164
Staple + Tow	2 054	2 217	2 298	2 230	1 823	2 020	2 110	2 151
Total Rayon + Acetate	3 455	3 559	3 661	3 532	2 959	3 208	3 277	3 315
Non-Cellulosic Fibres except Olefin								
Filament	2 867	3 213	3 833	3 785	3 763	4 128	4 318	4 595
Staple + Tow	2 742	3 164	3 807	3 702	3 590	4 466	4 823	5 351
Total Non-Cellulosic Above	5 609	6 377	7 640	7 487	7 353	8 594	9 141	9 946
Total Man-Made Above	9 064	9 936	11 301	11 019	10 312	11 802	12 418	13 261
% of World Total	38	40	43	41	44	46	45	48
Natural Fibres								
Raw Cotton	13 008	13 669	13 713	14 020	11 746	12 432	13 804	13 065
Raw Wool	1 566	1 457	1 432	1 510	1 508	1 446	1 445	1 470
Raw Silk	41	42	43	45	47	48	49	50
Total Natural Above	14 615	15 168	15 188	15 575	13 301	13 926	15 298	14 585
% of World Total	62	60	57	59	56	54	55	52
World Total Above	23 679	25 104	26 489	26 594	23 613	25 728	27 716	27 846
World Total %	100	100	100	100	100	100	100	100

The silk and man-made fibre data are on a calendar-year basis, while the figures for cotton and wool are on a seasonal basis.

MAN-MADE FIBRES: Textile glass fibre and olefin production not included.

COTTON: International Cotton Advisory Committee

WOOL: Commonwealth Secretariat. The data are on a scoured basis

SILK: International Silk Association: Food & Agriculture Organisation of the United Nations.

World production of jute and kenaf[16] was some 2 450 million kg during 1977/78.

the fibres and the cotton seed. The proportion of fibres to seed depends on the varieties and strains. It should not be overlooked that cotton seed is a very valuable product. The seeds contain from 16 to 24% of their own mass in high-grade oil[4].

Tables 2 to 4 give some information on cotton production while Tables 5 to 8 give some comparative figures for various fibres.

Although cotton production has been increasing steadily (see Fig 1)[10] its share of the market has been declining steadily (see Table 5 and Fig 2).

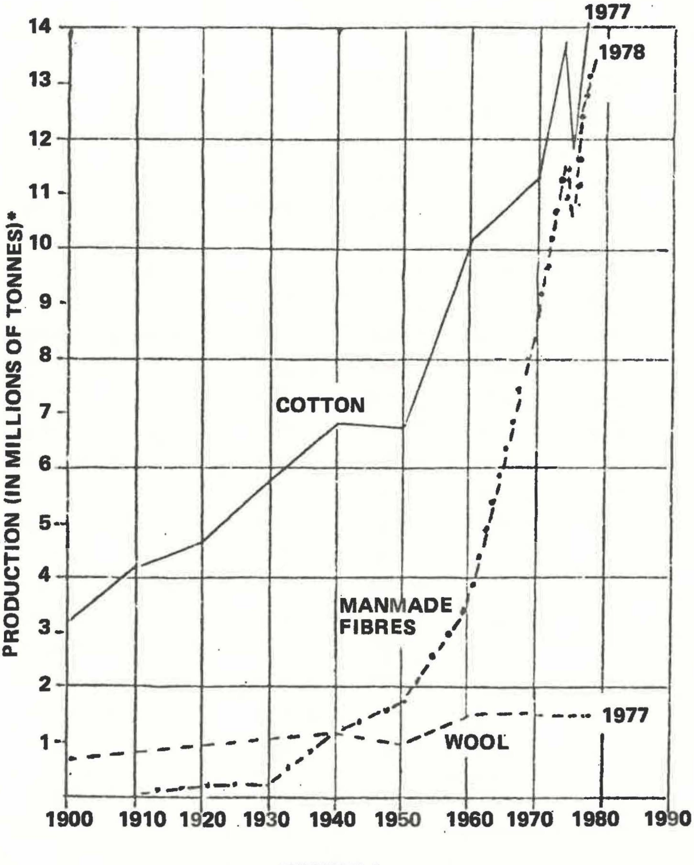


FIGURE 1

World Production of Textile Fibres[10]

*(To obtain kg multiply by 10^9)

TABLE 6

WORLD PRODUCTION OF MAN-MADE FIBRES[9]
(In thousands of metric ton)

Year	CELLULOSICS			SYNTHETICS			Total World Production of Man-Made Fibres
	Filament Yarn	Staple fibre	Total	Filament Yarn	Staple fibre	Total	
1930	205	3	208				208
1935	425	65	490				490
1940	542	585	1 127	1	4	5	1 132
1945	401	200	601	14	3	17	618
1950	872	739	1 611	54	16	70	1 681
1955	1 043	1 252	2 295	184	62	266	2 561
1960	1 131	1 533	2 664	417	286	703	3 367
1961	1 135	1 612	2 747	497	333	830	3 577
1962	1 202	1 729	2 931	638	441	1 079	4 010
1963	1 231	1 901	3 132	779	554	1 333	4 465
1964	1 328	2 051	3 379	977	711	1 688	5 067
1965	1 372	2 074	3 446	1 124	916	2 040	5 486
1966	1 378	2 083	3 461	1 300	1 133	2 433	5 894
1967	1 349	2 089	3 438	1 461	1 353	2 814	6 252
1968	1 419	2 239	3 658	1 847	1 802	3 649	7 307
1969	1 421	2 267	3 688	2 147	2 140	4 287	7 975
1970	1 391	2 194	3 585	2 398	2 411	4 809	8 394
1971	1 398	2 219	3 617	2 881	2 827	5 708	9 325
1972	1 343	2 393	3 736	3 235	3 276	6 511	10 247
1973	1 358	2 496	3 854	3 868	3 862	7 730	11 584
1974	1 287	2 443	3 730	3 826	3 754	7 580	11 310
1975	1 135	2 072	3 207	3 790	3 677	7 467	10 674
1976	1 187	2 285	3 472	4 176	4 551	8 727	12 199
1977	1 158	2 379	3 537	4 379	4 885	9 264	12 801
1978	1 164	2 423	3 587	4 691	5 517	10 208	13 795
1979	1 185	2 480	3 665	4 910	5 762	10 672	14 337
Est.[9] 1985	—	—	5				

1 metric ton = 1 000 kg

TABLE 7

BREAKDOWN OF WORLD PRODUCTION OF SYNTHETICS[8]
(in percentages)

Year	Polyamide	Polyester	Acrylics	Other Synthetics	Total Synthetics	Total World Production of Man-made Fibres
1971	37	37	20	6	100	+ 19%
1972	37	39	19	5	100	+ 14%
1973	35	41	20	4	100	+ 19%
1974	34	43	19	4	100	− 3%
1975	33	45	19	3	100	− 2%
1976	32	45	20	3	100	+ 17%
1977	31	46	19	4	100	+ 6%
1978	30	46	20	4	100	+ 10%
1979	30	47	19	4	100	+ 5%

TABLE 8

GEOGRAPHICAL BREAKDOWN OF WORLD PRODUCTION OF MAN-MADE FIBRES[8]
(in thousands of metric tons)

Year	Western Europe Total	USA	Japan	Rest of the World	World Total
1971	2 882	2 572	1 633	2 238	9 325
1972	3 049	3 032	1 601	2 565	10 247
1973	3 420	3 435	1 818	2 911	11 584
1974	3 171	3 317	1 620	3 202	11 310
1975	2 611	2 983	1 435	3 645	10 674
1976	3 164	3 327	1 616	4 092	12 199
1977	3 016	3 668	1 712	4 405	12 801
1978	3 223	3 869	1 823	4 880	13 795
1979	3 250	4 150	1 822	5 115	14 337
Change 1979: 1978	+ 1%	+ 7%	± 0%	+ 5%	+ 4%

1 metric ton = 1 000 kg

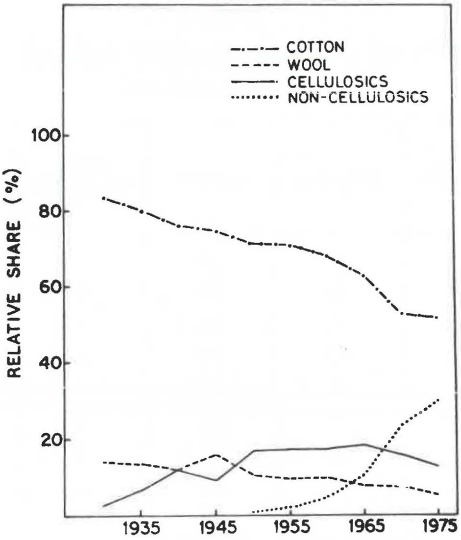


FIGURE 2

Relative share of various fibres in world consumption 1930—1975[11]

It has been predicted[14] that world cotton production could reach 70 to 76 million bales (217 kg each) by 1985 and between 75 and 84 million bales by 1990, with America producing some 10 to 13 million bales by 1990. It has also been predicted[15] that world consumption of textile fibres will be over 46 million tonnes (46x10^9 kg) in 1990, with man-made fibres accounting for 58% (26,5 x 10^9 kg) of the total.

There is great speculation on the relative importance of increases in fuel and energy prices on natural *vis-a-vis* synthetic fibre viability[12, 12a]. It has been estimated[13] that for each $1 increase in oil price per barrel the price of producing polyester will increase by about 2,2 cents per kilogram and the cost of growing cotton by 1,5 cents per kg .

Figs 3 and 4 illustrate trends in world fibre production and per capita consumption[11].

Koedam[17] estimates that cotton is grown on less than 2,2% of the world's arable land cultivated for crops and only 0,8% of the total agricultural land in the world is currently used for cotton growing[11]. It is also often overlooked that the cotton plant produces not only fibre but also cotton seed which is an important source of food. For every 1 000 kg of cotton lint, we get approximately 2 000 kg of cotton seed which yields 300 kg of cotton seed oil. For U.S. cotton the cotton seed comprises approximately 18,6% oil, 41% protein (cake) and 11 to 12% moisture, with hulls and linters making up the balance[213].

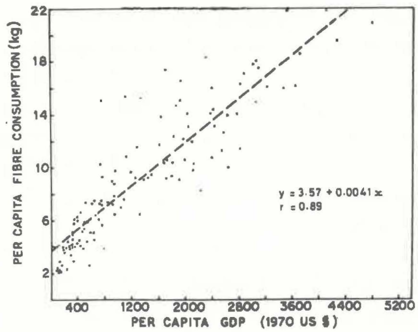


FIGURE 3

Relationship between per capita income and fibre consumption[11]

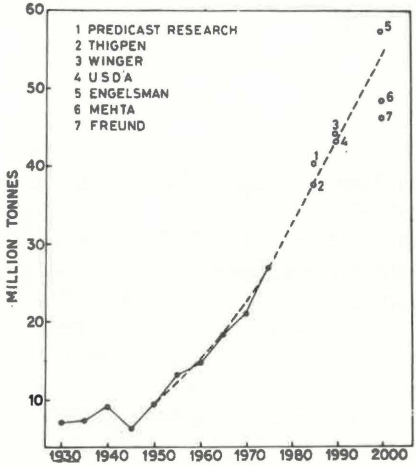


FIGURE 4

Projections of aggregate fibre consumption to AD 2000 by various authors[11]

***1 tonne = 1 000 kg**

In a number of developing countries, extraction of oil from cotton seeds is an established industry. Cotton seed is an important source of high-quality edible oil and protein-rich cotton seed cake for animal nutrition[17], thus contributing indirectly to the world food supply[11]. After extraction of the oil from the cotton seed the residue is exploited for food, animal fodder and fertilizer[4].

The amount of protein and lipid in cotton seed is dependent on maturity, environment, and variety[75]. These same factors affect the cotton fibre and the state of the fibre when it reaches the gin[75]. Ethanol extracts proteins and pectins as well as lipids; chloroform was regarded as best for lipid determination[71]. Free fatty acid content of cotton seed of highest quality is 0,5 to 0,6%[76]. Extremely bad oil may contain 15 to 25% of free fatty acid[76].

While protein isolated from cotton seed is unsuitable at present for human consumption due to the presence of gossypol, attempts are being made to solve this problem[11]. For example, at the SRRC in New Orleans, USA, and at the RRL in Hyderabad, India, a cyclone process has been developed to isolate gossypol-free protein from cotton seeds. (While this process has been successful on a pilot-plant scale, it seems to have run into difficulties in large-scale operation). There are also attempts to develop a gland-free variety of cotton seed, which would enable production of gossypol-free protein fit for human consumption. As and when this becomes technically and commercially feasible, cotton seed would make an important contribution to the protein availability in the world. The stalks of the cotton plant have been successfully used, though on a limited scale, to make building materials such as particle boards and sheets[11].

COTTON GROWING

Cotton belongs to the genus Gossypium of the Mallow[18] (or Malvaceac)[19] family which can be subdivided into other botanical varieties of presently cultivated cotton. None of the commercial varieties of cotton is genetically pure, in the sense of being a pure line[18]. The modern varieties of cultivated cottons belong to four botanically distinct species of Gossypium, two old-world diploid species (G. arboreum and G. herbaceum) and two tetraploid species (G. hirsutum and G. barbadense) which originated in the new world[20]. G. barbadense is the longest staple type and includes the Egyptian, American-Egyptian, Tanquis and Sea-Island varieties[316]. G. hirsutum accounts for most American Upland type cottons while G. arboreum and G. herbaceum cottons, referred to as Asiatic cottons, are the short-staple types and are largely grown in India, China, Iran, Iraq, Turkey and Russia[316].

Typically the cotton plant appears about one week after planting the seed, the flower appears about nine weeks after planting and the boll opens some 18 weeks after planting. In general, about 160 frostless days are required to grow cotton successfully, with long-staple cotton requiring a longer growing season than short staple cotton. Frost, soon after planting, will kill the young plant while if the frost occurs before the boll has completed its growth, immature cotton will result. The cotton seed will not germinate below a soil temperature of about 15°C while the optimum germination temperature is about 34°C[18]. The optimum temperature for development from germinated cotton seed into the emergence of young plants is about 24°C. Frequent warm showers are helpful in maintaining adequate moisture for germination and the emergence of young plants and germination of the seed is also favoured by a high oxygen content of the soil. Germination varies from about 7 to about 10 days depending upon the variety and environmental conditions. Under very favourable conditions the plant appears about four days after planting the seed, while if the weather is cold and wet it may take up to 14 days[18]. If the weather is extremely cold and wet the seed will not germinate. From four to six weeks after the emergence of the young plant, the young squares or floral buds usually appear. The four to six week period referred to above is characterised by the development and growth of stalk stems, leaves and root system. The bud is surrounded by three bracts or bracteoles (modified leaf), joined at their bases and often referred to as squares[213]. They form a "canopy" over the bud, probably offering some protection to it and the subsequent young boll[213]. The development from the young squares to the open flowers is usually referred to as the blooming period. In general, the cotton flower will open about 21 days after the appearance of the young squares. For a typical American Upland cotton, the flower appears (anthesis) some 60 to 70 days after planting, the flower having a life of about one day. Fertilisation invariably occurs on the day of anthesis (flowering), mostly by self-pollination[213]. The fruit (boll) ripens within 50 to 70 days after fertilisation, when the boll splits open and the cotton is ready for harvesting. The fruit is a dry dehiscent schizocarp of three, four or five loculi, each loculus containing about eight lint-bearing seeds (i.e. a total of about 30 seeds per boll)[213].

An increase in water supply, up to a certain point, increases the growth of the cotton plant, thereby increasing the branches, both fruit and vegetable, which results in more buds and consequently more flowers. Excessive rainfall, however, promotes the growth of more vegetable branches. Moderate temperature and ample sunshine are necessary for the development of flower buds to open. The soil fertility determines to a large extent the earliness of flowering and the amount of flowering[18].

In general, some 45 days are required for the transition of the flower to the open boll for most Upland varieties of cotton, but the late season blooms require 10 to 20 days longer, depending upon environmental conditions[18]. It is during this period of development of the cotton boll that the fibres are maturing within the boll. During the period of vegetative growth the temperatures should be within 15,5°C and 38°C, provided there is sufficient moisture in the soil; excessive cold or heat retards the growth of the cotton plant. During the second stage of growth a decreasing temperature and a greater range of day and night temperature favour the maximum production of cotton, for it checks the vegetative growth and induces the plant to convert the food material into seed and lint. The amount of rainfall should be at least 500 mm (20 inches) per annum but not more than 1 524 to 1 905 mm (60 to 75 inches) although the distribution of the rain and the manner in which it falls are important to the growth of the cotton plant. The rain should be slow and easy and come frequently during the first period and less frequently in the second period. Cotton plants will grow in practically all types of soil. Abundant sunshine during the lifetime of the cotton plant is necessary.[18].

Generally speaking, from the time the flower opens it will take about 45 to 65 days depending upon variety and environmental conditions, for the cotton fibre to mature in the unopened boll[18]. This is usually referred to as the boll development period. Environmental conditions predominate during the development of the cotton fibre and consequently in the variation in the fibre property. The matured cotton boil has its origin in the flower. The cotton fibre originates from the outer wall of the cotton seed and the development of each fibre begins with the sprouting of a single epi-dermal cell[22], which first elongates as a thin-walled tubular structure to its maximum length[18] (See Figs 5 and 6) before wall thickening commences. Once the cotton fibre has attained its maximum length, the thickening of the secondary wall takes place as a result of the deposition of layers of cellulose on the inner surface of the fibre. The fibre reaches its maximum perimeter (diameter) early during the period the fibre is elongating[50].

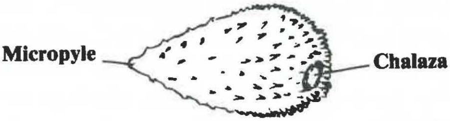


FIGURE 5

Cotton seed on the day of flowering[23, 24]

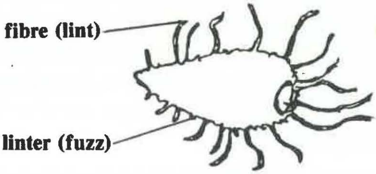


FIGURE 6

Development of normal fibres (lint) and linters (fuzz) on the cotton seed some three or more days after flowering[23, 24]

The cotton fibre springs up on the embryo seed on the day of flowering or within one or two days afterwards[26]. The elongating epi-dermal cells from the cotton seed are developed into two different types of fibres; the lint fibre, which is generally referred to as the cotton fibre, and the fuzz fibres that constitute a large part of raw material used as cotton wool, linters in explosives and for making rayon and other regenerated fibres[18,26]. The lint fibre appears first, the fuzz fibres appearing several days later. The fuzz fibres are generally unconvoluted, are shorter (being shorter than about 6,5 mm), larger in basal diameter and more thick-walled than the lint fibres. G. barbadense generally has almost fuzzless seed.

Beginning on the day of flowering or very soon afterwards, each lint fibre, hereafter referred to as fibre, elongates for a period of 15 to 25 days[18,25] (Lord[22] mentions 21 to 28 days) depending upon the variety and environmental conditions, to attain its maximum length[18]. The rate of elongation is small during the first few days, increases for a few days, and then diminishes and gradually levels off. Long-staple cotton requires more time than short staple cotton for reaching its full length. Fibre length is predominantly a varietal characteristic under a given set of environmental conditions although environmental factors do affect length development. Water stress will slow down the growth of the entire plant and consequently the rate of fibre elongation[18].

Staple length can be reduced by as much as 3 mm by water stress occurring during the sixteen days after flowering[20]. In most countries, lint quality varies as the season progresses, the fibres often becoming weaker, shorter and less mature at the end of the season. Some varieties are better than others in this respect[20]. When the fibre is fully elongated, it is tube-like in shape with the outside a thin membrane (primary wall) which is less than 0,5 μm thick[18]. This membrane is known as the primary wall of the fibre in which protoplasm is contained. The tube-shaped fibre has a diameter which is relatively constant. Since the cotton fibre is fully elongated within the boll it does not extend in a straight line but it bends back and forth at sharp angles. There are some 1 000 or more fibres on a single cotton seed[26] and the length of fibre is from 1 000 to 3 000 times greater than its diameter depending upon the variety of cotton[18]. For the Asiatic cotton it is about 1 000, for the American Upland varieties it is about 2 000 and for the Sea Island variety it is about 3 000. This means the corresponding fibre diameters are roughly 25 μm, 14 μm and 12 μm, respectively. The cotton fibre linear density varies about 340 mtex for coarse Indian cottons to about 100 mtex for St Vincent Sea Island[27].

After the period of elongation has ended and the tube-shaped fibre has reached its maximum length, the development of the fibre enters into the phase of thickening of the secondary wall by depositing cellulose on the inner surface of the tube-shaped fibre in successive layers[18]. The thickening of the fibre's secondary wall takes about a month, ranging from 25 to 40 days[18] (Lord[22] mentions 35 to 50 days). During this process sugar, produced from water and carbon dioxide by action of sunlight on the plant leaves, is transported into the fibre. Here it is chemically converted into cellulose and deposited in successive layers (lamellae) on the inner wall surface, producing rings reminiscent of the annual rings found in trees[18]. A cross-section of the fibre viewed under the microscope reveals adjacent light and dark rings, each pair of rings represents a day's growth, the dense area is deposited at night as the result of active photosynthesis of cellulose during the day, and the less dense area during the day — there being little photosyntheses during the night[28]. There would normally be about 30 to 40 lamellae in a cotton fibre regardless of fibre diameter. The so-called daily growth rings, or lamellae, are claimed to be analogous to the annual growth rings observed in the cross-section of trees, but are deposited in the inverse order. The existence of lamellae in the secondary wall remains unquestioned, but confusion exists regarding the number present. The observation that the number of lamellae in a fibre cross-section is dependent upon the cell-wall thickness of the fibre appears to be logical. Thus, thin-walled fibres and very fine mature fibres would have fewer lamellae than either thick-walled or coarse mature fibres. The actual diameter of the growing fibre and the degree of cell-wall development are largely inherited characteristics, but weather and soil environment also greatly influence the latter[22]. Some fibres die before they receive all the layers of cellulose they would otherwise have. Others, retarded in growth because of reduced moisture or food supply, are still under-developed at the end of the growing period. After growth ceases, in 40—70 days after flowering, the boll dries out[22].

Temperature variation is a major criterion in the production of growth layers in the cotton fibre[29]. Cottons without growth rings can be produced by growing the cotton plant in constant light and temperature and it appears that growth rings are able to slip at high loadings[30,31]. Even though the thickness of the secondary wall is varietally determined, environmental factors affect the varietal character[18]. Rainfall, temperature and sunshine affect the thickness of the secondary wall[18]. If growth conditions are poor, the commencement of secondary wall thickening is delayed, the thickening, once started, proceeds at a slower rate and ceases at a lower level. A normal fibre resembles a tube and comprises three parts, viz. primary wall, secondary wall and lumen[32] (see Fig 7). The primary wall, a thin membrane consisting largely of disorganised cellulose, pectin and waxes, determines the character of the fibre's resistance to wetting and abrasion[33].

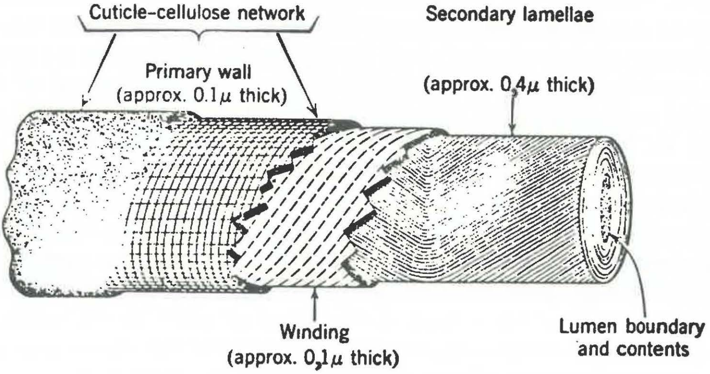


FIGURE 7

Schematic representation of structural parts of cotton fibre[105] (after Tripp)

The tenacity of the primary wall of a cotton fibre is roughly 100 cN/tex and that of the secondary wall 250 cN/tex[34].

Cotton fibres in the mature unopened boll are fully swollen, round tubes free of convolutions[35]. Never-dried cottons have been studied extensively in order to understand more about the structure of the cotton fibre[35—39a]. As soon as the boll opens, the fibres begin to dry and to shrink in both length and diameter until they collapse into the typical convoluted, flat-ribboned shape of the cotton fibre[35]. When the cotton boll opens and the fibre dries out, certain irreversible changes occur[40,41]. The cytoplasm, which maintains growth of the cell, dies and dries to a tiny proteinaceous remnant in the lumen. The fibre wall collapses forming a cross section varying from a bean or kidney shape to an oval or nearly circular shape, depending upon wall thickness. Four different zones have been distinguished in the secondary wall by virtue of their accessibilities and sensitivities to attack by the enzyme cellulose; these zones (see Fig 8) are interpreted to be characterised by substantially different densities of packing of fibrils and substantially different degrees of internal fibre strain; density of packing decreases from zone A to B to C, with the lowest density and highest accessibility to enzyme attach at the interface between A and C[40,41].

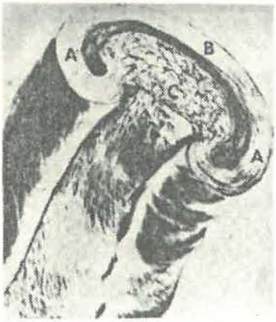


FIGURE 8

Morphological model of the secondary wall of the collapsed cotton fibre. Letters A, B and C denote regions of substantially different densities of packing of fibrils and strains[40, 42]

As the wall collapses, the cotton fibre becomes twisted and convoluted, much like a rubber tube evacuated by suction (See Fig 9)[40,43]. The presence and number of these convolutions depend on wall thickness, which in turn depends upon variety and maturity of the fibre — few or no convolutions for thin-walled fibres, numerous convolutions for fibres of intermediate wall thickness, and few convolutions for thick-walled fibres. Crystallite size and/or perfection of cotton cellulose decreases on initial drying in response to the stresses induced by the collapse of the never-dried cylindrical fibre into a convoluted shape[40,44].

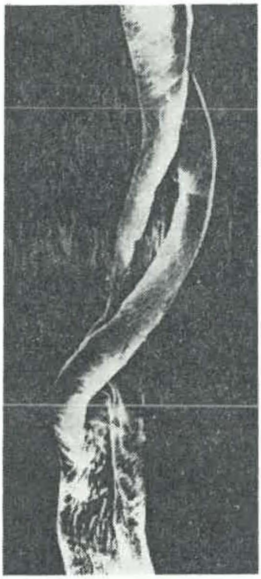


FIGURE 9

Portion of a collapsed, convoluted cotton fibre[40, 43]

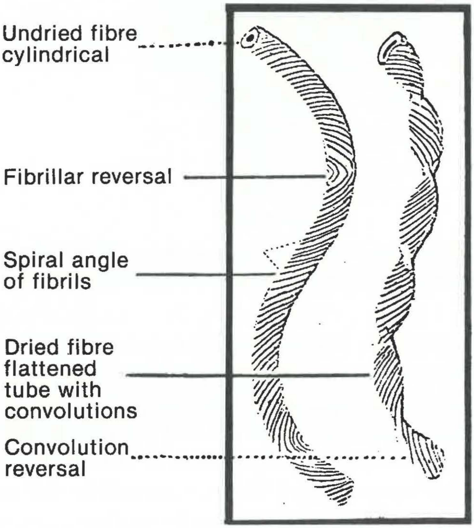


FIGURE 10

Cotton Fibre Structure — secondary wall only[45]

Fibre maturity (wall thickness) varies greatly from fibre to fibre within a boll (Lord) and is the main factor responsible for variations in fibre linear density. Fibre properties also vary according to where it grows on the seed.

An experiment was conducted to determine the variation in fibre properties from a single cotton seed: fibres from one cotton seed were divided into four zones, the fibres from each zone being carefully removed[18]. The resulting values of three fibre properties are tabulated below (see Fig 11 and Table 9).

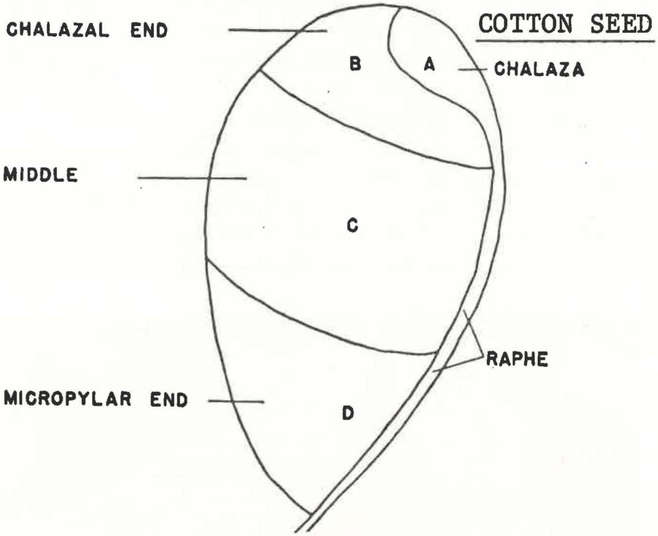


FIGURE 11

Diagram of cotton seed, showing the areas from which fibres were selected

TABLE 9

VALUES IN FIBRE PROPERTIES FROM FOUR DIFFERENT ZONES OF A COTTON SEED[18]

Properties	Zones			
	A	B	C	D
Upper half mean length (mm)	27,7	27,7	26,9	26,2
Strength (cN per fibre)	3,37	4,42	5,78	5,66
Fineness micronaire (μg/inch)	3,4	4,6	5,6	5,9
Fineness (mtex)	134	185	222	232

Source: USDA, Better Cottons p.931

Tests have revealed that short fibres on a seed are more mature than long fibres. The longest fibres attached to a seed are at the chalazal end and the shortest at the narrow or micropylar end. The thickest part of a fibre is towards its middle[46]. Within a cotton sample the single fibre tenacity reaches a maximum at a linear density[47] close to the average for the sample[47]. Wall thickness and linear density are highly correlated for mature cottons.

The distinguishing feature of the cotton fibre tip is the absence of both lumen and convolutions[46]. It is normally a tapered rod-like end. All cotton fibres taper towards the growth end[48] and the cuticle is continuous around an undamaged fibre tip. The cuticle is also continuous around the base but it is ruptured when the fibre is pulled away. The fibre diameter also becomes smaller at the base but not to the same extent as at the tip[48].

Perimeter of fibres from the raphe part of seed tend to be smaller than that of fibres from adjacent portions of the same general area[49]. The maximum fibre perimeter is reached very early on in the fibre elongation process[50].

Fibres from chalazal or rounded end of the seed are known to be thinner-walled than fibres from other parts of the seed[51]. Fibre perimeter is normally

FIGURE 12

Stereoscan photomicrographs of unmercerised cotton fibre cross-section[52]

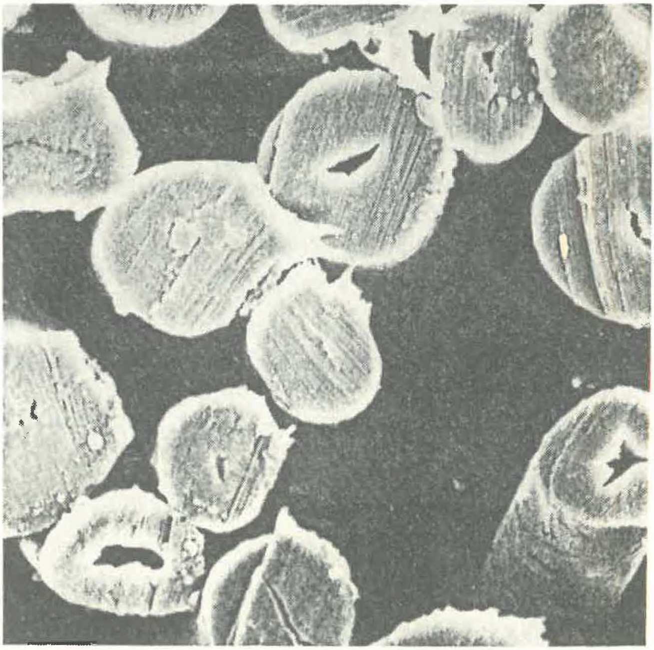


FIGURE 13

Stereoscan photomicrographs of mercerised cotton fibre cross-sections[52]

reasonably constant among American Upland cotton, although wide differences can occur[51], Fibres differing somewhat in their perimeters according to their position on the seed[49]. Fibre perimeters have been found to vary from $\approx$ 66 to 99 μm for undried fibres and $\approx$ 36 to 55 μm for dried fibres. The ratio of mercerised fibre diameter to diameter of uncollapsed mature fibres is $\approx$ 0,64 to 0,70 whereas the ratio of the perimeter of mature dried fibres to that of uncollapsed (actually primary wall stage) fibres is $\approx$ 0,58[49]. Some fibre cross-sections are shown in Figs 12 and 13.

All commercial cottons have similar crystallinities, cellulose contents, degree of polymerisation and spiral angle[53] and can therefore be expected to have the same ideal strength. Observed differences could be due to structural and morphological differences such as convolution angles, reversals, and molecular orientation[53]. It appears that, for fibre properties changed by cotton *variety,* the longer the cotton (i.e. UHML) the stronger and the finer (lower micronaire) it will be[18]. The variation in fibre properties is affected more in the boll development period than in any other period of plant growth. Given a variety of cotton planted in a certain type of soil, the variation in fibre properties can be explained to a large extent through the variation in rainfall and temperature[18].

For a long time, cotton breeders have recognised an adverse genetic association between lint yield and fibre strength[20,54], they being inversely proportional to each other[54]. Nevertheless, six breeding lines that deviate significantly from this relationship have been developed. Moreover, certain other properties are often genetically linked: good fibre length is associated with low ginning out-turn and vice versa, i.e. short staple means high fibre percentage[4]. This state of affairs is all too familiar, both with Egyptian and Asiatic cottons. In American cotton, which accounts for 85% of the world crop, every intermediate stage can be found[4].

By crossing various species and varieties and by selection, the breeder attempts to arrive at the best genetic combination — good ginning outturn, good fibre length and high yield[4]. The general endeavour is to breed a fine but very mature fibre. Already it is known that in OE spinning a cotton with low micronaire value performs better. Very often, however, these fibres are unripe, and present difficulties in dyeing[4].

The yield of a cotton variety is a genetic characteristic. There are strains that thrive in dry, light and poor soils, while other improved varieties yield good crops only if all the conditions are right — such as soil, climate, mineral fertilization and comprehensive pest control, etc. Naturally such varieties cannot be cultivated everywhere[4]. It is the breeder's function to find out which species or varieties are best suited for a given environment. Apart from the crop yield there are other properties that must be taken into account, such as:
— the response to fertilizers, with or without pest control;
— the resistance to various diseases and pests;
— the suitability of the plants for mechanical picking[4].

Growing area and conditions have a very significant effect on cotton fibre properties. As an example, a US variety giving 85 000 psi in the Mississippi region gives only 70 000 psi in Nicaragua, and 75 000 in Chad, and this result is repeated every year[4].

Micronaire and fibre perimeter both depend upon variety[55] and within a cotton variety maturity and fineness are correlated[56]. Within a variety longer fibres are finer[55] and stronger[57]. Long fine cottons are stronger than short coarse ones in spite of the former having more convolutions and structural reversals[58,59]. Longer cotton groups within a cotton sample are also more uniform in strength than the shorter groups[60]. Cotton fibre fineness, length and strength tend to vary together[57]. For various cotton cultivars, within a cotton, fibre stiffness, fibre strength, strength uniformity, maturity and reversals per unit length increase as the fibre length group increases, while elongation per unit load decreases[60]. It appears that both the longer and shorter cottons are generally finer than the medium length cottons (within a cotton sample) with the longer fibres the finest[57,61], although there is still some doubt about this[62].

FIBRE STRUCTURE

The structural elements of the cotton fibre are (1) primary wall; (2) secondary wall and (3) lumen. The outside of the fibre is covered with a thin layer of wax, pectic material and encrusting material presumed to be calcium and magnesium salts of pectic acid.

Primary Wall

The cotton hair consists of a thin membrane-like primary wall composed mainly of cellulose but containing some pectins, fats and waxes[63].

Some workers differentiate between the cuticle and the primary wall, whereas others consider these to be the same[33]. The primary wall of the cotton fibre results from the extension of certain epidermal cells of the developing cotton seed. It reaches its maximum length about 20 days after the cotton

TABLE 10

COMPOSITION OF THE DEPOSIT, COTTON SEED, TYPICAL COTTON FIBRE AND PRIMARY WALL[33, 65, 71]

Constituent	Percentage of dry mass[(a)]			
	Deposit	Seed[72, 73]	Lint[(b)]	Fibre primary wall[74]
Cellulose	yes[(c)]	yes	94	54
Protein (% Nx6,25)	25,3	19,2	1,3	14
Pectic substances	not detd.	—	1,2	9
Wax (alcohol-solubles)	15,2	—	0,6	8
(cotton seed oil)		18,1[(d)]		
Phospholipid	yes	yes	—	—
Gossypol	yes	yes	—	—
Cutin/suberin(?)	not detd.	—	—	4
Ash	not detd.	yes	1,2	3
Linters	yes	10,4-11,4	—	—

(a) The moisture regain of fibre is 8%, of the primary wall, 13%

(b) From USDA Publication AIC-61

(c) Present but amount not determined

(d) Based on fuzzy seed to 10% moisture content.

flowers. From studies made on the outer limiting membrane of the fibre, the primary wall seems to be less than 0,2 μm thick (some quote 0,5 μm) and to be made up of laminated microfibrils[33,64,65]. The first layer is oriented in a direction parallel to the fibre axis, whereas the second layer is oriented transversely[66]. Underneath this is a primary winding, or wide bands of microfibrils about 0,1 μm thick, which spiral around the fibre[67,68]. Other workers have concluded that the cellulose in the primary wall is either randomly arranged[69] or that the fibrils lie transverse to the fibre axis[33]. The composition of the separated primary wall and that of the entire mature fibre[65] is shown in Table 10. The primary wall constitutes about 5% of the mass of the cotton fibre and consists ≃ 50% cellulose with protein, wax and pectic substances occurring in lesser amounts[65]. The majority of the cotton wax is present on or near the surface of the cotton fibre[65].

Secondary Wall

The secondary wall constitutes the greater part of the cotton fibre and is composed of lamellae consisting of dense, and porous or less dense, areas[33]. A lamella is deposited each day after the primary wall has reached its maximum elongation[77]. The secondary wall is composed of cellulose chain molecules tightly packed together to form elementary fibrils which can be clearly seen under an electron microscope[63]. It appears that these elementary fibrils are very long, have a rectangular cross-section and the cellulose chains are arranged that they run along the length of the microfibril with complete hydrogen bonding between the chains so that the only hydroxyl groups which are accessible for chemical reactions are those at the surface of the microfibrils[63].

The secondary wall of cotton fibres can be divided into three distinct zones that differ in their accessibility and reactivity[78]. The concave part of the characteristic bean-shaped cotton fibre is more accessible and reactive than the convex part, with the highly curved ends the least accessible and reactive[78] (see Fig 8). Thus cotton fibres have an asymmetrical or "bilateral" structure as a result of variations in the packing density of their fibrillar or lamellar structure. Mature fibres have relatively thick walls (3 to 4 μm)[79].

Lower strength at (or just adjacent to) the reversals of the helix fibrillar structure has been observed for cotton[80].

General

Cotton fibres possess a highly porous structure and have been appropriately classified as a "xerogel"[81]. The lumen, which is the central hollow cavity within the fibre, is by far the largest single pore in cotton. Apart from the lumen, the cell wall of a cotton fibre contains pores which have sizes ranging from about 25 Å upward to those in the submicroscopic range. The porosity of cotton decreases with increasing period of fibre growth, as indicated by a progressive decrease in the moisture content of fibres and also by a reduction in lumen extent[81]. It is very difficult to remove all the moisture from cotton. The difficulty of drying cellulose is illustrated by the observation that when it is kept in a closed vessel over phosphorous pentoxide for a long period of time, it retains up to 1% of its moisture, even when dried in an oven at 105°C, it still holds up to 0,5% of physically bound water. Only by heating under vacuum can the moisture content be reduced to 0,4%[19].

Cotton is cellulose which is a high molecular compound[82]. Cotton fibres are complex structures consisting of cellulose macro molecules which are arranged in a certain order and do not completely occupy their geometrical volume[82]. The volume of voids in the dry fibre is estimated to be about 30 to 40%. The diameter of the different pores in dry cotton is 5 Å and after swelling 20—40 Å . This aspect is of great importance in studying the mechanism of dyeing and the reasons for bad dyeings[82].

Powerful swelling treatments, like mercerisation, and subsequent drying, substantially reduce the accessibility to liquids which are unable to break hydrogen bonds, but increase accessibility to water and dyes . Steaming treatments, following tension mercerisation and drying, were shown to have a permanent effect on the cotton fibre structure, suggesting that crystalline fusion of fibrils occurred[83]. The length of crystallites and less-ordered regions decreased on tension mercerisation[83].

The following graph illustrates the relationship between the degree of polymerisation (DP) of the cotton fibre and different stages in its growth.

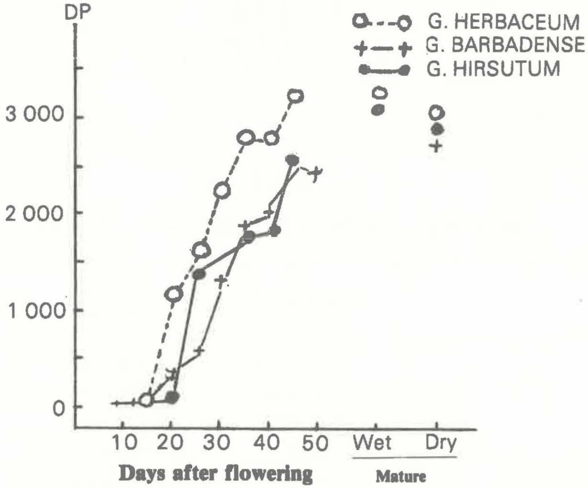


FIGURE 14

Effect of maturity on degree of polymerisation (DP)[84]

The degree of polymerisation (DP) of cellulose, seems to vary with its source and method of isolation. A DP (n + 2) of 5 000 seems average but samples of DP as high as 8 000—10 000 have been reported[19].

Some comparative results are given in various tables below.

TABLE 11

DENSITY OF CELLULOSIC FIBRES (BONE DRY)[85]

Fibre	Density	Degree of crystallinity[86] (%)
Ramie	1,550—1,556	70
Cotton	1,545—1,547	70
Ramie, mercerized with tension	1,543	47
Ramie, mercerized without tension	1,526	
Viscose rayon	1,518—1,525	40

TABLE 12

DENSITY OF NEVER-DRIED COTTON[37]

Sample	Description	Density, (g/cm^3)	Reference
McNair	Never-dried	1,536 (wet)	(37)
McNair	Once-dried	1,589 (wet)	(37)
Hopi Acala	Once-dried	1,573 (wet)	(37)
Cellulose	Dry	1,604-1,609 (dry)	(87)
Cotton fibres	Wet	1,609 (wet)	(88)
Crystalline cellulose	Dry	1,59-1,63 (dry)	(87)
Amorphous cellulose	Dry	1,48-1,59 (dry)	(87)

TABLE 13

PERCENTAGE OF CRYSTALLINE CELLULOSE[85]

Method	Cotton	Wood pulp	Mercerized cotton	High-tenacity rayon
Hydrolysis method				
Nickerson[89]	94	90	89	79
Conrad and Scroggie[90]	92—94	88—91	85—89	69—73
Philipp[91]	88	—	82	67
X-ray diffraction[86, 92]	69	65	47*	39
Density[93]	58	53	40	24—32
Calorimetry[94]	87	—	77	52
Deuterium-oxide exchange[95]	78	63	—	20

*Mercerized ramie.

TABLE 14

CELLULOSE CHARACTERISTICS[96, 97]

Source	Molecular weight	Degree of Polymerization
Native cellulose	600 000—1 500 000	3 500—10 000
Chemical cottons	80 000—500 000	500—3 000
Wood pulp	80 000—340 000	500—2 100
Rayon filament	57 000—73 000	850—450

TABLE 15

MOLECULAR WEIGHTS BY ULTRACENTRIFUGE[46]

	Molecular Weight	Number of Glucose Residues	Solvents
Cotton	200 000—300 000	1 200—1 800	Cuoxam
Regenerated cellulose	90 000—110 000	555—680	Cuoxam
Acetate	50 000—250 000	175—360	Acetone
Nitrate	100 000—160 000	500—600	Acetone
Ethyl cellulose	125 000	540	Dioxane
Methyl cellulose	14 000—38 000	—	—

TABLE 16

MOLECULAR WEIGHTS BY VISCOSITY[46, 98]*

	Molecular Weight	Glucose Units
Cotton	327 000	2 020
Cotton linters	233 000	1 440
Wood pulp	113 000—146 000	700—900
Regenerated cellulose	49 000—81 000	300—500

*According to Stuadinger and Feuerstein[98]

TABLE 17

THE EFFECT OF CERTAIN PROCESSES ON THE DEGREE OF POLYMERISATION (DP) (EGYPTIAN COTTON)[83]

	DP
Purified, unmercerised cotton	2560
Mercerised without tension	1775
Tension mercerised and air dried (T.M.)	2006
Tension mercerised and dried at 100°C and soaped	2056
T.M. steamed 60 min and soaped	2210
T.M. steamed 120 min and soaped	1206

Mechanical processing appears to degrade the cotton (reduce DP) but this is offset by the subsequent processing[99].

Cotton intrinsic viscosity (molecular weight) generally persist through to the fabric and is related to such characteristics as wet abrasion resistance or laundering shrinkage. Intrinsic viscosity may be important to monitor[21].

COMPOSITION OF COTTON

The cellulose content of raw cotton fibre ranges from 88 to 96% of the dry mass, a content higher than that of any other large commercial source. Scoured, bleached and dried cotton fabric is approximately 99% cellulose. The variation in cellulose content of raw cotton fibre is due to soil, climate, variety of cotton, and other factors which prematurely interrupt its growth. Low cellulose content usually indicates a high proportion of thin walled immature fibres.

TABLE 18

COMPARATIVE COTTON COMPOSITIONS
(in Percentages)[46]

	Cotton (Turner 1949)	Mature Cotton** (McCall & Jurgens 1951)[102]	Immature Cotton** (McCall & Jurgens 1951)[102]	American Cotton (Zeisel 1927)[103]	Egyptian Cotton (Zeisel 1927)[103]	Dry Mass Comparison**		
						Typical	Low	High
Cellulose	82,70	94,41	92,44	91,00	90,80	94,00	88,00	96,00
Hemicellulose + pectins	5,70	—	2,00	—	—	*1,20	*0,70	*1,20
Encrusting substance	—	—	—	0,53	0,68	—	—	—
Protein	—	1,00	—	—	—	1,30	1,10	1,90
Wax	0,60	0,45	1,14	0,35	0,42	0,66	0,40	1,00
Water	10,00	—	—	8,00	7,85	—	—	—
Ash	—	0,79	1,32	0,12	0,25	1,20	0,70	1,60
Water soluble components	1,00	—	—	—	—	—	—	—
Total Sugars	—	—	—	—	—	0,30	—	—
Pigment	—	—	—	—	—	Trace	—	—
Other	—	1,35	3,10	—	—	1,40	—	—

*Percentage of Pectic substances only shown
**Based upon dry mass

Another author states that data collected from various sources indicate the following approximate ranges for raw cotton[104] (conditioned).

	%
Cellulose	80—85
Water	6—8
Nitrogenous matter	1—2,8
Waxes, etc	0,5—1
Mineral matter	1—1,8
Pectate	0,4—1
Residue of pigment resin, etc	3—5

Pectic material in raw cotton is present mainly as calcium and magnesium pectates — long chain polymers. However, when cotton is boiled with dilute alkali, the complex combination is broken down and readily removed[104].

The *pigment of cotton* is most pronounced in the wild varieties and deepens as the cotton ripens. Egyptian cotton is usually much more pigmented than the American varieties. The exact constitution of pigments is still not completely clear[104].

It has been assumed that the *protein* material in cotton is the residual dead protoplasm left in the lumen after the cell dies when the boll opens[105]. The nitrogen content of raw cotton is approximately 0,3%, and if this were converted to protein by use of the usual factor of 6,25 — it would give a protein content of 1,875%. Raw American cotton contains 0,21% nitrogen (1,3% protein) while Egyptian cotton contains 0,3% (1,9% protein)[46]. Tripp found nitrogenous material in primary wall isolated from mature cotton, to the extent of 2% nitrogen which calculates to approximately 14% protein in the composition of the outer skin of the fibre. Kier boiling of cotton reduces the nitrogen content to about one-tenth the original value; the nitrogen content of scoured cotton is about 0,035%[46,105].

The *mineral matter* in cotton exists chiefly in the form of sodium, potassium, calcium and magnesium salts, much of which is soluble in water, but raw cotton direct from the bale is often contaminated with earth and sand. According to some authors, the ash content of raw cotton (1,1 to 1,6%) falls to 0,15 to 0,26% after steeping in water or scouring or bleaching and to between 0,02 and 0,06% after an acid-steep[104].

Kearney and Scofield[106] found the *average ash* content of cotton taken from unopened bolls to be 1,17% of the dry mass. One gram of cotton-fibre ash will neutralise 13 to 16 m*l* of normal acid. About 85% of the ash may be removed from the fibre by extraction with water, but most of the calcium, iron and aluminium remain in the fibre. The ash content of cotton after scouring and bleaching is usually negligible. The fact that washing cotton with water greatly increases its electrical resistance by removing most of the soluble potassium and sodium salts has made possible its adoption as a substitute for silk in tensile insulation of telephone cord, wire and cable[46].

The phosphorous content of cotton has received considerable attention. Geake[107] found the following average values, expressed as % P_2O_5, for the phosphorous content of raw cotton: American, 0,05; Sea Island 0,07; Sakellarides, 0,12; Egyptian other than Sakellarides, 0,09; South American, 0,07. Comber waste which is composed of the shorter fibres, may contain as much as 0,17% P_2O_5. According to Calvert the phosphorous compounds present in cotton are readily extracted with water. Fargher and Probert[108] give the average ash content in % of dry mass of combed, raw cotton grown in different parts of the world as shown below[46].

TABLE 19

ASH CONTENT OF VARIOUS COTTONS[46]

Type of Cotton	Per Cent Ash
North American	1,17
South American	1,16
American, grown in India	1,25
American, grown in other countries	1,47
Egyptian	1,20
Indian	1,28
Sea Island	0,98

More detailed information is given in Table 20 for various different cottons.

TABLE 20

PHYSICAL DATA AND CHEMICAL CONSTITUENTS OF RAW COTTONS AS PERCENTAGE OF DRY MASS[46]

Variety	Crop Season	Staple Length (mm)	"Fineness" (mtex)	Bundle Strength		Wax (%)	Pectate (%)	Organic Ammonia Nitrogen (%)	Total Nitrogen (%)	Phosphorus (%)	Mass Loss during Kier-boil (%)	Ash (%)	Ash Alkalinity[+] cc.N H_2SO_4
				psi	cN/tex								
Half and Half	1937	22,2	227	68 000±700	33	0,44	0,43	0,132	0,140	0,020	7,0	1,01	13,0
Rowden	1938	25,4	217	80 600±900	39	0,60	0,58	0,127	0,129	0,020	7,1	1,14	14,2
Wilds-5	1937	27,8	177	82 300±900	40	0,70	0,60	0,147	0,144	0,020	7,8	1,11	14,6
Acala	1938	25,4	164	81 700±600	40	0,75	0,69	0,165	0,172	0,020	8,0	1,20	13,6
Express	1938	26,2	161	80 500±800	39	0,90	0,77	0,168	0,168	0,019	8,2	1,17	14,8
Delfos	1938	26,2	121	73 900±400	36	0,87	0,71	0,172	0,174	0,019	8,6	1,26	15,4
Sea Island	1938	31,8	118	96 000±1600	47	0,89	0,76	0,232	0,234	0,022	8,5	0,80	16,3

[+] Defined as milli-equivalents of sulphuric acid to neutralise one gram of ash

COTTON WAX

Cotton wax is difficult to remove and some of it (0,1 to 0,3%) persists through all the scouring and bleaching operations[104]. The only way to remove it completely is by solvent extraction: Cotton-waxes which are assets to spinners can be a headache to the bleacher. Several authors have made considerable efforts to determine their exact constitution and now most of them feel that the waxes, constituting 0,4 to 1% of raw cotton, are complex mixtures of monohydric alcohols, esters and wax acids, together with hydrocarbons, fatty acids, resin acids, alcohols and fats. Tom and Schunk[104] reviewed the literature and according to them, the following are present at various times. They are gossypyl alcohol, alcohol, montanyl alcohol, glycols, glycerol, sterols, monotanyl acid, stearic acid, various hydrocarbons, oleic acid, etc. They tried to analyse the waxes and gave the following compositions[104].

	%
Saturated fatty acids	24
Unsaturated fatty acids	52
Alcohol	—
Sterols	10
Hydrocarbons	7
Inert constituents	6

The following table has also been given.

TABLE 21

COMPOSITION OF COTTON WAX[109]

Waxesters	22%
Thytosterols	12—14%
Polyderpenes	3—4%
Hydrocarbons	7—8%
Free Wax Alcohols	42—46%

Cotton wax, which is nearly all located in the primary wall of the fibre[26] contains only small quantities of free fatty acid[110] which may in fact have their origin in seeds broken during ginning[111].

The material extracted from the cotton fibre with chloroform, carbon tetrachloride, benzene, or other organic solvents is usually referred to as wax[105]. As extracted, the wax of ordinary Upland cotton is pasty or tacky; wax from green lint cotton is a hard, brown material similar in many respects to beeswax. The wax acts as a water-resistant protective coating on the raw cotton fibre. Raw cotton will float for days on a water surface, while cotton dewaxed by heating with dilute sodium hydroxide or by extraction with organic solvents will sink in a few minutes. Benzene is generally used for wax content determinations although in some cases hot ethyl alcohol is used to extract wax, the ethyl alcohol extract is treated with chloroform and water[51].

Cotton wax is almost entirely distributed over the fibre surface and in the primary wall, with the wax content per unit surface area substantially constant[51] for cottons grown under similar conditions[111]. Wax per unit surface area is ≃ 2,3 g/cm^2, with the melting point of the wax being ≃ 70—75°C. Surface area of cotton ≃ 2—3,5 cm^2/mg . Wax is ≃ 0,025 μm thick for American cottons[51]. It is related to maturity[112], and to cotton fibre fineness[51, 113], but is not greatly affected by conditions of growth[51]. Finer fibres therefore have a greater percentage by mass of wax than coarser fibres. Long term atmospheric exposure (11 weeks) or weathering, however, increases wax extraction results by ≃ 10%[112], the Conrad method giving higher wax content with lower melting point for weathered cotton[51]. Typical mature cotton contains about 0,6% wax[114], it varying from 0,4 to 1,3%[105]. A genetic strain of cotton having green coloured lint has been found to contain 14 to 17% wax. This wax has a melting point of 85 to 90°C, whereas wax from ordinary Upland cotton melts around 76°C[46, 105].

The wax is nearly all located in the primary wall (cuticle) of the fibre[26, 105]. Whether it is a purely mechanical coating outside the primary wall, or whether some of its constituents are chemically combined with the pectins, cellulose, or proteins in the primary wall is unknown[105]. At least part is located inside the fibre or bound to the cellulose.

From a processing point of view, wax is the most important constituent of the fibre other than cellulose[105, 115]. The presence of wax is necessary for proper spinning since it lubricates the fibres[105]. The natural wax of cotton decreases the tendency of the fibres to cling to each other, reduces the friction between the fibres, and hence lowers the tensile strength of yarn and fabric[105]. Solvent extraction of wax from cotton yarns can increase their strength by 25 to 40%[46, 116]. Cotton wax does not appear to be removed during mechanical processing[117]. Cotton wax affects wetting profoundly and also assists spinning[114] and cotton's processing can be considerably modified by scouring off pectins and waxes[118] and by adding lubricants[113].

Results obtained in industrial processing indicate that cotton wax is imperfectly removed in kier boiling, although the pressure kier is more effective than an open boil, and the use of a small amount of sulphonated oils assists in the emulsification of the waxes[105]. Careful investigation on fabrics kiered and bleached by either the hydrogenperoxide bleach method or the hypochlorite bleach method, showed from 0,3 to 0,5% remaining in the fabrics at the end of either process[105]. Technical scoured cotton contains about 0,3% of wax[46].

Considerable quantities of substances from various sources have to be removed from the cotton and these contaminants can be divided into three groups according to their origin and purposes[119]:

TABLE 22

FOREIGN SUBSTANCES TO BE REMOVED[119]

Naturally occurring	8—12%
Sizes	10—15%
Pretreatment chemicals	12—15%
	30—42%

A summary of the action of various solvents on the constituents of raw cotton is given below[46].

TABLE 23

EXTRACTION OF COTTON WITH VARIOUS SOLVENTS[46]

Solvent	Action on the Constituents of Raw Cotton		
	Extracts	Does not Extract	Mass Loss (%)
Water (hot or cold)	Ash (84%) Potassium salts Sodium salts Phosphates Sugars	Wax Protein (70 to 90%) Pectin Calcium salts Iron salts Aluminium salts	2,5
Ethyl alcohol 95 per cent (hot)	Wax Sugars Ash (25%)	Protein Pectin	
Chloroform, benzene and other organic solvents not miscible with water (hot)	Wax	Protein Pectin Ash	0,6
Acids, 0,1 N (cold)	Ash (97%) Sugars	Wax Protein (65 to 85%) Pectin	2,7
Ammonium citrate or oxalate (hot)	Pectin Sugars	Wax	
Dilute sodium hydroxide (boiling)	Ash (90%) Protein (90%) Wax (69%) Pectin (100%) Sugars		6,5

The amounts of ash constituents, nitrogenous substances and sugars extracted do not account for all of the mass loss of raw cotton when it is extracted with water. This indicates that substances of an unknown nature are present in the water extract.

The effects of steeping upon the removal of wax by subsequent boiling are illustrated below.

TABLE 24

AMOUNT OF WAX PRESENT IN COTTON[120]

Variety of Cotton	Kind of Scour with 1% of NaOH for 6 Hr	Residual Wax (%)		
		Not Steeped	Steeped in water	Steeped in 0,2 NH_2SO_4
Texan	Open kier	0,36	0,22	0,18
Texan	138 kPa (20 lb) pressure	0,20	0,15	0,11
Sakellarides	Open kier	0,40	0,26	0,22
Sakellarides	138 kPa (20 lb) pressure	0,26	0,19	0,18
Averages		0,31	0,21	0,17

TABLE 25

PURIFICATION OF COTTON

	Raw Cotton (%)	Purified Kier Boil (%)	Purified A.C.S. Method (%)
Cellulose	80 to 85	99,1 to 99,5	99,5 to 99,6
Wax, fatty acids	0,4 to 1,0	0,01 to 0,15	Nil
Ash	0,8 to 1,8	0,05 to 0,75	0,09
Pectins	0,4 to 1,1	Nil	Nil
Protein nitrogen	1,2 to 2,5	0,5 to 0,1	Nil
Pigment, resin	3 to 5	Nil	Nil
Moisture	6 to 8	Nil	Nil

The wax content of a cotton fabric affects its physical properties. As the wax content increases flex abrasion (see Fig 15), conditioned crease recovery[121], angle tear strength and elongation at break increase whereas absorbency decreases.

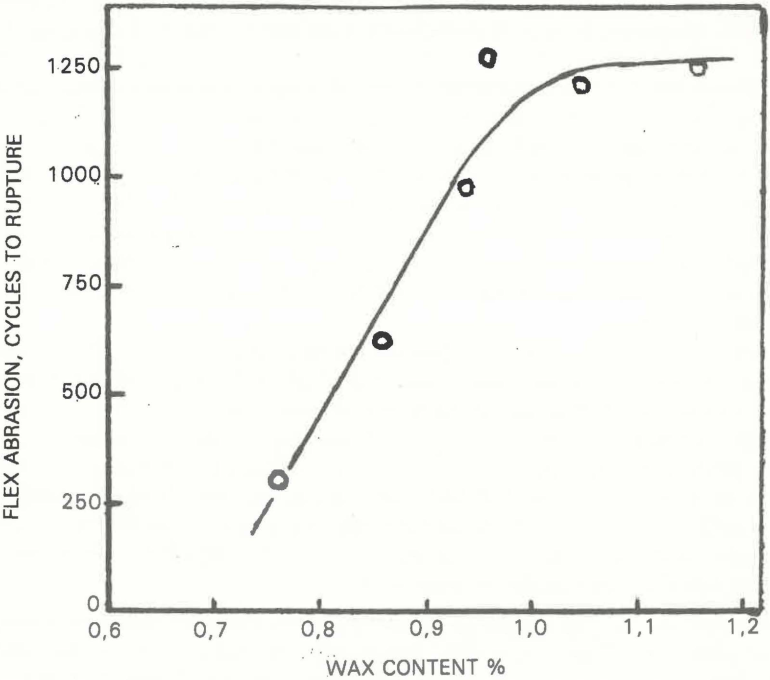


FIGURE 15

Flex-abrasion resistance vs wax content of cotton printcloth[123]

On untreated poplin and drill fabrics, an increase in wax content increased tear strength, flex abrasion and wrinkle recovery, reduced water absorbency and left accelerotor abrasion resistance largely unchanged[126]. These trends also occur to a large extent in mercerised-scoured and mercerised-scoured-bleached samples while after durable-press finishing, however, most of the trends are no longer present[126, 127].

PICKING AND GINNING

Hand picking yields a relatively clean cotton, whereas mechanically harvested cotton is contaminated to a greater or lesser extent[4, 20]. Not all varieties behave the same, however; those with hairy leaves are less suited for mechanical harvesting because bits of leaf cling to the fibres[4].

End breakage for hand picked cottons has been found to increase with increasing gin drying, whereas for machine-picked cotton there is a minimum. Yarn grade and strength decreased with gin drying[128]. Hand-picked cotton generally processed better than machine picked cotton, with neps and end-breakage during spinning increasing with increased cleaning[128]. Fibre breaking in the gin, however, is closely associated with the drying and cleaning[128].

If the defoliation of the field prior to picking does not succeed properly, green leaves will be picked together with the cotton and green spots will ensue. The same will happen if certain weeds are left in the field[129]. Most mature fibres are obtained if defoliants are applied 35 to 41 days after peak of bloom[130]. For spindle picking, about 85% of the cotton bolls should be open, whereas for the stripper, 65% should be open[131]. For the former, defoliation is carried out about seven days before picking, whereas for stripper harvesting it is carried out about 15 days before harvesting[131]. It has also been stated[4a] that, for mechanical picking, about 70 to 80% of the cotton bolls should be open before defoliation.

Table 4 presents some information on the proportion of cotton which is under irrigation, machine picked and roller ginned, respectively[6]. The inclusion of green leaf in machine picked cotton adversely affects the colour of the lint and increases the moisture content leading to deterioration in storage, before ginning[20]. The use of dessicants and chemical defoliants reduces the amount of leaf incorporated in the seed cotton, but also leads to some loss of fibre length and strength. New smooth leaf varieties, in which the leaves are practically glabrous, improve matters since leaf fragments are more easily removed from the lint during cleaning[20].

In addition to pre-cleaning equipment, lint cleaners are now extensively used at ginneries. These have their disadvantages and can cause fibre damage, particularly when poorly adjusted. Fragments of seed coat, consisting of a piece of the chalazal cap which had broken away during ginning, are virtually impossible to extract from the bulk of the raw cotton because of the tuft of fibres attached, and are generally incorporated into the yarns as a nep. Work has brought to light a correlation between the degree of fuzz on the seed of a variety and its proneness to produce seed-coat neps in the yarn. In commercial Upland varieties the seed is normally fuzzed, but semi-fuzzed tufted and naked seeds occur, these being classed as "black". Usually reduced seed-coat fuzz is associated with a reduction in ginning percentage and may also lead to greater fibre coarseness and a reduction in strength. Negative correlations between cotton quality and yield have been reported for many crops[20].

Average cleaning efficiency of two stages of saw-cylinder lint cleaning is roughly 35% per cleaner unit, it being greatly affected by the initial foreign matter content of the cotton and the location of the cleaning unit in the sequence, the first lint cleaner being more efficient[132].

Experiments have been conducted over a 4-year period to determine the amount of conventional seed cotton cleaning machinery and number of lint cleaners required for machine-stripped cotton to achieve acceptable ginning performance, maximise producer returns and insure satisfactory end-use performance of lint[133]. Seed cotton was processed through various combinations of cleaning-machinery sequences and was subjected to one, two and three stages of lint cleaning. The combined test data indicated that machine-stripped cotton can be satisfactorily cleaned with two extractors, two inclined cleaners, and an air-line cleaner[133].

At the gin, mechanically picked cotton receives a heavy beating both before and also after separation of the fibre[129]. Mechanically picked seed cotton generally comes to the gin, containing more moisture than the hand picked cotton and has to be dried in order to enable proper cleaning[129]. Hot air is used for drying — the temperature of which may rise as high as 232°C (450°F) at the impact point of the air with the cotton. A great number of cleaning cylinders beat the fibre to clean out trash. After fibre separation at the gin-stand, lint cleaners are used to get rid of some more of the foreign matter — which again means pretty rough handling of the fibre[129]. With mechanical picking, it is normal to wait until most of the bolls are open, generally between 70%—80%, before the machine enters the field. It is not usual to carry out more than two pickings with the machine — due to economical considerations. Therefore, often some weeks may pass from the day the first boll opens until the cotton is picked. Thus, humidity, rain or dust may cause colour deterioration. The same is of course true when, due to labour shortage, "once-over" hand picking is done[129].

If the cotton is picked too wet — over 12% moisture content — which may happen in the morning or late afternoon, and is stored for any period of time, it will result in spotted or yellow-stained fibre. Unlike the handpicked cotton, there is no way to dry it until it goes into the gin[129].

Some blame the recent discovery of dust-related problems in textile manufacturing on modern harvesting and ginning methods, supposing that today's cotton as it comes from the gin is dustier than in decades past. To minimise the dust problem, many textile concerns have taken close looks at the gin. They thought that additional cleaning here would pay off with reduced dust levels at carding[134]. But mill experience and research tests conducted on cotton produced from 1936 through 1971 indicate that additional gin cleaning with present technology and quality requirements may not provide the solution to textile mill dust problems[134].

According to a Clemson University study[134], if there was an increase in employee exposure to fine cotton dust particles in the past 20 years, the card and increased carding rates are mainly to blame. Further cotton cleaning at the gin is discouraged. Mechanical picking did not cause greater generation of waste[134]. According to the study, of all the machines that rank near the top in liberating dust in cotton textile manufacturing, the card is a leading culprit.

The card is responsible for removing fine non-lint materials from the fibres, and it is difficult to keep some of these materials from getting into the air[134]. This, however, no longer applies to modern cards which are totally enclosed and have dust extraction systems.

Fig 16 compares the average per cent non-lint content of the cottons produced by the United States gins during past decades. (Content was measured by tests conducted by the USDA Agricultural Marketing Service, utilizing a Shirley Analyser.) Both the visible waste (waste collected by the analyser) and the invisible waste (predominantly smaller particles) are shown, and several important conclusions can be reached[134]:

1. The advent of mechanical picking in the 1950's did not result in increased waste generation, a fallacy that has long prevailed. In reality, a dramatic reduction in waste percentage can be tied in with the almost blanket turn to mechanical picking in the early 1950's, together with improved cleaning at the gin.
2. Further cleaning of cotton at the gin with present technology is not only possible, but practical. However, the steady decline of waste levels from 1955 through 1961 brought about dire results.

For one, overworking of cotton at the gin to achieve these low levels of waste resulted in damaged cotton fibres and a dangerous increase in neps at the card. And this drastic reduction of quality in subsequent processes came at the same time that the nation's consumers were developing a heretofore unknown quality consciousness. The result was so negative that USDA, Universities and textile makers initiated studies to determine limits of gin cleaning that would not be detrimental to quality production. The conclusions of these studies led to the stabilised non-lint content shown on the chart for the period 1961 through 1971[134].

Early season picking has been found to produce the strongest yarns followed by the middle and then the late season[135]. Late season's cottons are generally shorter and finer (lower micronaire)[135]. Irregularities in fibre length uniformity may occur when the grower waits with the picking till all the bolls have opened. The upper bolls of the plants, which as a rule open last, have marked shorter staple than the lower bolls of the same plant[129].

It has been found that the fibre length characteristics differ between the first and second pickings (see below).

Fibrograph 2,5% span Length (mm)[129]

	First picking	*Second picking*
Acala 1517	28,96	26,67
Acala 4—42	27,43	26,42
Acala S.J.1	28,19	26,92

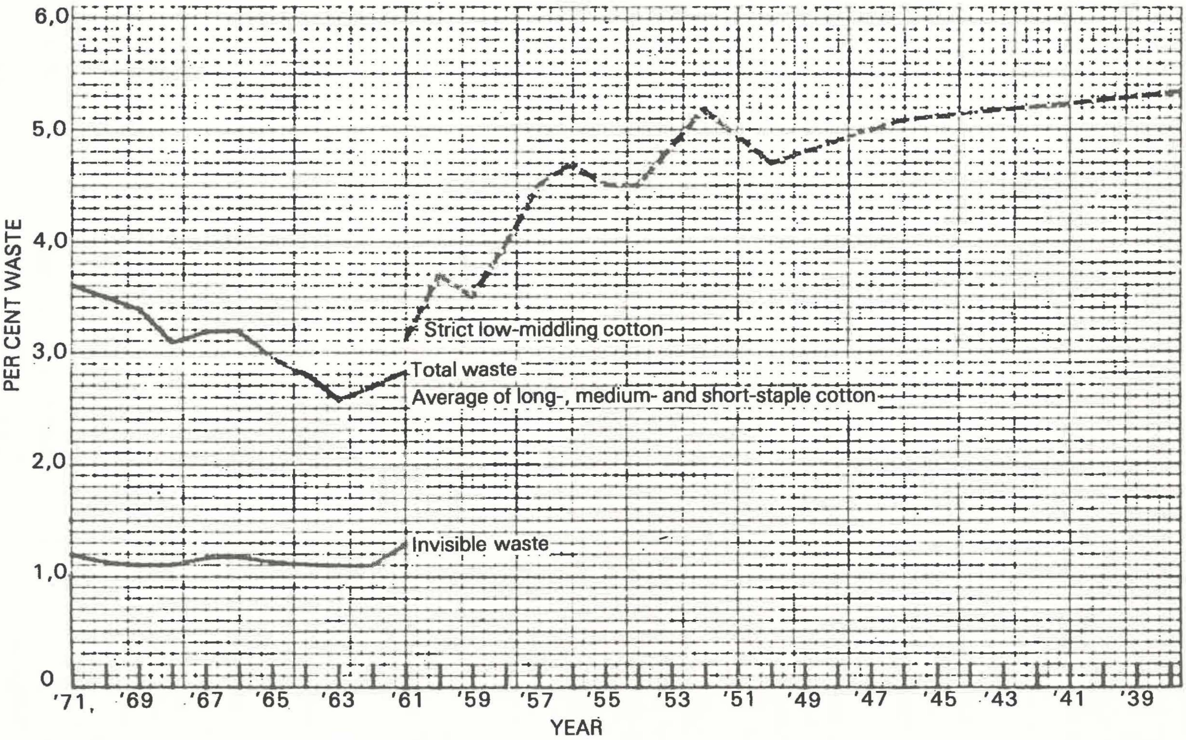


FIGURE 16

Trends in Shirley Analyser non-lint (waste) levels from 1939 to 1971[134]

The picking and ginning process has no influence on the fineness of the fibre, but if defoliation is applied too early, some of the bolls (especially the upper ones) will open prematurely, causing immaturity[129].

Just as with the staple length, micronaire uniformity may become irregular when using the "once over" picking method. Here are some figures which were derived from the same test as above[129]:

	Micronaire Values	
	First picking	*Second picking*
Acala 1517	3,7	2,7
Acala 4—42	4,2	3,4
Acala S.J.1	4,2	3,3

Spindle twists are tangled masses of fibre — twisted by the spindles of the picker resulting from faulty adjustment of the machine. Unfortunately these spindle twists occur quite frequently although they could be entirely prevented if the machine is adjusted properly. The gin cannot eliminate the twists. They get into the bale and may become quite a nuisance to the machinery at the mill[129].

It has been proved that the mechanical harvest and the gin may substantially add to the amount of neps. Table 26 shows the cumulative effect of different steps during the ginning process. These results, are representative of this specific trial only. Quite different figures may result from modified ginning processes or different seed cotton sources[129]. (See Table 26.)

TABLE 26

CUMULATIVE EFFECT OF DIFFERENT STEPS DURING THE GINNING PROCESS[129]

Source of samples	2,5% Span Length (mm)	Length Uniformity (%)	Neps/g
Seed cotton from Trailer	29,01	46,4	14,3
Seed cotton after drying and cleaning	28,91	46,0	29,7
Lint prior to lint cleaning	28,80	46,9	34,9
Lint after gentle lint cleaning	28,40	45,3	44,9
Lint after normal lint cleaning	28,02	44,4	47,4
Lint after double lint cleaning	27,84	43,7	60,4

In practice ginning is performed with two different types of machine[4]: — roller gins and saw gins. The roller gin is used in many countries for ginning long-staple cotton. Small versions of it are employed in research stations for ginning small samples[4].

The saw gin is used in most countries for ginning medium and short-staple cottons. Depending on which of these two machines is used, the same cotton will yield fibres of different length with different length distribution. The roller gin seizes the fibres and separates them from the seeds much more gently than the saw gin. Consequently roller-ginned cotton is always 1/16" (1,5 mm) or so longer, and its uniformity 2 to 3% better than that of saw-ginned cotton[4]. Nevertheless, the fibre length is influenced by other factors too. Delays in picking, adverse climatic conditions, above all dry air, strong sunshine and dew may modify the fibres or even damage them. Mechanised harvesting has no effect on the fibre length but cleaning and ginning the seed cotton may impair the quality of the fibres under certain circumstances, especially the staple length[4].

Often the ginning operation is followed by a so-called lint cleaner. This machine shortens the fibres by about 0,5 mm and causes additional neps if the fibres are very dry, very fine or immature[4].

The ginning percentage obtained by roller ginning is about 1% higher than that obtained by saw ginning[136]. The main advantage of the saw gin is its high productive rate and more uniform and clean lint which is obtained. At the same power consumption, the saw gin gives a higher rate of production than either single or double-roller gins, its labour requirements are also considerably lower. Saw gins are not suitable for ginning extra-long staple cottons[136]. Saw gins produce shorter fibres and more short fibres, more neps, lower Pressley values, lower micronaire values (because the cotton is cleaned), lower trash, lower yellowness and higher brightness (better colour) than roller gins[137]. Nevertheless, the only differences in yarn properties of any importance occurred in yarn appearance, where the roller gin had some advantage[137]. Roller ginning produces only about half as many neps as saw ginning in some varieties of American cotton[138] although the saw-gin gives better fibre blending than a roller gin[139].

Today's gins, if operated correctly, do not create more short fibres than gins of 25 years ago. Fibre moisture content and the number of lint cleaning stages have a greater effect on short fibre content than do ginning rates or saw speeds[140]. Fibre moisture content is the most important single ginning factor affecting the length characteristics of cotton and its subsequent manufacturing performance and yarn quality[141]. The cotton should be neither too dry (leading to static or fibre damage) nor too wet (not easy to clean if wet)[143]. Excessive drying of cotton prior to ginning could cause a deterioration in spinning performance[142] although damp cotton should not be ginned[144].

The recommended minimum moisture content of cotton prior to ginning is 5%[142] although 6 to 8% is best[144a].

Faulty adjustment of the drying equipment at the gin may cause smoke, colouring the cotton grey or blueish — this being mainly when oil fired burners are used. If too much heat for drying the cotton at the gin is applied, a marked shortening of the staple may occur and its uniformity impaired[129].

If the cotton lint is very carefully detached by hand from the seed (no breakage of fibres) it is found that the fibre length is remarkably uniform with a length approximately equal to the staple length as assessed subjectively. Ginning causes fibre breakage when the detachment force exceeds the fibre strength[48]. Fine and immature cotton fibres are therefore preferentially broken during ginning[128]. Generally, no whole fibres remain on the cotton seed after ginning. Lord[48] found the mean fibre length of machine (roller) ginned cotton to be about 86% that of the hand detached fibres. Roller ginning causes a 1,5 to 3 mm reduction in mean fibre length. The short fibre tail of a cotton fibre length distribution contains an excess of broken immature fibres, possibly due to the weaker immature cottons breaking more readily during ginning, etc.[48]. It is claimed that the lengths of fibres removed from cotton seed are approximately normally distributed[18], but after the cotton has passed through the ginning process it has a *bimodal distribution*. This is due to the damage done by ginning machinery, especially when the cotton is dry.

Mature cotton seeds are usually very dry and hard and remain intact during ginning whereas immature seeds are quite soft and mushy and contain much moisture and could quite easily disintegrate upon mechanical treatment[71]. Avoiding immature cotton seeds or allowing them to dry should therefore reduce problems during ginning, e.g. clogging of saw teeth[71].

Immature cotton bolls can create problems during ginning and when stripper harvesting, the immature cotton bolls are often ginned separately[71]. Material collected on the inner surface of gin roll boxes after ginning immature cotton was found to be 25% protein and 8% lipid with the rest being fuzzy fibres, lint and seed-coat fragments[71].

DELINTING COTTON SEED

The development of a new pollution-free dilute sulphuric acid process for delinting *cotton seed* was reported in 1975[145]. The new process was cited for three major advantages:

1. It totally eliminates the hazardous water and land pollutant produced by the conventional wet-acid method of delinting cotton seed.
2. It reduces by 98% the consumption of sulphuric acid used in delinting the seed.
3. It cuts production space requirements by 70%.

In addition, the new method produces a saleable byproduct that can be used for cattle feed or processed into glucose — and further processed into a commercial food-grade alcohol. It has been claimed that the new method eliminates the discharge of concentrated sulphuric effluent which is found in older delinting processes and therefore contributes to cleaner water[145].

The old wet-acid method of delinting cotton seed dissolved the linters in a 93% solution of sulphuric acid. The acid-linter waste was pumped into a settling pond, creating a serious pollution problem to the water table and land[145].

The following table compares yields of products when different methods are used for delintering of cotton seed[146].

TABLE 27

ESTIMATES OF COMPARATIVE YIELDS (in kg) OBTAINED FROM 2 000 kg OF SEED[146]

Process	Oil	Meal[a]	Hull	Linters	Hull fibre	Total[b]
Saw delintering	332	930	455	181		1 898
Abrasive delintering	332	930	455	181		1 898
Hulling undelintered seed						
41% meal	329	921	572		76	1 898
50% meal	329	745	824			1 898
Acid delintering with sulphuric acid	332	930	561	102[c]		1 925
Acid delintering with gaseous HC1	332	930	561	81[d]		1 904
Extracting whole seed	318	910	670			1 898

[a] When protein in meal is not specified, 41% meal is the basis
[b] Difference between these figures and 2 000 represents losses
[c] Hydrolyzed linters plus ammonium sulphonate
[d] Hydrolyzed linters plus ammonium chloride.

COTTON GRADE

Cotton *grade* provides an indication of the fibre colour and the waste content of the cotton. It is related to spinning waste[147] and also to bleaching and dyeing properties[147] but is particularly closely related to the cotton colour[148]. It also affects yarn appearance[149, 150].

Grade, as determined subjectively by the Classer, is characterised by the *preparation, colour* and *trash content* of the cotton. Cotton grading is an art and critically determines the ultimate market value[151] of cotton. Cotton colour (particularly that due to microbiological damage)[162] and foreign contaminants (stem, leaf or dirt) greatly affect the Classer's assessment of grade. The *grade* of cotton is arrived at by the Grader who evaluates colour, leaf and preparation in relation to the official standards[198]. Experience has shown the average relationship between picker and card waste and various grades of Upland cotton to be approximately as given in the tabulation shown in a subsequent section on manufacturing waste. In comparing these average grade figures with the picker and card waste data, it should be understood that variations from the averages for individual samples are attributable to the nature of the extraneous material present in the cotton, the characteristics of the fibre, and whether the grade designation was perhaps low because of poor colour[198].

The total number of non-lint particles has been shown to be correlated with the grade[151, 152], although the particle distribution (according to size) is very similar for the various grades. The ratio of the total measured particulate area to the total surface area of the cotton sample was found to be highly correlated with subjective assessment of non-lint levels[152].

Colour

Fundamentally, there are four courses of colour in cotton, viz. dirt, fibre geometry or morphology, intrinsic colour and extrinsic (environmental) colour[148]. In practice, at least five factors affect the colour of cotton[153]; (1) ageing in storage; (2) immaturity from a freeze or other means that kills the fibres suddenly; (3) dirt or soil such as tar; (4) minerals, and (5) field damage associated with microbiological decay.

Dirt comprises dust, soil or trash residues[148]. The removal of dirt does not greatly affect reflectance, the effect being greater for the lower grades of cotton. Dirt is not responsible for colour differences after bleaching. Fibre geometry or morphology appears to have little effect on reflectance, studied by dissolving various cottons in H_2SO_4. Differences in colour after bleaching are mainly due to extrinsic colour differences as a result of fungi which flourish under the correct weather conditions[148]. Part of cotton colour is also due to carbohydrates and proteinaceous materials left in the residue of the protoplasm when the fibres are suddenly killed by a freeze, insects or other causes[154]. Colour is therefore related to fibre immaturity and low micronaire readings[154].

Cotton colour deteriorates upon storage[155] with immature cottons yellowing faster than mature cottons[153]. Higher humidities increase colour change, it being best to store at approximately 50% RH[156]. Cotton can be stored for prolonged periods (15—20 years) under controlled relatively dry indoor conditions with little or no change in either ACV or strength[157]. Storage for shorter periods also appears to have little effect on spinning performance or yarn tenacity[158].

It is recommended that cotton reaching the spinning mill should have a moisture content of no more than 8%, as this is the figure at which bacteria cease to multiply[159].

Exposure to field weathering can greatly affect cotton fibre colour, thereby affecting the Classer's grade[160]. Wetting and drying cycles are believed to have the greatest effect on the fibre colour. The greying or darkening of a cotton fibre can indicate the onset of microbial damage and greatly affects grade[161, 162]. Classer's assessment of trash is affected by the colour of the lint[151]. Colour can be measured by a colorimeter and reported in terms of greyness or yellowness[163]. A Nickerson-Hunter Colorimeter is commonly used for colour evaluation of cotton in terms of the reflectance and degree of yellowness[164]. Besides colour it also indicates extraneous material content[115]. Cotton from bolls which opened after frost may be yellow and if unpicked cotton remains in the field for a long time it becomes duller and darker in colour[164]. All cottons tend to turn yellow, particularly if stored under warm and wet conditions. The presence of sugar and protein materials may be responsible for this discolouration. Certain fungi grow on cotton, when they sporulate, the cotton turns grey or some other shade, depending upon the species[164].

Cotton colour can be objectively measured in terms of reflectance and yellowness[151]. Cotton bale samples are highly variable in colour and thorough blending (e.g. Shirley Analyser) is essential[165] for reflectance measurements. Passing the cotton through a Shirley Analyser results in a slight decrease in 'colour' probably as a result of the removal of short fibres and trash[165] and the difference in reflectance may be used as a measure of trash content[165]. Elsewhere[151] it is stated that trash does not always affect instrumental colour measurements in a consistent manner.

Colour is a property which has hitherto received little attention from breeders. It is known that there is a correlation between length and colour. The shortest cottons are always whiter than the long-staple varieties[4].

With most cotton varieties grown the colour is not always constant. Shades are found from white to slightly yellowish, which are fixed genetically[4].

In some varieties the colour is permanent, while other display a light creamy colour when the bolls opens, which however bleaches out under the actions of sunlight if harvesting does not take place within a few days after opening. If the weather is damp, the fibres may turn grey and lose their lustre[4].

Under certain conditions the cotton may also turn yellowish during storage in pressed bales. Investigations are now being made to establish the proneness to yellowing of different cottons under identical storage conditions[4].

Preparation (character)

Cotton's "character" may be adversely affected by 'overheating' of the cotton prior to ginning by 'over-cleaning', by severe cold, by insect infestation or by some other causes[115]. The treatment the cotton gets during harvesting and ginning is reflected in its roughness or 'smoothness'[164]. Cotton ginned when 'wet' (i.e. without proper drying) is usually classified as 'poor preparation'. Badly ginned samples cause excessive waste in spinning and a deterioration in yarn uniformity. Fibres in a properly ginned sample have a uniform appearance and are evenly distributed in the sample. Well ginned samples are comparatively free of trash[164].

Trash Content

Cotton usually becomes contaminated by leaf and trash due to exposure in the field and the harvesting methods adopted[164]. Trash consists of whole seed, grass, dust, etc. Trash content helps to determine the type of cleaning equipment to be used in the blowroom so as to obtain maximum spinning efficiency. The presence of an appreciable quantity of foreign matter causes greater waste losses during processing, lowers output and affects the quality of the product. The fine particles of trash also becomes the nucleus of neps during processing[164]. Trash will be discussed in some detail later.

COTTON DAMAGE

When a cotton boll starts to open, it first cracks then flares open within a few hours; the fibres will dry if sunlight is sufficient and the humidity is low enough[166]. However, if the sky is overcast and the air humid, or the bolls are located in a damp environment (e.g. lower parts of the plant under the shelter of the leaves) microbial infection may take place at the cracking stage, and the moist fibre may be severely damaged[166]. Darkening or greying of cotton fibres results from humid preharvest weather and the colour change has been attributed[148] to microbial action. Microbiological degradation of the cotton fibres starts with the digestion of the non-cellulose cuticle[167]. Humid preharvest conditions also appear to increase the pH of the aqueous extract[168]. High pH values for the aqueous extract of cotton generally indicates a certain undesirable use-value of the cotton[169], although a high pH does not necessarily signify damage[168, 170, 171].

Arabitol and mannitol contents of cotton may be useful as an index of biological damage[166].

It has been observed that some cottons can be subject to deterioration of their fibre properties by the action of micro-organisms (fungi)[172] or their metabolic products[2]. This alteration of fibre properties has been called "cavitoma" and the cotton exhibiting this condition "cavitomic cotton". Increased fibre swelling in caustic soda and fibre breakage are most evident changes in such cottons[2]. A method of determining the extent of cavitomic cotton is to measure the pH and reducing material content. A high pH together with a small amount of reducing material is associated with cavitoma. The colour change of a solution containing Gramercy Universal Indicator (Fisher Sci Co) and Santomerse S (Monsanto) after cotton has been passed through it has also been used for detecting cavitomic cottons[2]. Cavitoma damage causes excessive short fibres giving a significant reduction in spinning performance and yarn strength[173], although 25% of such cotton can be tolerated. Cavitomic cotton is due to micro-organisms growing on the cotton under conditions of wet storage[174]. It shows little discolouration compared to the off-colour yellow-brown shades of the field damaged types (Cateye)[174]. "Cateye" cotton is due to cotton bolls that mature during lengthy periods of wet weather and suffering boll rot due to a fungus[174]. "Cateye" cotton has a doughnut shape rather than a kidney shape. It appears that when the cytoplasm dries in a cotton, tremendous surface-tension forces come into play causing the fibre to collapse into the characteristic ribbon. When, however, the lumen wall is damaged, as in "cateye" cotton, no such forces come into play and the fibre retains its circular shape[174].

Marsh et al[157, 161] found that cottons attacked by micro-organisms, either during humid preharvest weathering or during storage under humid conditions or an exposure to rain in outdoor storage, exhibit very *high ACV's without being accompanied by any change in their Arealometer values*[175]. The ACV data ranged from 250 to 330 depending on the severity of the damage, as against an ACV of 190 for the undamaged cotton sample. The microbial damage has also been found to lead to considerable loss in the tensile strength of the fibre[157, 161].

Damage that occurs during ginning and processing of cotton gives rise to a significant increase in its Congo Red value (3,6). However, the corresponding increase in its ACV is much less[161]. The ACV of yarn has been found to be approximately 12 units higher than that of the bale cotton[161]. This clearly indicates that a large increase in ACV arises mainly from microbial damage[175].

Undamaged cotton exhibit a very low Congo Red value with the number of stained fibres usually about 1%[175]. Congo Red values have been found to increase greatly from 18% for ginned cotton to 70% at spinning[176].

Increase in fluidity has been related to a decrease in strength[177].
Degradation of cotton is measured by the following tests[46]:

1. Breaking or tensile strength.
2. Cuprammonium viscosity or fluidity, a measure of average molecular chain length of the cellulose.
3. Nitrate viscosity or fluidity. This test does not break alkali-labile oxygen linkages present in cellulose modified by oxidising agents.
4. Copper number, a measure of aldehydic reducing groups present in a modified cellulose.
5. Methylene blue absorption, usually considered to be a measure of acidic carboxyl groups present in modified cellulose.
6. Alkali solubility, usually considered to be a measure of short-chain cellulose molecules.

The most accurate of these measures of degradation is the viscosity or fluidity in cuprammonium solution. An interpretation of its significance is given below in Table 28.

TABLE 28

VISCOSITY IN CUPRAMMONIUM SOLUTIONS[46]

Classes	Fluidity at 20°C in Reciprocal Poises	(Pa.s)$^{-1}$	Comments
1	1 to 5	10 to 50	Very mildy scoured and bleached cottons.
2	5 to 10	50 to 100	Normally scoured and bleached cottons
3	10 to 20	100 to 200	Significant loss in strength due to processing.
4	20 to 30	200 to 300	Overbleached, with serious loss in tensile strength.
5	30 to 40	300 to 400	Incipient loss of fibrous structure due to chemical attack.
6	40 or above	400 or above	Highly degraded by chemical attack to product described as oxy- and hydro-celluloses.

Fluidity under comparative conditions may be proportional to loss of strength but fluidities of a variety of products may not have any such definite relationship[46].

Use of aids to detect microbial damage[178]

A pH indicator solution sprayed on raw stock (a solution of cresol red and thymol blue with distilled water) initiates a colour change, which if purplish in nature indicates that damage is present[178].

To detect oil and immature fibre — UV light is used.

Variation in the intensity of ultra-violet fluorescence of bales of cotton could cause variations in dyeing of yarns, especially in pastel shades[179]. Cotton fibres can fluoresce (UV) differently because of ageing, light exposure, mildew attack[180] or heat application. The water soluble substances and the waxes and resins of the cotton fibres were not involved in the change in fluorescence with heating[180], even though the waxes and resins fluoresce themselves. Heating, therefore, changes the cotton itself and this changes the fluorescence. Immature fibres appeared to be more sensitive to heat degradation, heating increasing the cotton fibre bending stiffness[180].

The normal mechanical processing of cotton degrades the fibre[181]. Mechanical damage hardly changes ACV[161] but significantly increases the Congo Red value. The latter also increases with increasing microbiological damage to the fibre[161].

Weathering appears to affect coarse mature cottons less than fine immature cottons[182, 183]. Hence coarser cottons are to be preferred where weathering is an important consideration[184]. In one case it was found that weathering hardly affected the cotton fibre properties although differences emerged after laundering[185]. Elsewhere it is stated that weathering causes a decrease in cotton regain, dye absorption, Pressley strength and yarn strength[157]. Improved light and weather resistance of cotton results from mercerisation[186].

STICKY COTTONS

Sticky cottons annually cause significant production and quality losses in the cotton textile industries of certain countries. It may be caused by excessive quantities of mono-saccharides (sugars), mainly fructose and glucose, present on immature fibres[187, 188] or by honeydew[189–191], a sugar-containing sap excreted from plant nectaries or from insects such as aphids and whiteflies[192]. Sticky cotton causes lapping at rollers and is a plague to spinners especially in the early pickings[193]. Cotton can cause lapping when the wax exceeds 0,6% and sugar 0,3%. Other causes of poor spinning are contamination by lubricants from harvesting or ginning machinery and immaturity. The latter is caused by a number of factors: short growing season, low night temperatures, drought, disease and time of harvest[193]. It is also believed[396] that cotton-seed oil from seed-coat fragments and seed motes is related to stickiness problems in processing. The use of crush rollers at the card accentuates the problem.

Lapping or coating of rolls with wax and other materials is especially prevalent when very fine fibre (Micronaire 2 to 3) with a high sugar content is processed. This condition is particularly troublesome on card crush rolls. The fine fibres tend to follow the contour of the crush rolls and gum them up so that they lose their effectiveness[193]. Much of this can be avoided by examining the cotton visually under ultra-violet (black) light. A blue-white fluorescence indicates contamination from lubricating oils, yellow-orange means rust, greenish-yellow indicates fungi. A more sophisticated test, which must be carried out in a well-equipped laboratory, involves the use of infrared light that pinpoints contamination from cottonseed oil and wax[193].

The best way to cope with sticky cotton is to[193]:

- *open it early* and store it as long as possible while it dries out and blooms
- *blend extra well* at opening with the maximum possible mix
- avoid *low micronaire* cotton which often is immature
- *check cotton for seed fragments* and reject before purchase to avoid lap ups on crush rolls caused by cotton-seed oil
- *keep humidity as low as possible* at all processing operations, especially spinning.

Low micronaire or immature cotton fibres normally contain more sugar than mature ones, sometimes going up to 0,8 to 0,9%, sugar content in cotton decreasing as the fibres mature[194, 195]. The second picking of cotton, because it normally has a lower mature fibre content, is suspect for being sticky[195]. In the Sudan, where only hand picking is done, stickiness was reported on the second picking[195] and was found to be associated with the presence of honeydew[20]. A recent study[192] in America also revealed that stickiness in certain cottons was due to high sucrose and turanose levels, these being attributed to honeydew contamination from aphids and whiteflies.

The aphid is an insect which lives on the underside of the plant leaf, spends its whole life in one place, produces a new generation every five days, requires very small absolute quantities of foods high in protein, consumes huge quantities of plant sap high in sugars but low in protein, and excretes large amounts of undigested sugar it does not need by spraying it as far as it possibly can[195]. Thus, two well-known sources of sugar are honeydew from plant exudations and from aphid excretion[195].

To detect sugar and honeydew, a cotton specimen is placed in distilled water, kneaded thoroughly, and the extract poured off[178]. Fifteen drops of the extract can be placed in a test tube and a clinitest tablet (used by diabetics in urine analysis) added. The colour change is compared with a chart supplied with tablets. Observations indicating cotton registering above 0,3% may be troublesome during processing[178]. More sophisticated test methods are given elsewhere[192].

FIBRE LENGTH CHARACTERISTICS

From field to fabric, the length of the fibres is generally considered the most important physical property of cotton in both marketing and processing[196]. The staple (of classer's) length has long been accepted as the best criterion of a cotton's spinning value[197] and fibre length is also a principal determinant of yarn strength and the finest yarn which may be spun (see Part II of this series)[197a]. There is a worldwide trend to replace the subjective classer's staple length by objective measures of length characteristics (e.g. 2,5% span length).

Staple length is the length of a typical portion of the fibres in the samples as determined by the classer in comparison with official standards[198]. Uniformity of fibre length, as well as other fibre properties, influence to some extent the classer's selection of the typical portion of the fibres on which the staple length designation is based. In general, there is a fairly close relationship between the staple length as designated by the classer and the fineness and strength of the yarn that can be manufactured from the cotton. These relationships, however, are also influenced by other fibre properties[198]. The staple length corresponds very closely to the modal or most frequent length of the fibres when measured in a straightened condition[199, 200].

Seed cotton is remarkably uniform in length[201]. The upper half mean length, classer's staple length and upper-quartile length all give values which approximate to the average length of the fibres on the seed[201]. They indicate the length of the longest fibres in the cotton according to which the drafting rollers are normally set[201].

Cottons have been classified as follows according to staple length[20]: (See also part II of this series.)

Staple Length		Description
(mm)	(inches)	
< 20,6	< 26/32	Short
20,6—25,4	26/32—1	Medium
26,2—27,8	1 1/32—1 3/32	Medium long
28,6—33,3	1 1/8—1 5/16	Long
> 34,9	> 1 3/8	Extra Long

The spinning machines and their settings are primarily sensitive to *fibre length*[202]. The Fibrograph method of selecting fibres from the sample is the same as that selected by the drafting rolls, there being a greater probability of selecting longer fibres[202].

From a practical point of view, the Fibrograph 2,5% span length is the length when the amount of fibres indicated by the instrument is 2,5% of the amount of fibres reading at the starting point of 3,8 mm (0,15"). The *mean* length as measured on the Fibrograph is an estimate of the *average* length of the cotton fibres longer than 6,3 mm[18]. It has been found that there was more variation in yarn strength for cotton classified by conventional methods for grade and staple than when cotton was classified by instrument. Furthermore, the average number of ends down amounted to 35 per 1 000 spindle hours for cotton selected by conventional means and 20 for cotton selected on instrument measurements[18].

Longer cottons also require less twist in the rovings[203] and the 2,5% span length is also used to adjust roller distances in the various drafting zones so as to optimise fibre control and breakage[204].

The highest standard count (a kind of spinning limit) is correlated with both the 2,5% span length as well as the Balls Sorter mean length[205]. Typical drafting waves occur at 2,5 to 3 times the fibre staple length[206]. The effect of fibre length on yarn properties becomes more important as the fibres become shorter[150].

Long staple cotton tends to produce more neps, hence the necessity of combing. Lower carding rates are generally used for long fibres and also for low micronaire cottons.

Both the upper half mean length (UHML) and 2,5% span length are regarded to be close but not identical to the classer's staple length[207—209] with the differences generally less than 0,88 mm (1/32″) and it appears that the staple length from the Shirley Photo-electric stapler, and the 2,5 and 10% span lengths from the Digital Fibrograph can be used to rank cottons according to fibre lengths[209]. The Fibrograph samples are length biased[210]. (The UMHL is defined as the mean length of the longer half of the fibres by mass[210]). According to Wesson[211].

Staple Length (in mm) = 5,6 + 0,7916 UHML (in mm).

Cotton in the US crop is generally classed as follows:

Class	**Staple Length (mm)**	**2,5% Span Length (mm)**
Short	< 25,5	< 25,4
Medium	26,2—27,8	25,4—29,0
Long	28,6—31,8	29,2—32,7
Extra Long	> 34,9	> 32,7

The first three types are Upland cottons while the last is American Pima.

Tables have been given[212] for converting from Balls Sorter Mean Length to Fibrograph Upper-Half Mean Length. The *effective* length of cotton lint is longer than the *average* length and is a measure of the length of the bulk of the longer fibres in the sample[213]. It is regarded as being very suitable for characterising cotton by length and providing estimates of suitable draft roller settings in processing. In general, for Upland cottons from 24 to 35 mm staple length as determined by the grader, the effective length is about 2,4 mm longer than the corresponding American staple, while for the long-staple American and American/Egyptian cottons the two values are almost equal[213]. In general, the equation[214]:

Effective Length = 1,1 x American Staple Length

can be used for conversion.

Except for Egyptian cottons the modal length (of a numerical test) is closest to staple length[215]. For Egyptian cottons:

Modal length x 1,1 = Staple length.

The upper quartile length is related to classer staple length, but this relationship may vary[207].

The percentage fibres in a sample shorter than half the effective length provides a measure of the "waste" of the cotton spinning. Low fibre length uniformity (i.e. excessive fibre length variation) tends to increase manufacturing waste, decreases processing efficiency and decreases quality (in ring-spinning)[207]. It is, therefore, considered desirable for a cotton to have a low coefficient of variation of fibre length[198]. Short fibres in cotton are generally regarded as those shorter than 10 mm (⅜″)[197] or sometimes shorter than

12 mm . Short fibre content only has a small effect on the length parameters normally used to characterise cotton[216], although it is claimed that the proportion of fibres shorter than 12 mm as a percentage by mass of all fibres may be calculated with the following formula:

Short fibres (%) = 39,4 + (1,3x2,5% Span Length) – (4,6x50% Span Length)

Obviously, in practice the percentage short fibres will be highly correlated with the length of the cotton. If the short fibre content (fibres shorter than, say, 12 mm) increases then the ring spinning performance and yarn strength and appearance deteriorate[197,218,219]. A short fibre content of about 10% is regarded as about the maximum acceptable for efficient mill processing[197].

Ginning can radically alter the short fibre content of a cotton sample[220] when all the lint cotton is removed from the seed by hand, the short fibre content (< 10 mm) is roughly 4% by mass[220]. Short fibres are more important than their low mass suggests[201].

Short fibres (e.g. shorter than 10 mm) will be more harmful in longer cottons since the drafting distances will be longer and less control will be exercised than in the case of the shorter cottons[221].

Increasing the percentage short cotton fibre increases processing waste and optimum roving twist[205] cause uneven roving and yarns, weaker yarns and higher end-breakage rates[201,205]. It also affects fabric properties adversely[222].

Increases in cotton short fibre content decreased fabric strength, elongation, flex abrasion, handle and tear strength but had no effect on crease recovery[223].

Rotor yarn evenness is less sensitive to short fibres than is the case for ring yarn evenness[224] and combing has little effect on rotor yarn (hosiery) properties.

An "ineffective" length of 10 mm is postulated for cotton yarns in the sense that fibres shorter than this contribute little, if anything, to yarn strength. Such fibres slip rather than break[221,222,225]. The blending in of shorter cottons was found to have the greatest detrimental effect upon spinning performance and yarn quality[173]. Increases in short-fibre content appear to affect short-to medium-term yarn irregularity and not long-term irregularity[221], the effect becoming more pronounced as the yarns become finer[221]. Short fibres do not affect twist required for maximum strength but lowers yarn strength by about 1% for each additional 1% of short fibres[220]. Balls Sorter percentage short fibres (< 9/16″) by both mass and number is highly correlated with percentage short fibres (by number) measured on the digital Fibrograph[205].

The amount of *floating fibres* is a measure of the uncontrolled fibres between the drafting rollers, it decreasing by roughly 5% for every 1% increase in combing waste extracted[226]. In view of the fact that drafting rollers are adjusted according to the staple length or 2,5% span length, floating fibres are generally expressed as an index which takes into consideration the staple or 2,5% span length. Percentage floating fibres (Ff) has been defined as the percentage of fibres in the drafting zone (1:1 draft) not clamped by either front or back rollers[227,228].

It is given by[227]:

$$F_f = [(S/L) - 0,975] \times 100$$

where S is the 2,5% span length and L is the mean fibre length (in mm)

L may be estimated as follows[229]:

$$L = 3\,(S_t - 2,5)$$

where S_t is the 66,7% span length (in mm)

Actually the mean length computed from the 66,7% span length in the above way is from 12 to 15% lower than the actual mean length. The 12,5% span length of the Fibrograph agrees very closely with the mean length[205,230] and it should be used in preference to the computed result.

The following equation has been obtained[231] when relating *mean* length (Y) to 2,5% span length (X):

$Y = 0,821\,X + 0,095$ where the length values are in inches or

$Y = 0,821\,X + 2,41$ if mm units are used.

When the mean fibre length was taken into consideration, floating fibres and percentage short fibres still affected spinning performance whereas percentage fibre length irregularity did not[205].

The floating fibre index (FFI) is generally calculated as follows:

$$\text{FFI} = \left[\frac{2,5\%\ \text{Span Length}}{3\,(66,7\%\ \text{Span Length} - 2,5)} - 1\right] \times 100$$

The reciprocal of the uniformity ratio is also related to the floating fibres, a uniformity ratio of ≃ 35% corresponding to a floating fibre index of ≃ 100%, and a uniformity ratio of ≃ 45% corresponding to an FFI of 40%[205].

It appears that the cotton fibre staple or modal length changes very little during manufacture, up to and including the fabric[230,232]. Nevertheless, the 2,5% Span length should ideally, increase from card lap to roving because of the removal of short fibres. If optimum conditions and settings are adopted at each processing stage (including combing), 2,5% Span length can increase by up to 10% from the card sliver to the roving[204]. It has been found[226] that, on average, combing increases the 2,5% Span length by 6% and the 50% Span length by roughly 15%. For every 1% of combing waste (noil) extracted the 2,5% Span length increased by roughly 0,5%, the 50% Span length roughly by 1,2 to 1,5%, the 66,7% Span length roughly by 1,8 to 2,0% and the uniformity ratio roughly by 0,8 to 1,0%[226]. Combing performance can in fact be assessed by comparing the 50 and 66,7% Span lengths with those of the carded sliver[226].

The Digital Fibrograph 50/2,5 uniformity ratio values are a measure of the relative uniformity of fibre length in the samples[198]. They represent the ratios between the 50% Span length and the 2,5% Span length, expressed as percentages. Larger values indicate more uniform fibre length distribution. Unusually low fibre length uniformity tends to increase manufacturing waste, to make processing more difficult, and to lower the quality of the product. The following adjective descriptions will serve to classify cottons from the standpoint of fibre length uniformity[198]:

Uniformity Ratio (50/2,5)[198]

Below 41	Very low
41—43	Low
44—46	Average
47—48	High
Above 49	Very high

Data source — 2076 American Upland lots tested from the crops of 1971—75.

The following values are given for the array upper quartile length (i.e. that length which is exceeded by 25% of the mass of the fibres in the sample[198]) using a Suter-Webb fibre sorter. The upper quartile length is correlated with, but usually longer than, the 2,5% span length.

Upper Quartile Length	*Classification*
< 27,9 mm (1,1″)	Short
27,9 mm to 31,5 mm (1,1 to 1,24″)	Medium
31,8 mm to 35,3 mm (1,25 to 1,39″)	Long
> 35,3 mm (> 1,39″)	Extra long

Array Coefficient of Length Variation	*Classification*
< 26	Very low variation
26—29	Low variation
30—33	Average variation
34—37	High Variation
> 37	Very high variation

Ratings of cotton samples with respect to fibre length variation are given below[2]:

CV%	**Rating**
< 27	Low Variability
27 to 34	Average Variability
> 35	High Variability

Ratings of cotton fibres with respect to uniformity ratio[2]:

Uniformity Ratio*	Rating
Above 80	Uniform
76 to 80	Average Uniformity
71 to 75	Slightly Irregular
70 and below	Irregular

Source: United States Department of Agriculture

*In this case, Uniformity ratio is defined as: $\frac{\text{Mean length}}{\text{Upper-half mean length}} \times 100$

Theoretically, the maximum uniformity ratio possible decreases as the fibre length increases[210].

MICRONAIRE

Next to length, micronaire is probably the most important factor determining many textile machine processing variables[197]. For a particular cotton variety the micronaire values are related to maturity and are primarily influenced by growing conditions and time of harvest. The importance attached to micronaire probably stems from the fact that it is generally a measure of maturity, which in turn is reflected in the dyeing characteristics and nepping potential of the cotton.

Micronaire is more critical for shorter cottons and for finer yarns[233].

The micronaire test is probably the most widely used test for cotton[234].

There appears to be fairly general agreement that, for ring-spinning, both very low and very high micronaire cottons should be avoided. Micronaire of about 3,5 to 4,0 appear to give optimum spinning performance and yarn quality[173].

Low micronaire ($\leq$ 3,5) and high micronaire ($\geq$ 4,9) cottons tend to be sold at discount prices because they cause problems in textile processing[235]. Low micronaire cottons cause neppiness during carding, necessitating lower carding speeds. High micronaire (i.e. coarse) cottons reduce yarn and fabric strength and increase end-breakage rates during spinning because of the low number of fibres in the yarn cross-section[235].

Originally, the micronaire value was taken to represent the fibre linear density in μg/inch which could be converted into millitex by multiplying by 39,4. In actual fact, however, micronaire is a function of both fibre maturity (M) and fibre linear density (H) with the result that the fibre linear density (mtex) for a particular micronaire will depend upon the *fibre maturity*[236]. It is therefore conceivable that the effect of micronaire will depend upon whether its variation is due to changes in the intrinsic fineness of the cotton or to changes in the fibre maturity. If the fibre linear density remains constant, then micronaire reading will increase with increasing fibre maturity[139].

In one article[237], micronaire reading was related to MH for a large number of Indian cottons. When MH was plotted against micronaire, the Herbaceum cottons differed to some extent from the other cottons and airflow through the cotton plug is also, therefore, to some extent dependent upon factors other than MH . Nevertheless, it appears that micronaire values agree pretty well with fibre linear density (μg/inch) for American Upland cottons[237].

The general relationship[139] is:

$$\begin{aligned} MH = M^2H_s &= aX + bX^2 + C \\ &= 3{,}86X^2 + 18{,}16\,X + 13{,}0 \end{aligned}$$

where M is the maturity ratio (see next section).
H is the fibre fineness or linear density (in mtex).
H_s is the standard fibre fineness or linear density, which is the fineness the cotton would have at a standard maturity of one, and X is the micronaire as measured on a standard air-flow meter. This is an instrument test which measures the resistance of a plug of cotton to air flow[198]. A representative standard mass of cotton fibres is placed in the instrument specimen holder and compressed to a fixed volume. Air at a known pressure is forced through the specimen and the amount of flow is indicated by a direct reading scale. Readings obtained are relative measures of either the mass per unit length (linear density), or the cross-sectional size of the fibres. Because the instrument values may differ from the actual linear density, depending upon the fibre characteristics of the sample, the results are reported in terms of "micronaire reading" instead of micrograms per inch. These readings are taken from the curvi-linear scale adopted in 1950, and now in international use. Fibre fineness contributes to yarn strength, particularly when fine yarns are spun, but it also tends to increase neppiness and to require a reduced rate of processing[198]. Repacking the cotton into the micronaire instrument after fluffing it out does not necessarily give the same reading[139], although the effect is small if the cotton is fluffed out properly. Shirley Analysed lint packs more uniformly in the sample holder than raw cotton[139], and so does card web. Large vegetable particles should be removed although a low proportion of small chaff is of negligible importance.

Card web, hand opened and Shirley Analysed samples all give similar micronaire values[139].

Cottons are generally graded as follows in terms of their micronaire values:

MICRONAIRE GRADING[238]

< 3,0	Very fine
3 to 3,9	Fine
4 to 4,9	Average
5 to 5,9	Slightly coarse
> 6	Coarse

The prediction of the micronaire value of a blend from its components must be made according to the "weighted" harmonic mean[239].

When producing ring yarns, low micronaire levels cause excessive fibre breakage, a large number of neps during carding, poor yarn appearance and poor dyeing. Very low micronaires (below 3) result in poor performance as a result of sticking during processing, low production rates and high manufacturing mass losses. On the other hand low micronaire cottons generally give fewer end-breakages during spinning and stronger yarns, particularly for finer yarns[235,241–243]. Micronaire does not appear to affect yarn evenness in a consistent manner, intermediate micronaires appearing to be preferable in this respect[197].

In ring- and rotor-spinning, an increase in micronaire has an adverse effect on end-breakages and yarn strength and elongation, has a beneficial effect on dyeing quality (only valid for a critical dye) and wet processing losses but has little effect on yarn evenness[233]. Ring- and rotor-yarn appearance generally improves with an increase in micronaire[233]. Differences in dyeing quality associated with micronaire level have been found to be much smaller for rotor- than for ring-spun yarns[233]. It appears, however, that blanket conclusions concerning micronaire level should not be made without knowledge of the genetic character and intended end-use of the cotton[233].

Lower micronaire cottons have also been reported to produce more even rotor yarns because of the greater number of fibres in the yarn cross-section[224] and fewer end-breakages during spinning. Fibre fineness (micronaire) is more important than length in rotor spinning[224]. As the micronaire decreases so the optimum twist required in the roving decreases[203].

One study[238] found both low micronaire (2,9) and high micronaire (5,3) to give higher end-breakages during ring-spinning than an average micronaire (4,2) cotton. In another study[244], no effects of micronaire on rotor- or ring-yarn strength was observed.

Maximum yarn strength is generally reached at lower twists for low micronaire cottons than for high micronaire cottons[242].

Micronaire is generally negatively correlated with CSP[242,245,246] i.e. an increase in micronaire decreases (CSP) but this is not always the case[247].

Lower maturity or micronaire increases yarn strength probably due to a greater number of fibres in the yarn cross-section[245]. Micronaire to a large extent determines carding rate. Lower micronaire cottons are more prone to nep formation and are therefore carded at a lower production rate[197,233,248].

Micronaire also affects roving and yarn twists required for maximum processing efficiency and minimum yarn breakage during spinning[197]. Fine cottons can be spun at higher production rates than coarse cotton. Of the various fibre properties, micronaire probably has the greatest effect on yarn appearance. All other factors being constant, an increase in micronaire causes a decrease in yarn strength, since there are fewer fibres in the yarn cross-section. Micronaire has, however, little effect on yarn elongation[197].

Nolen[236] gives the following table as a guideline for cleaning speeds:

TABLE 29

HOW MICRONAIRE VALUE DETERMINES CLEANING SPEEDS[236]

Micronaire	**Fibres in cross-section of a 60 tex (10's) yarn**
FAST CLEANING SPEEDS	
8,0	180
7,5	200
7,0	214
6,5	231
6,0	250
5,5	273
5,0	300
4,5	333
MODERATE CLEANING SPEEDS	
4,4	341
4,0	375
3,5	429
USE CAUTION IN CLEANING	
3,4	441
3,0	500
2,5	600
2,2	692

The formation of neps reflects and represents the net sum of all interactions that occur between the physical and chemical properties and other conditions of the fibres on the one hand and their handling and mechanical processing on the other hand, whether the latter takes place at the gin, mill or elsewhere.

The figure below illustrates the effect of micronaire on card neps[249].

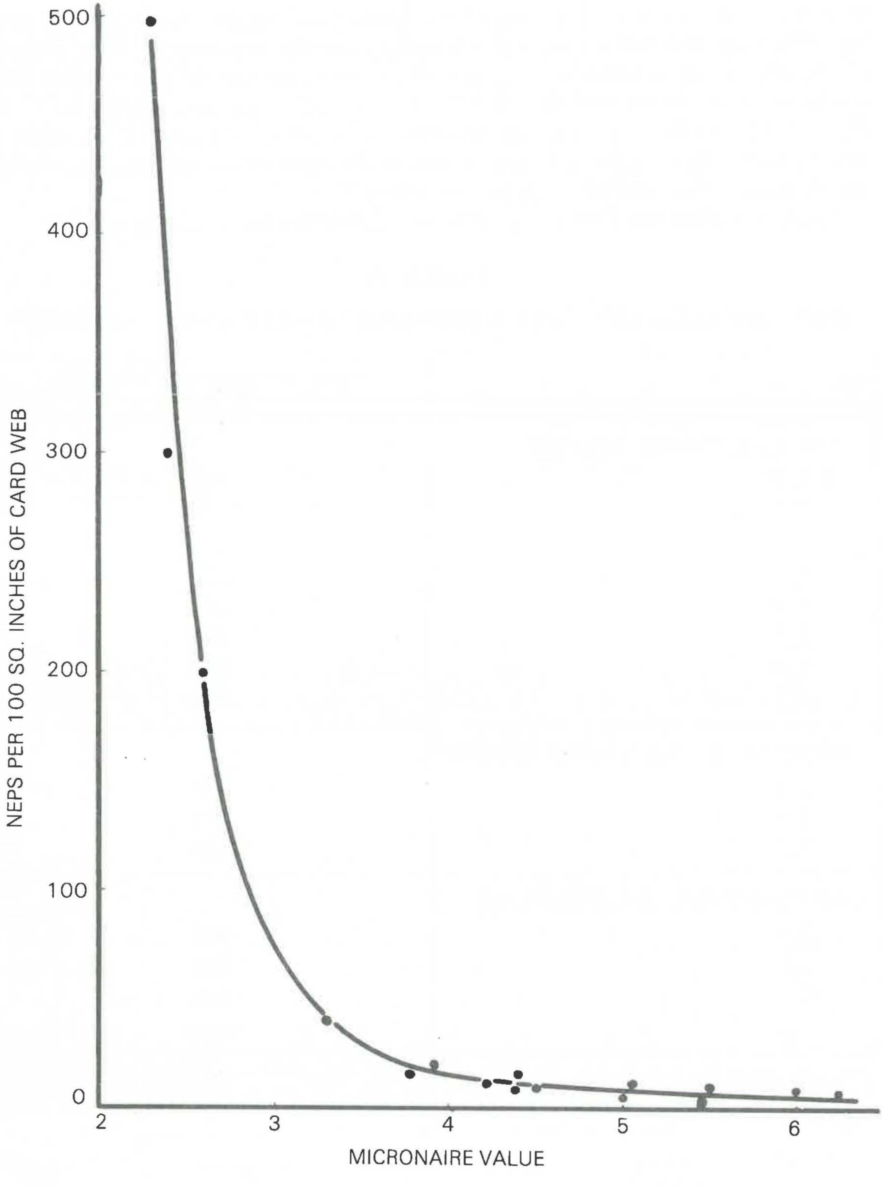


FIGURE 17

The effect of micronaire on card neps[249]

In one study[242] the lowest micronaire cotton produced stronger, more abrasion resistant, more elastic and softer fabrics than the coarser cottons[242]. Resin treatment counteracted most of these advantages, however. The lower micronaire cottons produced slightly poorer crease recovery however[242].

It is customary to blend different micronaires so as to produce the required micronaire although the proportion of the low micronaire component is usually very low[250]. Blending cottons differing greatly in micronaire appears to have little effect on yarn and fabric properties relative to an unblended cotton with similar micronaire[197,242,250—252], although there are exceptions. Care must be taken, however, when blending extremes in fineness, particularly if there are no bales of intermediate fineness present[253], since homogenous blending may not be possible.

In one study, yarn imperfections increased as the low micronaire component in a blend increased, even though average micronaire remained constant[254]. Blend level (micronaire blend) had no apparent effect on other yarn properties or end-breakage rates.

In one study a blend of 30% low and 70% high micronaire cottons gave slightly greater fibre breakage at higher carding rates and ends down during spinning[250].

Increased card cylinder loading (i.e. low cylinder-to-doffer fibre transfer) is responsible for a deterioration in card sliver quality as micronaire decreases[235].

FIBRE MATURITY

For a detailed discussion of maturity see ref. 238.

Attacks by disease, or a particularly bad growing season, can cause the growth of cotton fibres to cease before full maturity is reached. The immature fibres show little or no development of a secondary wall and, therefore, have little rigidity. Such fibres easily entangle into knots of dead cotton, called "neps", which are not easily disentangled during spinning. Because of their thin walls they have different reflectance characteristics compared with mature fibres and the neps may show up as white spots in the dyed goods[255]. Immature fibres also dye differently to mature ones[256].

Fibre maturity is regarded as a central characteristic of a cotton fibre through its direct and indirect correlation with the principle physical properties of commercial and technical importance[257]. The maturity of a cotton fibre is equated with its wall thickness, i.e. with the thickness of the secondary cell wall in relation to the diameter of the fibre swollen in caustic soda[256]. Maturity has a high correlation with fibre linear density, but genetic differences and differences in wall thickness caused by plant diseases, soil and water conditions during growing interfere with this relationship[258].

The fibre diameter and wall thickness are largely inherited characteristics but the latter is also greatly influenced by weather and soil environment[26]. The perimeter (p) of a cotton fibre is stated to be a genetic factor[259]. As a rough guide, immature fibres have a wall thickness below 2 μm, cotton wall thickness normally varying from about 2 to 7 μm[259]. Normal commercial cottons contain about 25% of thin-walled fibres[26].

Within a particular sample, fibre fineness (micronaire), length and maturity are correlated[260]. Maturity index is not all that highly correlated with micronaire when using a cross-section of world cottons[260]. Nevertheless, micronaire and maturity are closely related for a particular cotton, a particular seedstock and a particular crop year[256]. Fibre perimeter divided by fibre fineness is a measure of fibre cross-sectional area. A close relationship between maturity and the length of the cellulose molecules in the secondary wall has been observed, the longer the molecules the more mature the fibre (see Fig 14). The maturing process apparently continues until the boll opens[256]. No cotton boll contains only mature fibres, even fully opened bolls grown under favourable conditions contain at least 5% of immature fibres[256]. In some cottons the chalazal end consistently produces tufs of immature cotton[261]. For most cottons the shorter fibres are the most immature[139].

A small proportion of immature fibres may not affect the average maturity by much but nep-up sufficiently to markedly lower yarn appearance[139]. As a general rule, coarse mature cottons produce fewer neps than fine immature cottons. Often the intrinsic fibre fineness (H_s) is pretty constant and then the micronaire becomes a measure of fibre maturity. A coarse cotton generally assumes a deeper dyed shade than a fine one and a mature fibre a deeper shade than an immature one[139]. Different micronaires can therefore produce different dye shades; other fibre characteristics can, however, also lead to differences in shade. Fibre immaturity is partly genetic and partly environmental[262]. Environmental effects on fibre maturity appear to affect micronaire values most in practice (for cotton of a particular type)[139].

The most satisfactory measure of fibre maturity, and one that is independent of fibre perimeter (p) is the "degree of wall thickening (Θ)" defined as follows[263,264]:

$$\Theta = \frac{\text{cross-sectional area of fibre wall}}{\text{area of circle of the same perimeter}}$$

The degree of thickening (Θ) may be regarded as a fundamental unbiased measure of fibre maturity, measuring the extent of fibre wall relative to its maximum potential (Lord). For commercial[265] crops $\Theta > 0{,}48$. If Θ is less than 0,45 the cotton is regarded as dangerously immature[27]. According to Peirce and Lord[264,265] the cell wall thickening (Θ), which is a geometric measure of maturity, is defined as follows:

$$\Theta = \frac{4\pi A}{p^2} = \frac{A}{\pi r^2}$$

where A is the cross-sectional area of the cell wall,
p is the perimeter of the fibre (= $2\pi r$)
and r is the radius of a circle having a perimeter p.

For practical use the maturity ratio (M) has been recommended. M is the ratio of the average degree of cell-wall thickening of the sample to that at a standard level of maturity. A more precise definition is given later.

The area of the secondary wall thickness at standard maturity ($M = 1$) is 0,577 times that of a circle with the same perimeter[139,264] and the fineness (H) of this cotton is defined as H_s which is a measure of intrinsic or standard fineness (in mtex) .

$$H_s = \frac{H}{M} .$$

Empirically it has been found that[264]:

$$\Theta = 0{,}577\ M \text{ or } M = 1{,}73\Theta$$

In most countries, H_s usually varies within ± 5%. For rain grown crops M may easily range from about 10% above average for good conditions to 20% less than average for poor conditions, this having a great effect on micronaire seeing that it depends upon M^2 (see later)[238]. Nevertheless, for most practical purposes and for the same cotton cultivar[238], micronaire differences can be used as an indication of differences in maturity.

Mature cotton contains 94% cellulose whereas immature cotton may contain only 81% of cellulose. The sooner the fibre is gathered, the smaller the degree of maturity, and the lower the cellulose content. The following two tables illustrate this.

TABLE 30

CELLULOSE AND ASH CONTENT IN RELATION TO MATURITY (DAYS)[82]

Maturity (Days)	Cellulose %	Ash %
20	81,00	3,08
30	88,06	2,20
40	89,20	2,06
50	92,60	1,76
60	94,20	1,14
Fully mature	94,50	1,14

The scouring and finishing losses of immature cotton is greater than those of mature cotton and can be anything from 19 to 6%[82, 265a].

TABLE 31

THE MOISTURE CONTENT OF THE RAW-COTTON FIBRE AT VARIOUS MATURING STAGES[266]

Fibre Properties / Days after Flowering		17				26				36				45				59			
Fineness* (μg/in)	Micronaire Fineness	1,20				2,90				4,80				5,40				5,80			
	Causticaire Fineness	1,20				3,00				4,87				5,50				5,77			
	Arealometer Fineness									4,70				5,50				5,83			
Maturity	Immaturity Ratio									2,10				1,93				1,84			
	Maturity Index	48,0				62,0				77,3				81,5				84,7			
Sugar (%)	Reducing Sugar	21,9				5,34				1,44				0,84				0,11			
	Total Sugar	23,8				5,18				1,51				0,89				0,11			
Relative Humidity % / Temperature °C		20	25	30	35	20	25	30	35	20	25	30	35	20	25	30	35	20	25	30	35
30	Moisture Content %	4,00	3,80	3,80	3,80	3,20	3,20	2,80	2,50	4,20	4,20	3,90	3,20	3,00	3,00	3,00	2,60	2,80	2,80	2,80	2,80
40		5,70	5,60	5,50	5,50	4,60	4,60	4,40	4,00	5,20	5,20	4,80	4,10	4,00	4,00	3,90	3,60	3,80	4,00	3,60	3,30
50		8,40	7,80	7,00	7,00	6,40	6,30	6,10	5,90	6,20	6,30	5,80	5,20	5,40	5,30	4,80	4,60	4,90	4,80	4,90	4,00
60		11,7	9,90	9,70	9,80	8,00	7,70	7,60	7,20	8,00	7,80	7,50	6,60	6,60	6,20	6,10	6,00	6,00	5,60	6,00	5,20
70		16,5	13,6	13,6	13,6	10,6	10,6	9,80	9,60	10,0	9,90	9,20	8,20	8,00	8,00	7,90	7,60	7,50	7,00	7,50	6,70
80		24,7	23,2	22,5	22,2	14,3	14,2	13,5	13,4	12,7	12,6	11,6	10,7	10,2	10,0	10,0	9,60	10,0	9,80	10,1	9,40
90		41,0	39,0	37,0	36,4	25,0	24,9	23,0	22,0	17,5	17,1	16,0	14,7	14,5	14,5	13,7	13,1	13,6	13,0	13,5	12,0
95		49,8	46,6	46,0	44,5	36,2	36,0	35,0	34,0	21,4	21,0	20,0	18,8	18,2	17,8	17,0	15,0	16,8	16,4	16,7	14,6

*To convert μg/in to mtex multiply by 39,4

There is an optimum fibre maturity above which it is too stiff and bristly for easy processing and below which it is too flabby and unresilient[27]. A clear relationship between maturity and fibre strength has been observed for Soviet cottons[256]. Cotton fibre tenacity (cN/tex) decreases with decreasing maturity within a cultivar[259] and convolution frequency and fibre friction increase as cotton fibre maturity decreases[267]. Bundle tenacity appears to be negatively correlated with p[310].

A very high coefficient has been obtained between the cell-wall thickness of cotton and the number of flexural cycles required for rupture[268].

Immature fibres can also lead to roller lapping during processing and can cause difficulties with respect to nep formation and stickiness (due to excessive sugar), unevenness in yarns and webs and non-uniformity in wet processing[257].

Immature fibres break easily during processing, have a tendency to become entangled around particles of leaf and trash, thus making cleaning more difficult[258] and increasing the amount of fibre removed with foreign matter[130]. They adversely affect yarn appearance and dye unevenly[258]. Immature lint, in a mill at high humidity, causes many problems in the spinning process and may be one of the chief causes of nep formation[115,198] and neps consist mainly of immature fibres[269].

Finer fibres increase neppiness and therefore have to be processed at lower rates. Increased fibre maturity improves yarn and fabric appearance and decreases picker and card waste[198] but has little effect on yarn strength[149,150].

Low micronaire (immature) cottons lead to excessive end-breakage rates[248].

Cotton fibre maturity also appears to be reflected in fabric lustre[270]. It appears that dimensionally finer cottons are more lustrous[271].

Fine (and relatively immature) cotton appears to perform well during wear[272], and also swell more upon wetting[265a]. Initial Young's modulus is correlated with birefringe which in turn is correlated with maturity[257]. Mature fibres have higher elastic moduli than immature fibres[257].

The results of one study[266] showed that lint which has dyed perfectly green by the differential dyeing method is immature. However, laboratory dyeing experiments, carried out with direct dyes on immature cotton fibres of known origin, showed that maturity did not affect the amount of dye absorbed at *equilibrium*. The absorption and desorption *rates*, however, were higher for immature than for mature fibres. Mercerisation of the fibres before dyeing did not greatly affect the differences. Besides the effect of optical differences, the differences in depth between dyed neps and fabric are due to the more rapid desorption of dye from immature fibres. Such differences would be exaggerated by unsuitable processing conditions, e.g. during rinsing, which was confirmed by some laboratory dyeings on fabric samples. It was predicted that, in order to obtain an even colour on a fabric containing immature as well as mature fibres, dyeing should not be carried on until equilibrium is reached and that rinsing and aftertreatments should be carried out so that the dye desorption will be as small as possible[269].

It has also been stated[273] that immature or dead fibres in cotton piece goods can be dyed continuously at the same time as normal fibres and to the same shade, by impregnating the material with a padding liquor (which, in addition to dyestuffs, contains a cellulose ether) and then fixing the dyes evenly on the fibre surface whilst insolubilising the cellulose ether with a solution of a salt or acid salt of a polyvalent metal or a solution of a quarternary ammonium compound[273].

A pretreatment involving impregnating fabrics with 100 to 110% pick-up with a solution containing 4 to 7% caustic soda plus a surfactant plus a reducing agent, steaming for 60 to 90 minutes, washing, neutralizing and then dyeing seems to give good coverage of immature cotton[274]. If a fabric is mercerised before dyeing the colour difference between the neps and rest of the fabric will be reduced[269]. Certain dyes will dye neps to almost the same colour as the rest of the fabric[269].

Various tests have been used to obtain a measure of fibre maturity. Some of these, however, depend upon other fibre properties as well as fibre maturity. Some of the more important tests used to determine fibre maturity are described below:

Caustic Soda Swelling Methods

Under the action of a strong (18%) caustic soda solution, mature cotton fibres lose their natural twists and assume a cylindrical shape, while immature and dead fibres acquire new twists. It has been suggested[256] that a clearer distinction between mature and immature fibres can be made if a 32% caustic soda solution is used instead of an 18% solution. The same lye should always be used, since different lyes or lye concentrations yield different maturity indices even with the same procedure. This is important since a lye concentration of 16,5% is sometimes used[256]. Although a cotton fibre is generally regarded as mature if its wall thickness is a quarter or more of the fibre diameter after treatment in 18% NaOH[256] (i.e. the fibre wall thickness is 50% or greater than the diameter of the lumen, as measured along its major axis[2]) this ratio is considered to be less than ideal, values of 0,67 (2/3) or 0,75 (3/4) being regarded as better.

In the standard maturity test used in the U.K. (United Kingdom) the cotton fibres are swollen in an 18% caustic solution and examined under a microscope. The fibres are then classified into the following groups[238]:

1. *Normal* fibres where the fibres have swollen into solid rods, show no continuous lumen and have no well-defined convolutions;
2. *Dead* fibres where the fibres have a continuous lumen and the wall thickness is a fifth or less than the ribbon width measured at the widest portion of the fibre in the microscope field. This effectively means that the

ratio of the apparent wall thickness to the apparent lumen width is one-third or less.

3. *Thin-walled* fibres are the remaining fibres and represent the intermediate fibres.

These values are then generally expressed as percentages which are represented by N (normal) and D (dead).

The *Maturity Ratio* (M) is then calculated as follows[139, 264, 275]:

$$M = \frac{N-D}{200} + 0{,}70 \quad \text{also: } \Theta = 0{,}577 \left(\frac{N-D}{200} + 0{,}70\right)$$

$$\Theta = 0{,}577\,M \qquad \text{i.e. } M = 1{,}73\,\Theta$$

In another article[213] it is stated that when cotton lint is treated in 20% caustic soda the cellulose in the cell walls begins to swell and in fully mature fibres it continues to swell until the lumen is completely occluded and the cell resembles a solid rod when viewed through a microscope. These are referred to as normal (N) fibres while those that do not swell at all and remain thin-walled and convoluted are called "dead" (D) fibres. The maturity ratio (M) is then calculated as above.

The theoretical range for M is from 0,2 for all fibres dead to 1,2 for all fibres mature (normal).

The following classification of various cottons according to maturity ratio (M)[238] has been given:

TABLE 32

CLASSIFICATION OF COTTONS ACCORDING TO MATURITY RATIO[238]

Maturity ratio (M)	U.S.A. Upland Classification	Sudan-Egyptian
$\geqq 1{,}00$	Very mature	High-grade — mature
1,00 — 0,95	Above average	Med. grade — average
0,95 — 0,90 0,90 — 0,85	Mature	Low grade — below average uncommon
0,85 — 0,80	Below average	
0,80 — 0,70	Immature	
$\leqq 0{,}70$	Uncommon	

The US test for the maturity of cotton fibres swollen in 18% NaOH only classes the fibres into two categories viz. mature (where the apparent wall thickness to ribbon width is greater than 0,25, i.e. where the lumen occupies less than 50% of the total fibre width)[276] and immature (i.e. the remaining fibres)[238]. When using the fibre array method and swelling in NaOH, the number of mature fibres expressed as a per cent of the total number of fibres in the test specimen, represents the maturity[2] (P_m):

$$P_m = \frac{F_t - F_i}{F_t} \times 100$$

F_t = total number of fibres examined

and F_i = total number of immature fibres

i.e. $P_m = \frac{\text{No. of mature fibres}}{\text{Total number of fibres}} \times 100$

The following table has been given for rating maturity as determined by the array method and swelling in NaOH (18%), immature fibres being classed as those having their wall thickness one-half or less than the diameter of the lumen[2].

TABLE 33

ARRAY FIBRE MATURITY (P_m)[2]

P_m (%)	Rating
> 85	Mature
76 to 85	Average
66 to 75	Immature
< 65	Very immature

The percentage mature fibres (P_m) so obtained can be related to maturity ratio (M) as follows[22, 238]:

$$M = 1{,}76 - \sqrt{(2{,}44 - 0{,}0212P_m)}$$

Also $P_m = (M - 0{,}2)(1{,}565 - 0{,}471M) \times 100$

and degree of thickening (Θ) $= 0{,}577\ M = 1{,}017 - \sqrt{(0{,}812 - 0{,}00707P_m)}$

In another test[212], the fibres are also swollen in 18% NaOH and classified as follows according to the wall thickness (W) and lumen width (L):

Mature fibres : $L/W < 1$

Half-mature fibres : $1 < \frac{L}{W} < 2$

Immature fibres : $\frac{L}{W} > 2$

From these values the *maturity coefficient* (M_C) is then calculated as follows:

$$M_C = (M + 0{,}6\,H + 0{,}4\,I)/\,100$$

where M, H and I are the percentages of mature, half-mature and immature fibres[212].

TABLE 34

RATINGS FOR M_c

M_c	Rating
$< 0{,}70$	Immature
0,70 to 0,90	Medium mature
$> 0{,}90$	Mature

Airflow Tests

Maturity is often determined by double-compression airflow tests. Examples are the Arealometer, CRITER and IIC-Shirley testers[238]. These generally involve compressing the fibre sample to two different densities and then measuring the airflow at a constant pressure. A primary cause of resistance to airflow through a sample is the amount of external fibre surface exposed to the airflow and this resistance is used as a measure of specific area. The resistance, however, is modified by the distribution and orientation of these surfaces; hence on suitably compressing the sample, that change in resistance which is essentially due to re-orientation of flattened fibres becomes a measure of the immaturity ratio[2]. The apparent increase in specific surface area at higher compressions (air-flow test) is attributed to rotation of the fibres within a plane perpendicular to the direction of flow[277]. Less mature fibres are flatter and, therefore, provide a greater increase in a resistance when compressed than do the more mature fibres.

Airflow through a plug of cotton is determined by the specific surface area (S_O) i.e. the surface area per unit volume which in turn is a function of MH[238, 278, 279, 284].

$S_O = p/A$

where p is the fibre perimeter and

A is the cross-sectional area of the cotton fibre[279, 280].

$A = V \times H = \frac{H}{\rho}$ where ρ is the fibre density and

V = specific volume.

It appears[280] that: $S_o^2 = \frac{a}{\Theta H} + \frac{b}{\Theta H^2}$

From this it would appear that no single regression equation is sufficient to establish fineness and maturity from airflow[280].

The IIC-Shirley Fineness/Maturity tester works on the double-compression system and allows micronaire, maturity ratio (M) and fibre fineness (mtex) to be determined. It is increasingly being accepted as probably the best method for determining the above fibre properties on a routine basis.

The IIC-Shirley Fineness/Maturity tester gives the mean fineness and mean maturity of a 4 gram sample of cotton. The resistance of airflow of the cotton fibres is determined at two packing densities, with the value obtained at the lower packing density giving the micronaire and the difference between two readings is used to calculate the maturity ratio (M) which is closely correlated with the values determined by the caustic soda test. For maturity tests on airflow type instruments such as the IIC-Shirley Fineness/Maturity tester, it is recommended that mechanical opening of the sample be carried out (e.g. miniature card, Shirley Analyser or fibre blender) to give a fleece or web of substantially random orientation[238]. Trash has to be removed since they affect the results.

Heap[281] presents the following figures relevant to measurements made on the IIC/Shirley tester, from which it appears that the instrument gives a very accurate measure of cotton maturity and fineness.

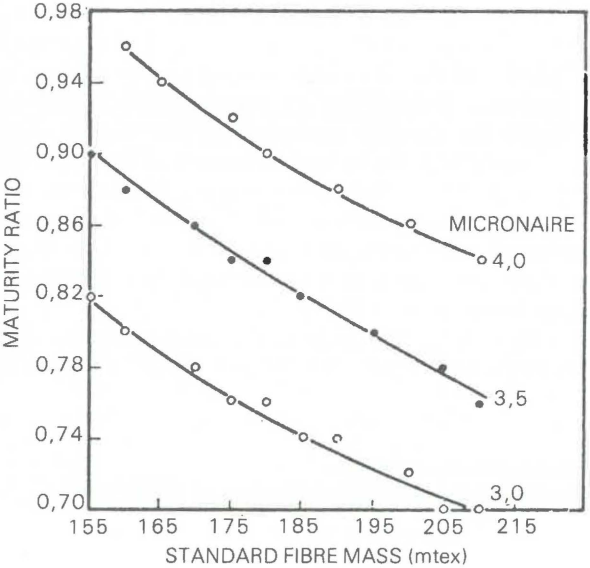


FIGURE 18

Maturity ratio (M) as a function of micronaire and the standard fibre mass or linear density (H_S)[281]

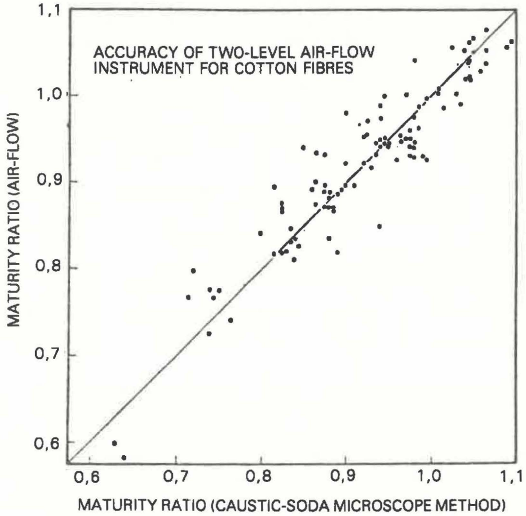


FIGURE 19

Correlation between maturity ratio results determined by air-flow and caustic soda swelling, respectively[281]

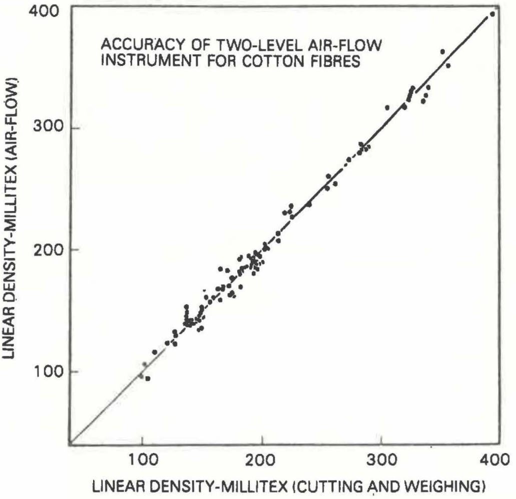


FIGURE 20

Correlation between IIC-Shirley fineness and that obtained by cutting and weighing[281]

In the *Causticaire* test for maturity the relative change in air permeability (airflow) between untreated and treated (i.e. mercerised in 18% NaOH) cotton fibres is used as a measure of maturity.

For causticaire we have[282, 283]:

$$M_I = \frac{UT \times 100}{T}$$

$$F = 1{,}185 + (0{,}00075\ T^2) - (0{,}020\ M_I)$$

where M_I = Causticaire maturity index (in %)
UT = Causticaire reading on untreated sample
T = Causticaire reading on treated sample (i.e. NaOH mercerised)
and F = Causticaire fineness in μg/inch. To convert F to mtex, multiply by 39,4.

The above tends to underestimate coarse cottons and to be higher for mature than for immature cottons[284]. According to Lord[238], the Causticaire test contains some inherent disadvantages with the Causticaire maturity biased according to fibre fineness[284, 285].

For American Upland cottons we have:

M_I	**Classification**
< 72	Very low
72 — 75	Low
76 — 79	Average
80 — 83	High
> 85	Very high

Another rating of fibres according to their Causticaire values is also given below[2]:

Causticaire Maturity Index (M_I)	**Rating**
> 82	Mature
76 to 81	Average
70 to 75	Immature
< 70	Very immature

J.S.I.F. have developed a formula:

$$M_I = 61{,}7 + 59{,}5\ (P_L/P_H)$$

where P_L and P_H are the IIC-Shirley readings.

Dye Tests

A differential dyeing technique was developed by Goldthwait *et al*[286] to estimate cotton fibre maturity. After dyeing with a mixture of green and red direct dyes, the maturity of cotton fibres can be estimated visually[286, 287] or by spectrometrically analysing the red and green dye uptake after the dye extraction from the differentially-dyed samples[288]. Red and green direct dyes are used in the same bath, immature fibres tend to dye green and mature fibres tend to dye red[289], subsequent stripping in boiling water may be required for clearer distinction[289]. Colour differences appear to be due to structural differences (porosity) during dyeing rather than to differences in wall thickness *per sé*[289]. The molecular weight of the green dye is twice that of the red, hence greater fibre porosity will favour it. The action of heat, in ginning for example, also has an effect on dye uptake.

Dye absorption has been related to fibre properties[290] (see also ref. 292).

The tests consist of dyeing three-gram samples of cotton in a bath of distilled water, Diphenyl Fast Red 5BL Supra 1 and Chlorantine Fast Red BLL, the redyeing twice in the same bath plus sodium chloride and washing. The colour of the samples is compared with that of standard samples[2].

The fibre fineness also affects the appearance of the fibres in addition to the fibre maturity. Dyeing tests for maturity are discussed in detail elsewhere[238, 293, 294].

Alkali and Glycerol Centrifuge Tests

The amount of alkali retained by cotton fibres after the fibres have been immersed in 15% caustic soda solution for 15 min and then centrifuged is termed the Alkali Centrifuge Value (ACV) and has been used to assess cotton fibre maturity[175]. It is a measure of the alkali swelling of the fibre and is a function of the cell wall thickness (i.e. maturity) as well as microbial or mechanical damage[161] to the primary wall[161, 175].

The ACV of an undamaged cotton is of the order of 190 and that of severely damaged cotton 330.

If, therefore, the ACV is to be used as a measure of maturity it must be ensured that the fibre is not damaged or else an Arealometer value must be obtained and the results checked using a graph given by Marsh *et al*[157, 161].

The imbibition of glycerol by cotton has also been used as a measure of fibre porosity which includes a major contribution from the fibre lumen[295]. Cotton is swollen in glycerol to saturation and subjected to centrifugation until constant mass is attained. The glycerol retention value (GRV) is calculated from the increase in mass of cotton after swelling and centrifugation. This method was applied to determine GRV's and pore space of 12 American cottons which have different wall thicknesses but more or less the same fibre perimeter. A high negative correlation was obtained between GRV and the percentage of mature fibres for various raw and extracted cottons. It has been shown that the average lumen area in the swollen state can be calculated from GRV and gravimetric fineness[295].

Polarized Light Tests

The anisotropic nature of the fibrillar structure of the cotton fibre has been used to assess the fibre wall development[238, 296–300]. When examined through a microscope illuminated with plane-polarized light, fitted with crossed polarizer and analyser and having a first-order red selenite plate to give a magenta background to the field of view, cotton fibres assume different colours according to their wall thickness. Fibres with very thin walls appear violet or indigo, immature fibres are blue and native fibres with still thicker walls appear yellow. This test does not, however, classify the fibres according to Θ, the colour depending essentially upon the absolute wall thickness (i.e. not the relative wall thickness). Furthermore, colour is generally assessed subjectively which is a disadvantage[238].

In another article[256] it is stated that, after interposing a Red 1 gypsum plate the fibres appear in the following colours viewed lengthwise:

Mature fibres (thick-walled)	green to yellow
Immature fibres (thin-walled)	indigo to blue
Dead fibres	colour of basic tone.

Under polarized light, mature and immature fibres not only reveal a different interference colour but also different luminosity, depending on the thickness of the cell wall and thus on the maturity[256]. Dead fibres emit no light at all.

The basis of the polarized light method of determining maturity is the ability of the fibres to transmit light. The immature fibres will transmit the polarized light with the lumen appearing the same colour as the background. The mature or thick-walled fibres do not transmit light as do the immature fibres and will appear as a complementary colour to the background[256].

Every maturity test gives a different value. Nominal values are given below of the degree of maturity of cotton obtained by different processes on cotton from seven different origins with the same micronaire value of 4,3 (from the Koch-table)[115, 256, 300].

TABLE 35[115, 256]

Principle	**Mexico Altamira**	**USA Memphis**	**Mexico Mexicali**	**USA El-Paso**	**USA California**	**Guatemala**	**Iran**
Micronaire value	4,3	4,3	4,3	4,3	4,3	4,3	4,3
Causticaire value	77	76	78	77	76	77	77
Red-green test	3—4	3—4	4	3	3—4	3—4	3—4
Mean fineness (dtex)	1,62	1,84	1,80	1,61	1,82	1,88	1,67
Caustic soda solution (18%)							
Percentage of mature fibres	60	55	70	60	59	60	54
According to CLEGG	60—38	55—36	70—29	60—40	59—40	60—39	55—46
British Standard	0,82	0,79	0,91	0,80	0,80	0,81	0,74
Polarization (swollen fibres)							
Percentage of mature fibres	66	53	64	52	66	67	65
According to ROEHRICH	7,6	5,5	7,6	7,2	7,4	7,8	7,8

In one article the correlation between various measures of maturity has been investigated. The IIC Shirley Fineness/Maturity tester was also studied[301].

FIBRE FINENESS

Correctly speaking, by definition, the fineness of a textile fibre or yarn is its mass per unit length (i.e. linear density). Originally the fineness of cotton was expressed as micrograms per inch (μg/inch) and initially air-flow instrument values (micronaire) were expressed in these units but it soon became evident that the micronaire reading was a function of both the cotton fibre *fineness* and *maturity*. Thereafter the air-flow reading was more correctly described as micronaire or micronaire units since it is not a unique function of fibre fineness although, as mentioned earlier, within a cultivar, micronaire is a function of maturity and so is fineness. Hence, within a cultivar, micronaire is generally a measure of the cotton fineness.

Fibre fineness (i.e. mass per unit length or linear density) can be measured by the "cutting and weighing" technique where a known length of cotton fibre is weighed and then the linear density calculated. This is, however, a time consuming and not all that simple exercise and in recent years special techniques and instruments have been developed which allow the fibre fineness to be determined by the air-flow technique in which the rate of air-flow is measured with the loose fibre assembly being compressed to two different densities. One such instrument which is becoming widely used is the IIC-Shirley Maturity/Fineness Tester which allows micronaire, fineness and maturity to be accurately determined in a very short time. This has allowed fineness to be determined on a routine basis and it now becomes possible to determine the importance of fineness *per sé* on processing performance and yarn and fabric properties. As mentioned earlier, the units for expressing cotton fibre fineness were originally μg/inch but today millitex (mtex) has been accepted almost universally. Fibre fineness in mtex is the fibre mass in grams per 1 000 000 metres of fibre, or, equivalently, the mass in milligrams (mg) per 1 000 metres of fibre. It follows that to convert from μg/inch to mtex we must multiply by 39,4.

Cotton fibre fineness and length are closely correlated[302]. As the cotton fibre becomes finer so the minimum twist required to produce maximum yarn strength decreases[302]. Fineness also affects the twists used for rovings, while fine fibres together with low yarn twists are regarded as ideal for bulky hosiery yarns[302]. Provided no other fibre properties are adversely affected, finer fibres produce stronger yarns, particularly in the case of rotor yarns, mainly because there are more fibres and therefore a greater surface-to-surface (and therefore interfibre frictional forces) in a yarn of given linear density. Finer fibres reduce end-breakages on rotor (OE) machines[303].

In general, finer cottons should have a beneficial effect on yarn evenness and strength because of the greater number of fibres in the cross-section of a yarn of a certain linear density (tex), this being particularly important for rotor (OE) yarns where fineness has assumed greater importance than is the case for ring yarns. On the other hand, finer cottons are more prone to nep formation during carding and have to be carded at slower speeds. This increased nep formation adversely affects the yarn appearance. If cotton fineness is a measure of, or is associated with, immaturity which is generally the case within a particular cultivar, then the adverse effect of lower maturity may outweigh the beneficial effect of the increasing fineness (i.e. lower mtex and therefore a greater number of fibres in the yarn cross-section). The ideal appears to be to breed a cotton which is fine and yet mature, such a cotton would appear to have particular potential in rotor spinning.

The *mean fibre linear density* (H) can be obtained by weighing bundles of fibres cut to a standard length or by the IIC-Shirley tester. This is a measure of the cotton fibre linear density but does not distinguish mature from immature fibres.

The *standard hair mass* (H_S) is a measure of the intrinsic fineness of cotton fibre and is obtained from the formula $H_S = H/M$ and represents the average fibre fineness of the cotton were its maturity ratio (M) to coincide with an arbitrary level of unity (i.e. when M = 1, then $H = H_S$)[264].

Micronaire (X) is related to maturity and fineness as follows[139, 238]:

$$MH = M^2H_S = 3{,}86\,X^2 + 18{,}16\,X + 13$$

where M is the maturity ratio

H is the average fibre linear density (mtex)

and H_S is the standard fibre linear density (mtex)

$$H_S = \frac{H}{M}$$

Heap[281] gives the following graph for the yarn linear densities for different cotton varieties assuming 100 fibres in the yarn cross-section.

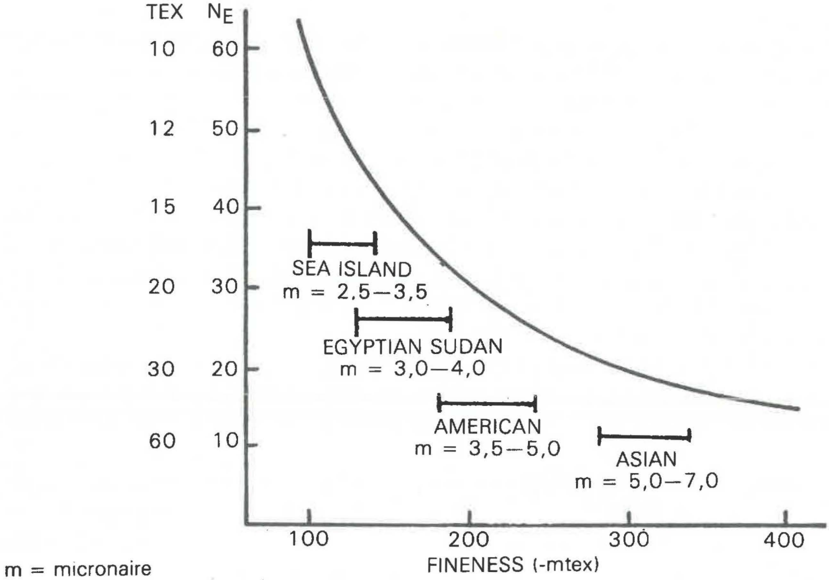


FIGURE 21

Theoretical Count Limits for OE Yarns (100 Fibres in Cross-Section)

SUMMARY OF RELATIONSHIPS INVOLVING MATURITY AND FINENESS

Some Definitions

H = fibre fineness or linear density (mtex)

A = cross-sectional area of fibre cell wall (μm^2)

p = perimeter of fibre (μm)

S_o = specific fibre surface area per unit volume ($mm^2/mm^3 = mm^{-1}$).

S = specific fibre surface area per unit mass (mm^2/g) = S_o/ρ

ρ = density of fibre wall.(g/cm^3) = 1,52 g/cm^3 for cotton cellulose.

V_f = specific volume of fibre wall (cm^3/g) = $\frac{1}{\rho}$ = 0,653 for cotton cellulose.

r = radius of a circle with a perimeter p and equals the radius of the fibre before it dries out and collapses.

A_O = πr^2 = area of a circle with a perimeter p = area of fibre plus lumen before the fibre collapses.

H_S = standard fibre linear density (mtex) = linear density of a particular cotton when its maturity ratio (M) equals one.

Θ = degree of wall thickening = A/A_O = geometric measure of maturity[263].

I = Immaturity ratio[304] = $A_0/A = 1/\Theta$

M = Maturity ratio[263, 264] = $\dfrac{\text{actual linear density}}{\text{standard linear density}} = H/H_s$

Θ = 0,577 M (empirical relationship)[264].

N = Percentage "normal" fibres (see earlier sections)

D = Percentage "dead" fibres (see earlier sections)

Derived Relationships[22, 238, 264, 279, 280, 304]

$$Ao = \rho^2/4\pi$$

$$\Theta = 4\pi A/p^2 = A/\pi r^2$$

$$So = p/A$$

$$S_0^2 = \left(\frac{p^2}{4\pi A}\right)\frac{4\pi}{H\,V_f} = 4\pi I/H\,V_f = 4\pi\rho/H\Theta$$

$$H = A\rho = A/V_f$$

$$A = 0{,}66H \text{ (in } \mu m^2)$$

$$p = 4\pi\frac{I}{S};\ S_0^2 = \frac{4\pi I}{A} = 4\pi\rho\frac{I}{H}$$

$$S_0 = S\rho = S/V_f;$$

Empirical Relationships

Total surface area of a cotton fibre of constant length is α p (where p is the perimeter) but[309]:

Surface area $\alpha \sqrt{H_s}$ and

$p = 3{,}8\sqrt{H_s}$

where H_s is in mtex. The fibre perimeter (p) is fairly constant for a pure cotton strain and is largely unaffected by environmental conditions[22, 311].

If, in addition, the specific volume (V_f) or density (ρ) is assumed constant then[264, 279, 304, 311]

$$\Theta \,\alpha\, H$$

$$\Theta = 0{,}577M$$

$$I = \frac{1}{\Theta} = \frac{1{,}73}{M}$$

The relation between the surface area per mass (S) and fineness and maturity has been determined empirically by Peirce and Lord[264, 306] as

$$S = 3{,}79 \times 10^3/\sqrt{MH}\ (\text{mm}^2/\text{g})$$

Generally it is assumed that the lumen area is negligible i.e. that $\rho = 1{,}52$ and $V_f = 0{,}656$ which gives

$$S_0 = \frac{S}{0{,}656} = \frac{5{,}75 \times 10^3}{\sqrt{MH}}\ (\text{mm}^{-1})$$

and

$$S_0^2 = \frac{3,32x10^7}{MH} \text{ (mm}^{-2}\text{)}$$

Nevertheless, the lumen is not negligible in the collapsed fibre (an average value for the lumen area being of the order of 10 μm^2) and Lord[264, 278] considered a value $V_f = 0,75$ more realistic for the specific volume of the fibre plus lumen. In this case it follows that:

$$S_O = \frac{S}{0,75} = \frac{5,05x10^3}{\sqrt{MH}} \text{ (mm}^{-1}\text{)}$$

and

$$S_0^2 = \frac{2,55 \text{ x } 10^7}{MH} \text{ (mm}^{-2}\text{)}$$

Other relationships already mentioned are:

$$\text{Maturity Ratio (M)} = \frac{N—D}{200} + 0,70$$
$$= 1,73\Theta = 1,76 - \sqrt{(2,44\text{-}0,0212P_m)}$$

$$\text{Percentage Maturity } (P_m) = (M\text{-}0,2)(1,565\text{-}0,471M)\text{x } 100$$
$$= 150,5 - 38,1 \text{ x I}$$
$$= 1,011 \text{ x } M_I - 2,4$$
$$M_I = 151 - 37,7 \text{ x I}$$

where M_I = Causticaire maturity index.

$\Theta = 86,8 - 21,9 \text{ x I}$

$MH = M^2H_S = 3,86 X^2 + 18,16X + 13$

where X = micronaire value.

Empirically it has also been found that[53, 265, 280]:

$A = \pi r^2 \Theta = 0,655H + 18$

$\Theta = 0,01 \text{ x } (0,79N + 0,41T + 0,23D)$

$\Theta = 0,575M + 0,079.$

$A = 0,665H + 18.$

According to these relationships $\Theta = 0,654$ when $M = 1$ which contrasts with the frequently quoted value of 0,577.

STRUCTURAL REVERSALS AND FIBRE CONVOLUTIONS

It is first of all important to distinguish between *structural reversals,* which are generally not visible except through polarized light, and *convolution reversals* (see Figure 17).

Structural reversals occur in the fine structure of the cotton, and refer to the reversal in direction of the spiral (fibril) structure or helix along the length of the fibre. At the point of reversal, the fibrils, for a short interval, lie parallel to the fibre axis. *Spiral* (or helical) *angle* is the angle the fibrils form with the fibre axis and is approximately 22° for the unconvoluted fibre regardless of variety[311—318], although it decreases somewhat from the fibre surface to its centre[317—320, 328].

When the cotton fibre dries it collapses into a flattened ribbon-like form which spirals or twists along the length of the fibre. The place at which a twist occurs is referred to as a *"convolution"*. The convolutions or twists frequently change direction forming *convolution reversals.* The convolution pitch depends upon the ribbon width and cell wall thickness[318]. Convolution reversals are related to the structural reversals[318]. Convolutions affect both the *apparent* spiral angle as well as the mechanical properties, explaining the observed relationship between *apparent* spiral angle and mechanical properties, since, as already mentioned, the true spiral angle is virtually constant[318].

Cotton fibre twist (or convolutions) changes direction frequently along the length of the fibre, forming convolution reversals[321]. It appears that the folds in the cotton fibre as it lies inside the boll in many ways determine the convolution reversals[321]. Between two bends (folds) in the fibre there is a reversal and on either side of this reversal there is an equal (and opposite) number of convolutions[321]. The average length between bends ranges from 1,5 to 2,0 mm . The bend is more often a reversal than not. Structural reversals are often a weak spot in the cotton fibre[320] although it appears that fibres break preferentially adjacent to reversals[322, 323, 323a].

Convolution angle is a function of both the fibre perimeter and the wall thickness[324] (i.e. maturity)[310]. The number of twists or half-convolutions in raw cotton fibres varies widely. Immature fibres are practically non-convoluted, while mature fibres of the same variety may be highly convoluted. Bowman [325] gave the following table of estimates of average number of convolutions per cm for different classes of cotton (see also Table 38).

TABLE 36

CONVOLUTIONS IN DIFFERENT COTTONS[46, 325]

Cotton	Convolutions/cm
Sea Island	59
Egyptian	45
Brazilian	42
American	38
Indian (Surat)	30

Very thin-walled and very thick-walled cottons are almost devoid of convolutions[26].

The presence of cotton fibre convolutions greatly affects many of the fibre physical properties[318, 314, 326]. Hearle and Sparrow[318] recently reviewed the relationship between fibre structure and tensile properties. Convolution angle is a gross measure of fibrillar orientation and is highly correlated with fibre bundle tenacity (for G. hirsutum) as well as 40 or 50% X-ray angle, the latter two being more suitable measures of orientation[327]. The number of structural reversals in cotton other than G. herbaceum is ≈ 20 per cm, while for G. herbaceum it is about 2 to 5 per cm[327]. G. hirsutum cottons have ≈ 32 convolutions per cm and ≈ 23 structural reversals per cm . Convolution angles of G. herbaceum vary from 5 to 8° while those for G. hirsutum vary from 7,7 to 12,5°[310], convolutions per cm varying from about 30 to 45 for the former and from about 45 to 75 for the latter[310].

Birefringe measurements are regarded as a better measure of fibre orientation than convolution angle, it being correlated with bundle tenacity for both hirsutum and herbaceum cotton[310].

Hebert[314] found a high correlation between convolution angle and zero-gauge tenacity for different genetic varieties. He derived:

$$T_o = T_k e^{-k \sin^2 Q_c}$$

where T_o = zero-gauge tenacity (cN/tex)
T_k = zero-gauge tenacity of unconvoluted fibre = 52 cN/tex
Q_c = convolution angle corrected for edge curling.

TABLE 37

ZERO-GAUGE TENACITY AS A FUNCTION OF CONVOLUTION ANGLE[314]

T_o(cN/tex)	Convolution Angle (°)	
	Uncorrected	Corrected (Q_c)
26,3	13,6	18
29,6	11,5	15
33,1	10,5	14
37,2	8,0	10
44,5	7,8	10
37,9	9,9	13
45,6	6,2	—
45,9	5,4	—
42,9	4,5	—
46,4	6,5	—

Fibre tenacity is inversely related to both X-ray angle and reversal frequency[329], as the 40% X-ray angle increases, zero-gauge tenacity decreases[312]. Elongation is directly related to both structural features[329]. Bundle tenacity at zero-gauge and bundle elongation at 3,2 mm (1/8″) gauge are highly correlated with the 20% and 75% X-ray angles, respectively[330], the latter possibly being the best estimate of the spiral angle[331].

Cotton Crimp

Cottons vary greatly in crimp[59, 205] with finer cottons generally having lower crimp energy than coarser ones[59]. An optimum crimp has been postulated[21].

FIBRE DIMENSIONAL PROPERTIES

Most American cottons vary in staple length from 19 to 34 mm and in diameter from 15 to 22 μm[46]. In Sea Islands cottons, lint lengths up to 60 mm have been observed although staple length is generally around 44 mm . The total wall thickness of different types of cotton vary from about 0,35 to 15,5 μm .

Some properties of various cotton types are given in the following tables:

TABLE 38

CONVOLUTION ANGLE AND TENSILE STRENGTH OF COTTON FIBRES[332]

No. Cotton	Ribbon width (μm)	Convolutions/cm	Convolution angle (deg)	Pressley Strength	
				(1 000 psi)	(cN/tex)
C. arboreum indicum					
1. Coconada	18,38	43,4	7,2	76	37
2. Sirsa	18.30	59,5	9,7	79	38
3. Nandyal-14	20,09	46,0	8,3	80	39
4. Karungani-5	18,61	35,6	6,0	86	42
5. Karungani-2	19,04	37,3	6,4	87	42
6. H.420	18,95	48,5	8,2	90	44
7. Karungani-5	18,51	32,6	5,4	91	44
8. Gaorani-12	16,17	40,8	5,9	96	47
9. Gaorani-6	18,64	39,7	6,6	97	47
10. 122	18,38	31,3	5,1	102	50
G. arboreum bengalense					
11. Mollisoni	24,84	53,5	11,8	56	27
12. Mollisoni	22,66	51,4	10,4	64	31
13. 231-R	24,34	42,9	9,3	74	36
14. 231-R	24,10	40,2	8,7	75	36
15. Hathras	25,90	41,6	9,6	76	37
16. Virnar	18,25	37,5	6,1	84	41
17. 35-1	19,44	43,2	7,5	84	41
18. Jarila	21,83	27,9	5,5	90	44
19. Virnar	20,18	33,5	6,1	91	44
20. Virnar	17,46	31,1	4,9	92	45
G. Herbaceum					
21. Wagad	28,65	30,0	7,7	69	33
22. Kalyan	21,90	44,7	8,8	70	34
23. Westerns	20,90	47,7	8,9	75	36
24. Vijalpa	20,47	34,8	6,4	78	38
25. Suyog	23,50	34,6	7,3	78	38
26. Vijay	17,81	46,6	7,4	81	40
27. Westerns	21,65	40,7	7,9	82	40
28. Jaydhar	17,93	48,1	7,7	84	41
29. 1027-ALF	20,24	34,0	6,2	85	41
30. Jaydhar	18,18	51,8	8,4	85	41
31. Vijay	19,35	36,5	6,3	86	42
32. Surat 1027 ALF	19,55	47,0	8,2	90	44
33. Digvijay	18,62	40,0	6,7	92	45
G. hirsutum (Indian)					
34. Laxmi	19,70	57,3	10,1	64	45
35. Madras Cambodia Uganda-1	20,85	62,8	11,6	68	33
G. hirsutum (Indian) *cont.*					
36. Cambodia CO2	19,00	73,1	12,3	70	34
37. Buri-0394	18,84	73,7	12,3	74	36
38. Madras Cambodia Uganda-1	19,86	62,0	10,9	75	36
39. 320F	17,87	73,7	11,7	78	38
40. Laxmi	17,20	57,7	8,8	79	38,5
41. 320F	17,68	72,4	11,4	80	39
42. 320F	18,98	54,4	9,2	81	39
43. Parbhani American	18,14	62,1	10,0	83	40
44. Punjab American L.S.S.	18,46	58,6	9,6	88	43
G. hirsutum (American)					
45. Delfos	19,71	58,4	10,3	72	35
46. Deltapine	18,97	68,0	11,5	72	35
47. American Elpaso	19,29	56,4	9,7	77	37
48. Stoneville	19,93	63,4	11,2	79	39
49. A.R. Busoga (E. Africa)	18,30	50,5	8,3	86	42
50. Acala	18,47	53,8	8,9	97	47
51. Bobshaw	18,39	42,7	7,0	97	47
G. barbadense (Egyptian)					
52. Egyptian Karnak	17,82	53,6	8,5	77	37
53. Ashmouni	17,63	52,2	8,2	84	41
54. Egyptian Karnak	16,82	50,8	7,7	86	42
55. Giza-47	17,12	53,1	8,1	87	42
56. Egyptian Karnak	16,48	53,8	7,9	89	43
57. Egyptian Karnak	15,96	50,9	7,3	93	45
58. Bahtim-185	17,61	48,3	7,6	95	46
59. Menoufi	16,40	45,4	6,7	97	47
60. Egyptian Karnak	16,79	46,9	7,1	99	48
61. Giza-45	15,55	49,1	6,8	101	49
G. barbadense (W. Indies)					
62. MSI	17,88	45,6	7,3	86	42
63. Puerto Rico P.S.I.	16,74	42,1	6,3	89	43
64. V.H. 10	17,32	45,2	7,0	95	46
65. Seabrook, 12-B-2	16,81	41,7	6,3	101	49
66. St. Vincent Superfine V-135	14,44	30,3	3,9	105	51
67. V.H. 8	15,65	38,6	5,4	109	53

TABLE 39

CIRCULARITY AND THE OTHER CHARACTERS OF COTTON FIBRES OF DIFFERENT SPECIES[333]

Cotton	Circu-larity*	Mean fibre length (mm)	Micronaire value (μg/in)	Mean ribbon width (μm)	Perimeter (μm)	Area of cross-section (μm^2)	Secondary wall thickness (μm)
1	2	3	4	5	6	7	8
C. arboreum							
C. J. 73	0,772	20,8	4,0	19,21	57,5	206,1	4,89
N. 14	0,770	20,3	4,5	18,16	55,5	196,1	4,88
Nandicum	0,766	21,1	5,0	19,11	56,8	197,0	4,68
Virnar	0,743	19,8	4,7	18,34	56,5	188,5	4,41
Adonicum	0,705	23,1	5,1	19,66	61,2	210,6	4,46
Mean	**0,751**	**21,0**	**4,66**	**18,90**	**57,5**	**199,7**	**4,66**
G. herbaceum							
Kalyan	0,726	21,0	5,2	20,56	64,7	244,7	4,98
Westerns 1	0,713	21,8	3,8	20,64	65,0	240,7	4,83
Digvijay	0,709	22,6	3,7	18,94	61,6	208,0	4,24
Vijalpa	0,689	24,0	4,7	19,78	64,1	214,8	4,23
V. 797	0,682	22,6	5,2	18,37	70,0	262,1	4,76
MEAN	**0,704**	**22,4**	**4,52**	**19,66**	**65,1**	**234,0**	**4,61**
G. hirsutum							
Laxmi	0,685	24,6	3,5	13,21	54,4	160,0	3,73
Mysore 14	0,676	26,8	3,6	13,68	56,9	172,5	3,85
MCU. 3	0,669	25,4	3,7	13,06	53,9	152,8	3,58
LL. 54	0,666	25,4	3,7	13,68	56,5	167,1	3,73
320F	0,700	21,9	3,9	13,52	57,8	161,4	3,43
MEAN	**0,660**	**24,8**	**3,66**	**13,43**	**55,9**	**162,8**	**3,66**
G. barbadense							
Sea Island	0,739	30,0	3,6	17,58	54,6	176,2	4,28
Andres Giza 45	0,700	28,7	3,6	15,52	50,0	138,2	3,58
Menoufi	0,699	29,7	2,6	16,46	53,3	156,8	3,74
Dandara	0,688	25,9	3,4	16,60	52,9	151,9	3,67
Ashmouni	0,644	23,4	3,6	18,08	59,3	177,2	4,72
MEAN	**0,694**	**27,5**	**3,36**	**16,85**	**54,0**	**160,1**	**3,80**

*Circularity $= \frac{4\pi A}{p}$ where A = Fibre cross-sectional area (μm^2) and p = Fibre perimeter (μm)[333a]

TABLE 40

AVERAGE CROSS-SECTIONAL FEATURES OF COTTONS IN FOUR RANGES OF FINENESS[334]

Samples	Areas (μm^2)			Diameters (μm)				Ratio Major	Av. Wall Thickness (μm)
				Lumen		Fibre			
	Total	Lumen	Nett	Major	Minor	Major	Minor	Minor	
Very fine	98,90	10,54	88,38	9,77	1,20	16,73	6,20	3,07	2,50
Fine American Upland	155,26	11,89	143,37	10,92	1,05	20,02	7,83	2,77	3,39
Coarse American Upland	230,05	19,02	211,04	14,22	1,55	24,97	9,49	2,90	3,97
Very coarse Asiatic	374,26	27,49	346,78	12,53	2,24	27,26	14,57	2,07	6,17

Some further data on microscopical dimensions are given below[46]:

A typical, mature raw cotton fibre is a flattened tube; examined under the low-power microscope, it is a long, twisted ribbon with slightly thickened edges. The basal fibre end is open and irregular, where it is torn from the seed coat in ginning, while the tip is closed, symmetrical, and tapered. There are many individual deviations from this typical fibre such as the more or less unflattened, tubular shapes that characterise extremely thick walled fibres, particularly those of Asiatic origin, and abnormalities such as forked, branched, and bulged tips[46].

Fibres of different species and varieties of cotton range in length from 1 000 to 4 000 times their widths, with values of 1 200 to 1 500 for the more common types. Actually, fibre width has only limited significance inasmuch as it may not reveal the amount of functional substance the fibre contains. In other words, both fibre width and wall thickness must be known if the dimensions are to have any meaning[46].

The ways in which cotton fibre dimensions may change with various imposed constraints are illustrated in figure 22[335].

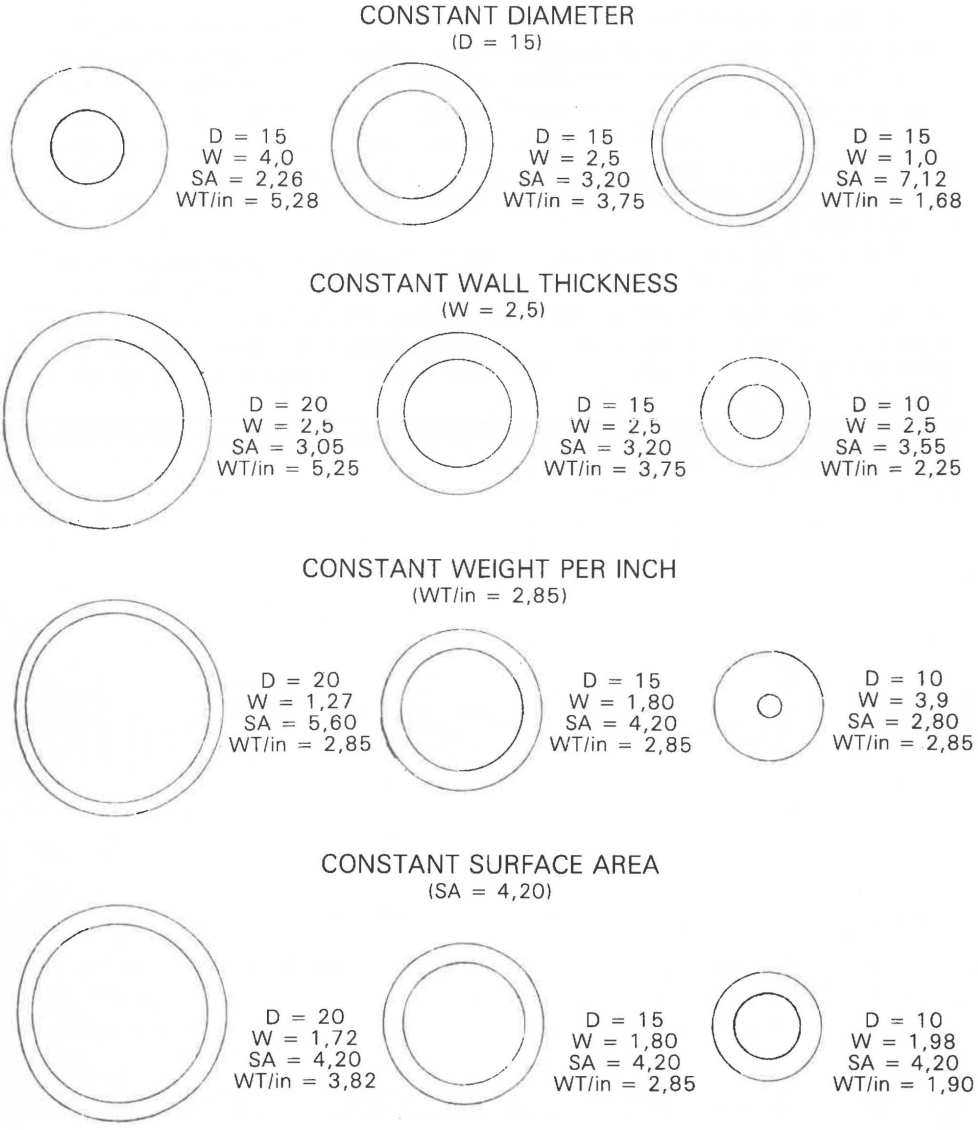


FIGURE 22

Effect of holding one fibre measurement constant and varying others[335]

TABLE 41

CROSS-SECTIONAL PARAMETERS OF SEVERAL COTTON VARIETIES[336]

Sample variety	Area (A), μm^2	Perimeter (p), μm	Axis for ellipse		b/a	C*
			Major (a), μm	Minor (b), μm		
"Karnak"	112,2	44,5	9,3	3,9	0,42	0,71
Unknown (Egyptian)	127,9	47,9	9,9	4,1	0,41	0,70
"Carolina Queen"	153,8	52,0	10,7	4,6	0,43	0,72
"Acala"	159,1	51,0	10,3	4,9	0,48	0,77
"Deltapine"	161,6	53,2	11,0	4,7	0,43	0,72
"Lockett"	196,9	59,6	12,3	5,1	0,41	0,70
"Nankeen"	197,2	59,4	12,2	5,2	0,43	0,70
Unknown (Indian)	263,9	64,4	12,9	6,5	0,50	0,80
"Garo Hill"	312,1	75,7	15,7	6,4	0,41	0,68
Unknown (Chinese)	346,7	77,1	15,8	7,0	0,44	0,73
Least significant difference	26,8	4,25	1,06	0,58	0,07	

*$C = 4\pi A/p^2$ after Skau[337], a measure of circularity

Swelling by mercerising for instance, causes the fibre to approach a circular cross-section[338]. Also, because of the structure of the primary wall, fibre perimeters are constrained during swelling. Cotton swollen by various agents, increases in area and approached circularity but tends to maintain a constant perimeter[338]. In water a cotton fibre swells about 25% in cross-sectional area[339] and shrinks about 2% in length[340].

Caustic concentration affects fibre circularity and cross-sectional area but shows little effect upon perimeter[336]. Caustic concentrations above a certain amount have little or not effect on fibre area and perimeter but significantly alter fibre circularity as measured by the two techniques. If tension is applied during swelling, a significant decrease in perimeter can be produced. The tension restricts the area increases and contributes to enhanced fibre circularity[336].

TABLE 42

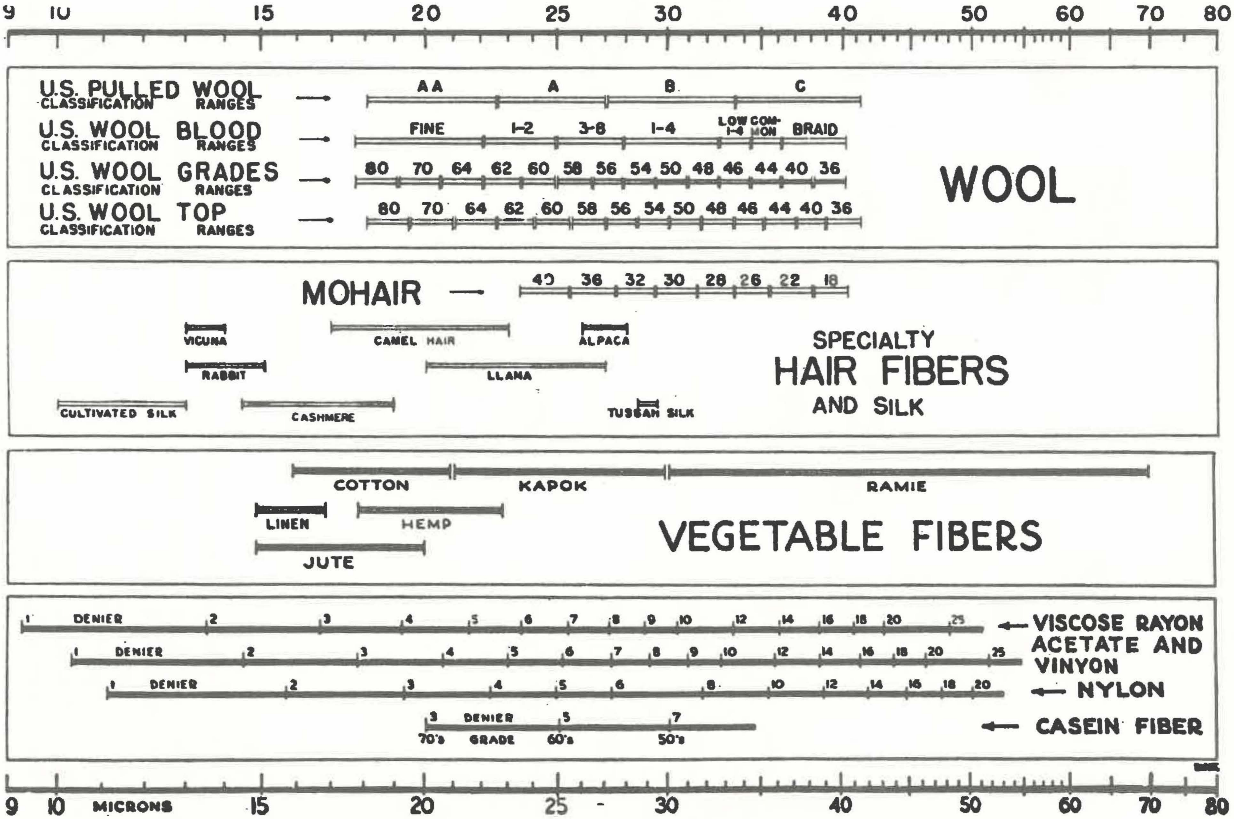
COTTON FIBRE SHAPE CATEGORIES[341]

Fibre Shape Category	Area Ratio ($4\pi d/p^2$)	Axis Ratio (minor/major axis)
Roundish	greater than 0,8	0,5 to 1,0
Elliptical	0,5 to 0,8 incl	0,22 to 0,5
Linear (flat)	less than 0,5	less than 0,22

The finess[342] of various fibres is compared in Table 43.

TABLE 43

COMPARATIVE SCALE FOR FINENESS OF VARIOUS TEXTILE FIBRES[342]



In the following figure the finenesses of some fibres are compared as well:

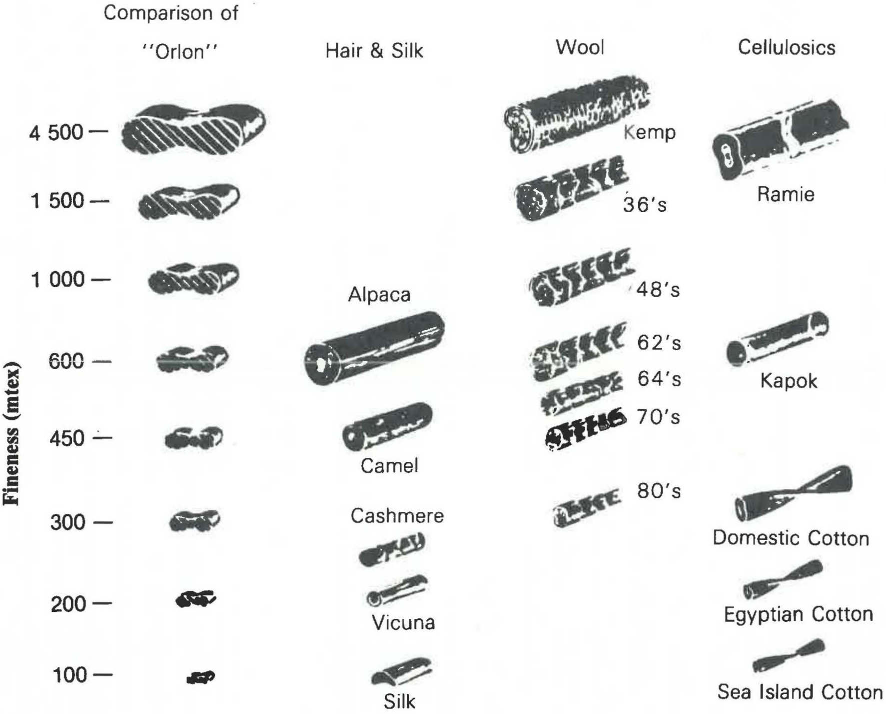


FIGURE 23

Comparison of Orlon Acrylic Fibre with Other Fibres[343]

FIBRE STRENGTH

General

Fibre strength is of paramount importance in both ring- and rotor-spun yarns[344]. The zero-gauge bundle (or Pressley) test is the most common for assessing the strength of cotton although it is generally accepted that the 3,2 mm (⅛″) gauge test is a more reliable indicator of carded and combed yarn strength[59, 240, 345–347]. It is therefore not surprising that this test is increasingly being used, particularly in systematic studies of the relationship between fibre and yarn properties. All other factors being constant rotor yarn strength is directly related to the cotton fibre strength[344].

It appears that often 70% or more of the changes in ring- and rotor-spun yarn strength are explained by the 3,2 mm (⅛") gauge strength[345].

Stronger cottons tend to produce fewer end breakages during spinning, the effect being larger for finer and low twist yarns[197].

The cotton classer's subjective strength ratings agree better with 5 mm-gauge tests than with zero-gauge tests, the former are also regarded as a better measure of tyre-cord and woven fabric strengths[348].

Some typical stress strain curves are given below and illustrate the differences between the different fibres and the effects of tension and slack mercerisation in caustic soda on the fibre tensile properties[349].

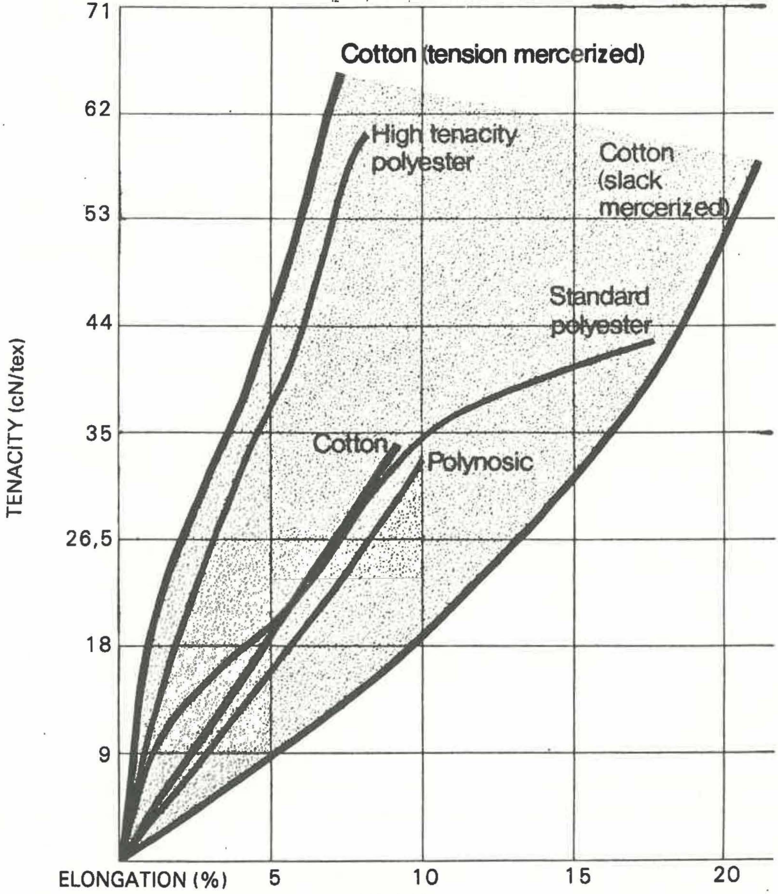


FIGURE 24

Fibre tensile properties. Note that slack-mercerised and tension-mercerised cottons form two extremes between which fall the tensile properties of the other fibres shown[349]

Because of the inherent variability of the cotton fibre it is rather time consuming to carry out single fibre strength tests and it is therefore far more common to measure the tenacity of a bundle of parallel fibres at either zero-gauge (i.e. the jaws of the tester not separated) or the jaws separated by ⅛″ (3,2 mm). For this purpose either the Pressley or Stelometer testers are used with the values always corrected to a common (international) level by using standard cotton samples supplied by the United States Department of Agriculture. On average, the Pressley tester gives values which are about 16% higher (10 to 15% has also been mentioned)[350, 351] than those obtained on the Stelometer[350]. A difference of 14% was observed in special test checks[351]. It must be emphasized though that the use of calibration or standard cottons should eliminate such differences and it is important always to use calibration (standard) cotton samples. All the results are adjusted to the Pressley level by means of the USDA calibration samples and when a zero-gauge is used the results are generally given as Pressley in 1 000 psi regardless of which instrument is used.

Bundle tenacity and extension values are correlated with single fibre results[352].

Various ways of expressing the fibre tenacity are used (see Part II of this series) some of which are discussed below.

Bundle tenacity tests:

$$\text{Pressley Index} = \frac{\text{bundle strength in (lbs)}}{\text{bundle mass (in mg)}} = \text{strength-weight ratio}$$

Pressley (commercial in 1 000 psi) = Pressley Index x 10,812 − 0,12
To convert Pressley (in 1 000 psi) to cN/tex multiply by 0,486.
Strength-weight ratio = Pressley (in 1 000 psi) x 0,0925
= (cN/tex) x 0,190

$$\text{for } ⅛'' \text{ (3,2 mm) gauge: cN/tex} = \frac{\text{breaking load in kg x 14,7}}{\text{bundle mass in mg}}$$

In one publication[353] it was stated that cotton tenacity at zero-gauge (in cN/tex) = 0,454 x Pressley (in 1 000 psi). The conversion factor of 0,486 normally used is to bring the values into line with those obtained on a Chandler tensile tester.

Tenacity tests carried out at ⅛″ (3,2 mm) gauge are more highly correlated with spinning tests[2, 198]. There is a correlation between such tenacity results and fibre length[198], the longer cottons being stronger. The Pressley Index varies from about 7 for weak cottons to 11 or more for the very strong cottons[2].

For ⅛″-gauge (i.e. 3,2 mm) tests, the strength/mass ratio (i.e. lbs force divided by bundles mass in mg) is called the Pressley *ratio* and, based upon the average ratio of 3,19 obtained for the U.S.A. Crop in 1954, an index can be calculated as follows for a particular cotton[2].

$$\frac{\text{Pressley ratio}}{3{,}19} \times 100$$

If this index is 100 the cotton equals the average for 1954; if it is below 100 the cotton is below average, etc. In one investigation[2] it was found that the strength of cotton at a gauge length of 4 mm was 42 to 55% lower than when tested at a zero gauge length.

Cottons have been graded as follows[354]:

TABLE 44

Grading of Cotton according to Pressley (in 1 000 lbs/inch)[354]

Pressley (1 000 psi)	*Classification*	*cN/tex*
< 70	weak	< 34
70 to 74	unsatisfactory	34 — 36
75 to 80	average	36,5 — 39
81 to 86	strong	39,5 — 42
82 to 92	very strong	42,5 — 45
> 93	excellent	> 45

(0-gauge)

The following USDA classification has been given[198]:

TABLE 45

CLASSIFICATION OF COTTONS IN TERMS OF BUNDLE TENACITY[198]

Staple length group and descriptive designation	Zero-gauge strength		⅛" gauge strength	
	(thousands psi)	cN/tex	gf/tex	cN/tex
Short staple:				
Low	75—79	36,5—38	18—19	17,5—18,5
Average	80—84	39—41	20—21	19,5—20,5
High	85—89	41—43,5	22—23	21,5—22,5
Medium staple:				
Low	74—80	36—39	19—21	18,5—20,5
Average	81—87	39,5—42,5	22—24	21,5—23,5
High	88—94	43—45,5	25—27	24,5—26,5
Long staple:				
Low	77—83	37,5—40,5	20—22	19,5—21,5
Average	84—90	41—43,5	23—25	22,5—24,5
High	91—97	44—47	26—28	25,5—27,5
Extra-long staple:				
Low	95—98	46—47,5	29—31	28,5—30,5
Average	99—102	48—49,5	32—34	31,5—33,5
High	103—106	50—51,5	35—37	34,5—36,5

Data source: 317 short staple, 1 565 medium staple, 194 long staple and 100 extra-long staple lots of cotton tested from the crops of 1971—75.

Cotton fibre strength is inversely related to yield[355], it being claimed that, for a particular seed, the product of the "amount of cellulose and the specific fibre strength" is a constant[356].

It has been claimed[53] that to the extent that all commercial cottons are known to have nearly the same crystallinity, cellulose content, degree of polymerisation, spiral angle, etc., all cottons can be postulated to have the same "ideal breaking strength". The differences in the observed strength of different cottons can possibly be attributed to morphological and structural differences such as convolution angles, reversals, molecular orientation, etc. Hearle and Sparrow[318] recently reviewed the relationship between fibre structure and tensile properties.

Cotton fibre breaking stress and elastic modulus are correlated with the fibre cross-sectional area[59]. Immature cotton fibres sometimes have a lower intrinsic strength than mature cotton[48].

Nolen[236] used the following formula to derive a cotton single fibre strength index from bundle strength.

Fibre Strength index = $4{,}29 \times 10^{-5} \times$ Pressley x micronaire

where Pressley is in thousands of pounds per square inch.

He states that the index so calculated gives a good indication of the nepping potential of a cotton.

Cotton fibre strength appears to have little effect on processing efficiency including spinning[357—360].

Higher strength cottons produce stronger singles and two-ply yarns[360] but cotton fibre strength does not influence the amount of twist required for maximum yarn strength. Fibre strength does not affect sliver, roving and yarn evenness nor yarn extension at break[360]. Blending cottons differing in strength affects yarn strength but not spinning limits. Blending, within practical limits, can be carried out without serious disadvantages[173]. Fibre strength is regarded more important than fibre length in determining yarn strength[57].

In one report[361] it was stated that, at optimum twist, fibre strength accounts for about 88% of the variation in yarn strength. In another study it was reported[344] that, if micronaire is held constant, some 96% of the variation in rotor (OE) yarn strength can be accounted for by zero-gauge bundle tenacity.

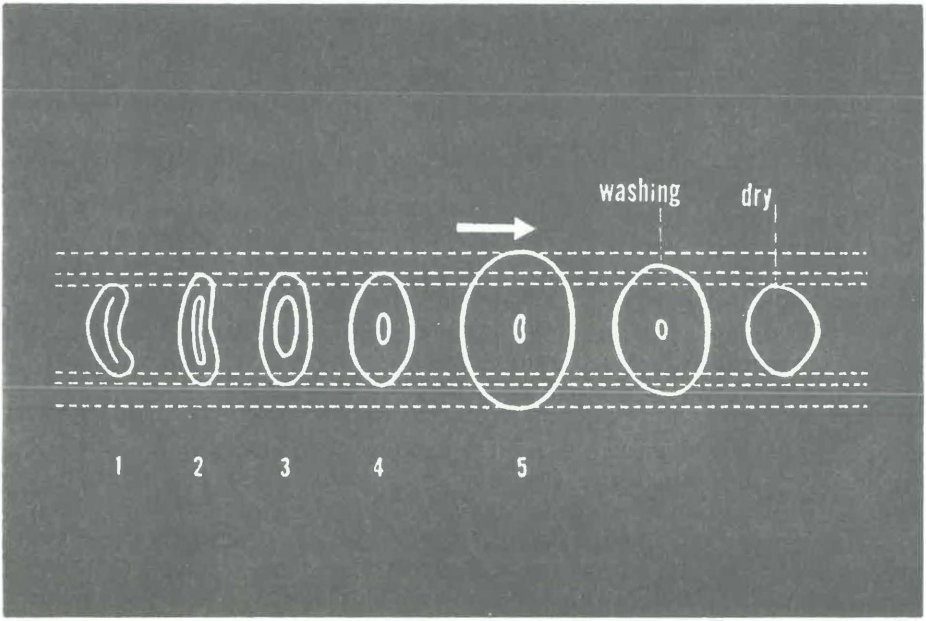
Stronger cottons produce stronger knitted fabrics, whereas finer cottons produce stronger yarns but not necessarily stronger fabrics[362]. In a study on woven print cloth the following conclusions were drawn[363]. The strongest cotton produced the strongest fabrics in the warp direction (grey, bleached and dyed) but this did not hold in the weft direction for the bleached and dyed fabrics. Fabric extension at break appeared to be influenced more by mechanical treatment during chemical processing than by fibre properties. Fabric tear strength was correlated with bundle tenacity at zero-gauge. Fibre strength hardly affected abrasion resistance. Bundle strength (5 mm) also affects strength of resin treated cotton fabrics[364].

SOME EFFECTS OF MERCERISATION

The changes occurring in the cotton fibre during mercerisation are more physical than chemical in nature[365]. The most obvious changes are greater lustre, greater strength and improved dye affinity. During mercerisation the cotton fibre untwists and assumes a more circular shape. The lumen swells and is almost closed. A mercerised fibre is more like a straight rod than a flattened, twisted ribbon[365].

During the mercerisation process, proper tension must be applied. Otherwise, swelling will occur but the amount of untwisting will be greatly reduced. The entire process, consisting of impregnation, neutralisation and washing-off, must be one continuous operation for optimum results. Tension must be uniform and consistent until washing-off is completed. Low tension can cause a loss of lustre[365].

The effect of mercerisation on cotton fibre shape is illustrated below[365]:



1. Untreated cotton fibre as it enters mercerizing range.
2. Caustic impregnation — small change occurs in physical form.
3. Greater change occurs with time.
4. Neutralization — more change occurs.
5. Caustic wash-off — fibre has become round, hollow centre is almost closed.
6. Some shrinkage occurs upon further washing.
7. More shrinkage occurs during drying.

FIGURE 25

Effect of mercerisation on cotton fibre shape[365]

The density of mercerised cotton is nearly the same as that of the native cotton[366]. Mercerisation reduces the effect of weak places in cotton fibres[367]. It appears that cottons with low maturity and low strength uniformity ratios (i.e. ⅛" gauge to zero-gauge tenacity ratios) benefit most in strength as a result of mercerisation[368, 369].

High-maturity cottons, having a high strength-uniformity ratio, show a reduction in zero- and ⅛"-gauge tenacity upon slack mercerisation, irrespective of the cultivar[370]. There appears to be a negative correlation between strength uniformity ratio and tenacity ratio (i.e. mercerised to unmercerised tenacities), the higher the former the lower the latter[370].

FIBRE ELONGATION

Bundle extension of cotton is positively correlated with fibre diameter and negatively correlated with fibre wall thickness[371]. Extension appears to be a function of the cotton spiral angle. Most commercial cottons vary in bundle extension between 6 and 9% which could correspond to the 20 to 23° range of spiral angles for such cottons[371].

Yarn elongation is related to fibre elongation, usually measured on a Stelometer at 3,2 mm (⅛") gauge[59, 197, 372—374]. The degree of correlation is affected by the yarn linear density and twist and by the fibre length[373, 375].

Fibre elongation has no major effect on processing prior to spinning but affects end-breakages during spinning slightly[376]. For medium staple cottons an increase in fibre elongation from 6 to 10% allows an increase of 1 000 rev/min in spindle speed for medium yarns[197]. Higher fibre elongation results in higher greige fabric elongation but after finishing the effect largely disappears[377].

Blending cottons differing essentially only in bundle elongation affected combed yarn strength and extension[375] but no definite trends in spinning performance could be detected. Bundle elongation of the blended fibres was lower than the arithmetic averages. Improvements in yarn elongation may be obtained by selection of cottons with the required elongation[375]. Higher elongation cottons form more neps, however.

Louis *et al*[375] found that the tenacity and elongation of single combed yarns were related to the cotton fibre elongation, with the fibres which were less stiff and had higher elongations tending to form more neps.

In one study bundle elongation did not affect nep formation or sliver evenness but was reflected in fibre hook reduction. The higher elongation cotton spun better than the lower elongation cotton, particularly at low twists and for fine yarns, hence higher spindle speeds could be used. Fibre tensile stiffness and toughness were directly related to the equivalent yarn properties[376]. An increase in fibre bundle elongation increased both single thread strength and elongation[376].

The *fibre bundle elongation* results obtained on the Stelometer are usually multiplied by 0,8 to allow for slippage and these are the values actually quoted. The following classification applies to American Upland lots[198].

Descriptive designation	*Fibre elongation (%)*
Very low	5,2 and below
Low	5,3 — 6,1
Average	6,2 — 7,0
High	7,1 — 7,9
Very high	8,0 and above

Data source: 2076 American Upland lots tested from the crops of 1971—75.

STIFFNESS AND COMPRESSIONAL PROPERTIES

Often the ratio of fibre tenacity to fibre elongation (either bundle or single fibre) is taken as a measure of the stiffness of cotton fibres, i.e.

$$\text{Average fibre tensile stiffness} = \frac{\text{Breaking Tenacity}}{\text{Breaking Elongation}} \times 100$$

$$\text{Toughness index} = \frac{\text{Breaking Tenacity} \times \text{Breaking Elongation}}{200}$$

For fibres approximately equal in maturity, differences in nep formation can be related to differences in fibre stiffness. Stiffer fibres form fewer neps[375], during carding.

The bulk compressibility and resilience of cotton fibre and their importance have been discussed in various articles[378, 379]. Rees found values for the compressional resilience of cotton of the order of 37 to 39 while that for 70's wool was 56[378].

Temperature and humidity have pronounced influences on fibre rigidity or stiffness to bending. At room temperature the rigidity of a cotton fibre is six times as great in dry air as in a water-saturated atmosphere; at constant

TABLE 46

TORSIONAL RIGIDITIES OF VARIOUS COTTON FIBRES[46] (AFTER PEIRCE)[381]

Varieties	Rigidity*	
	Pa (N/m²)	dynes/cm²
Sea Island	0,001 to 0,002	0,010 to 0,021
Egyptian nubarri	0,0024	0,024
Egyptian affifi	0,0032	0,032
Peruvian hybrid	0,0063	0,063
Trinidad native	0,0045	0,045
Upland Memphis	0,0039	0,039
American	0,0061	0,061
Upland	0,0045	0,045
Permams	0,0071	0,071
Indian Bharat	0,0111	0,111

*The rigidity of the fibre is the torque, or twisting force, in the fibre when one cm is subjected to one complete twist.

The single fibre bending recovery plus a small frictional restraining couple ($\simeq$ 4%) give a good indication of the crease recovery of cotton fabrics[382] moisture regain, rigidity decreases as temperature rises. The cotton fibre is about one-tenth as rigid a structure as a glass fibre of similar dimensions. Farrow[380] showed that the initial modulus of a cotton fibre decreased by one-third upon wetting. Peirce[381] found that mean rigidities of cottons range from 0,010 to 0,111 dyne/cm² and tabulated values for different varieties[46] (see Table 46).

The high rigidity of thick-walled fibres suggests why coarse cottons must be more highly twisted than fine cottons to produce yarns of the same size[46, 381]. The greater the cell-wall thickness of a cotton fibre, the greater its flexural fatigue life, the latter also increasing with an increase in work-of-rupture[383]. Flexural-fatigue life is increased by slack mercerisation because of an improvement in fibre uniformity and the removal of many weak places in the cotton fibre[383].

FIBRE FRICTION

Examples of typical data obtained for cotton fibre friction are shown below[384]. Some values (where it appears feasible) were added by using the ratio

TABLE 47

FRICTIONAL COEFFICIENTS OF COTTON MEASURED BY VARIOUS INVESTIGATORS[384]

Investigator	Normal Force (cN)	μ_s	μ_k	Comments
Morrow		0,396+	0,220	1931, Pads++
Mercer & Makinson	0,17—0,18	0,570	0,316+	1947
Krowicki		0,452+	0,249	Deltapine 1960 Rotating Incl. Plane.
McBride	0,026	0,540	0,300	Empire WR 1965
Viswanathan	0,020	0,587	0,327	1966, Fringes
Bryant	0,020	0,523	0,290	Empire WR 1966
Levy	0,020	0,500	0,275	Empire WR Bale 1966
Gunther	0,020	0,590	0,240	Empire WR 1966
Belser	0,020	0,520	0,271	High Draft 1967
Belser	0,020	0,496	0,243	Low Draft 1967
Cromer	0,020	0,490	0,250	Empire WR 1968
Whitworth	0,020	0,453	0,225	Pima Menoufi Comber Lap
Whitworth	0,020	0,386	0,173	Comber Noil 1967

μ_s = Static coefficient of friction; μ_k = Kinetic coefficient of friction
\+ = Values were determined by calculation from only one value cited using μ_s/μ_k
++ = All crossed pairs of single fibres unless noted.

TABLE 48

FRICTION MEASUREMENTS BETWEEN FIBRES OF DIFFERENT MATERIALS[384]

Normal Force (cN)	μ_s	μ_k	μ_s/μ_k	No. of Measurements Averaged
	Cotton Against Nylon[+]			
0,002	1,06	0,36	2,92	29
0,005	0,68	0,25	2,69	29
0,010	0,67	0,25	2,68	20
0,0195	0,60	0,24	2,56	29
	Cotton on Glass			
0,002	0,93	0,29	3,17	38
0,005	0,67	0,23	2,89	29
0,010	0,56	0,18	3,07	49
0,0195	0,53	0,16	3,32	29
	Nylon on Glass			
0,0022	0,59	0,29	2,19	9
0,0055	0,59	0,26	2,10	9
0,0100	0,49	0,21	2,34	59

[+] Nylon was 16,7 dtex; cotton was Empire WR; glass fibre diameter was not recorded.

μ_s/μ_k as 1,80 for comparison purposes. These values are marked with an asterisk[384].

Although values of the coefficients of friction determined are not absolute due to the many variables encountered, the general frictional behaviour of fibres was outlined in the article and data giving a better insight into free fibre behaviour has been presented[384]. Dewaxing increases cotton fibre friction.

Strong cottons tend to have low shear frictional values. Shear friction is also correlated with fibre fineness, tenacity, length and stiffness, etc[385]. Cottons with low shear frictional values were found to give better running performance.

To card a fibre efficiently, the fibre should have a low shear friction and a high recovery from compression[386]. These properties enable it to transfer easily from cylinder to doffer, thereby reducing the cylinder load and providing good carding action[386].

In one study a second degree quadratic equation was fitted to the minimum twist of cohension vs fibre friction results[387].

Some fibre properties are given below for a few different cottons[388].

TABLE 49

COTTON FIBRE PROPERTIES[388]

Variety	Friction	2,5% Span Length (mm)	Fineness A (mm)$^{-1}$	Immaturity D (mm)$^{-1}$	Tenacity ⅛" gauge (cN/tex)	Elongation (%)
Deltapine Smooth Leaf	0,566	29,2	458	35	18,7	9,0
Stoneville 7A	0,555	29,2	488	46	17,2	7,3
Lankart 57	0,629	25,1	552	64	16,1	8,7
Cal-7-8	0,540	27,2	446	28	21,7	6,2
Acala 4-42	0,552	28,2	516	48	21,4	7,8
Pima S-2	0,520	34,5	495	34	29,7	9,0

Rapid changes in cotton fibre frictional properties occur above 65% RH and is partly responsible for the increased end breakages observed during spinning[384, 388]. The poor spinning performance of cotton at high relative humidity (> 65% RH) is partly explained by the following typical curve[389].

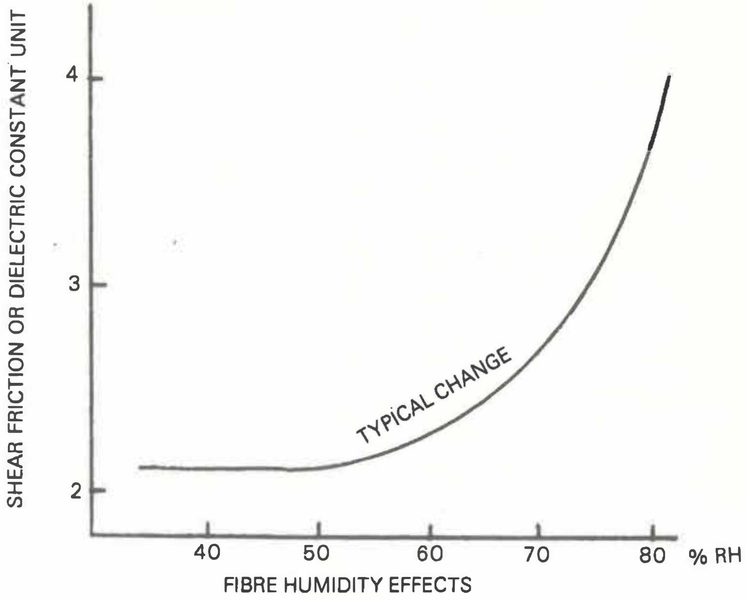


FIGURE 26

Effect of relative humidity (RH) on shear friction and dielectric constant[389]

Frictional values increase with processing up to the carding stage (possibly due to fibre damage) after which it decreases again[384]. Processing tends to smooth the cotton fibres and remove damaged ones, thereby reducing the average fibre friction[384].

In one paper a correlation between fibre friction and convolution angle was found[390].

GENERAL FIBRE PROPERTIES

The following tables give some general fibre characteristics for various cottons.

TABLE 50

FIBRE CHARACTERISTICS OF VARIOUS COTTONS[213] (AFTER LORD, 1962)

Cotton	Effective Length		Maturity ratio (M)	Fibre Linear Density H (mtex)	Standard hair mass or linear density H_s (mtex)	Tensile Strength at zero-gauge S (cN/tex)
	32nd in.	mm				
Sea Island St Vincent V.135	62	49	0,92	108	117	54
Egyptian						
Karnak EX	49	39	0,97	116	120	53
Sakel GS	50½	40	1,01	141	141	50
Ashmouni FG	38	30	0,97	187	193	43
American Upland I						
USA 11/8th SM/GM	41	33	0,90	185	205	40
Uganda BP 52	41	33	0,84	139	166	39
Tanzania CLA	38	30	0,82	153	186	41
Tanzania MZA	38	30	0,83	166	201	38
Nigeria NA 1	36	29	0,84	177	211	40
American Upland 2						
USA 15/16th M	33	26	0,90	219	243	39
Indian						
Bengals	25	20	1,05	336	320	37

TABLE 51

SOME COTTON FIBRE PROPERTIES[391]

ID Code	Cultivar	Span Length (mm)		Micronaire	Bundle Test (1/8" gauge)		Toughness index** (cN/tex)	Stiffness* (cN/tex)
		2,5%	50%		Tenacity (cN/tex)	Ext. (%)		
A	Acala S-J 1	30,2	13,7	4,4	22,2	7,5	0,83	296,0
B	Deltapine 16	29,0	12,4	4,3	18,1	10,0	0,91	181,0
C	Rilcot 90	22,9	9,9	3,1	16,9	8,5	0,72	198,8
D	Brawley 70-118	27,2	12,2	4,5	21,2	5,5	0,58	385,5
E	Pima S-4	34,3	15,0	3,9	23,9	10,4	1,24	229,8

Samples A, B, C and D are G. hirsutum L., and sample E is G. barbadense L.

$$*\text{Stiffness} = \frac{\text{Tenacity}}{\text{Extension}} \times 100 \qquad **\text{Toughness} = \text{Tenacity} \times \text{Extension} \times 0{,}005$$

The relationship between strength and length is illustrated on next page for American Upland Cotton[392] (read Figure 27 in conjunction with Table 52).

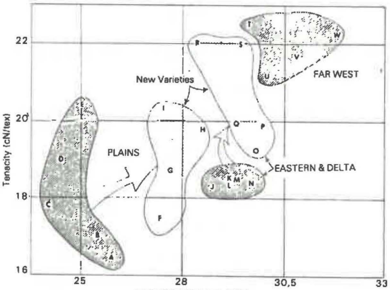


FIGURE 27

Cotton quality improvement in 23 American Upland varieties[392]

TABLE 52

		2,5% Span Length		Strength T_1 (cN/tex)	Source of Data*
		(mm)	(in.)		
A	Lankart 57	26,2	1,03	16,1	P
B	Northern Star 5	25,9	1,02	16,7	P
C	Paymaster 54B	24,6	0,97	17,4	P
D	Paymaster 101A	24,9	0,98	18,6	P
E	Gregg 35	25,4	1,00	20,0	P
F	Lockett 4789	27,4	1,08	17,1	PQ
G	Paymaster 111	27,7	1,09	18,4	PQ
H	Dunn 56C	28,4	1,12	19,4	PQ
I	Tamucot	27,4	1,08	20,0	PQ
J	Stoneville 213	28,7	1,13	17,9	D
K	Deltapine Smooth Leaf	29,2	1,15	18,1	D
L	Deltapine 45A	29,2	1,15	18,1	D
M	Coker 201	29,2	1,15	18,1	D
N	Deltapine 16	29,7	1,17	18,1	D
O	Stoneville 508	29,7	1,17	18,9	HQ
P	Coker 413	30,0	1,18	19,5	HQ
Q	TH-149	29,2	1,15	19,6	HQ
R	Atlas 67	28,2	1,11	21,7	HQ
S	SC-1	29,5	1,16	21,7	HQ
T	Hopicala	29,5	1,16	22,0	W
U	Acala SJ-1	30,0	1,18	20,8	W
V	Acala 1517D	30,7	1,21	21,3	W
W	Acala 1517V	31,8	1,25	21,9	W

*Results of 1967 Regional Cotton Variety Tests, ARS 34—105

P = Plains
D = Delta
W = Western
PQ = Plains Quality
HQ = High Quality

TABLE 53

MICRONAIRE AND ZERO-GAUGE STRENGTH FOR SOUTH AFRICAN GROWN COTTONS[393]

Locality	Characteristic	Clarcot C.S.2	Del Cerro	Acala 1517-70	Albar C900	Caroline Queen	Acala SJ1	Acala 1517-BR1	Cape Acala	Albar 637
Upington	Micronaire index	4,6	4,3	4,3	5,4	4,8	4,7	3,9	4,3	5,3
	Strength : Mpsi	94	110	101	91	93	88	97	101	96
	cN/tex	45,6	53,5	49,1	44,2	45,2	42,8	47,1	49,1	46,7
Oudtshoorn	Micronaire index	4,8	4,3	4,5	5,5	5,0	5,0	4,6	4,5	5,6
	Strength : Mpsi	96	111	106	94	88	99	94	96	102
	cN/tex	46,7	53,9	51,5	45,7	42,8	48,1	45,7	46,7	49,6
Vaalhaarts	Micronaire index	4,4	3,5	3,8	5,1	3,8	3,5	3,1	3,8	5,3
	Strength : Mpsi	82	100	95	88	78	85	91	88	91
	cN/tex	39,9	48,6	46,2	42,8	37,9	41,3	44,2	42,8	44,2
Komatipoort	Micronaire index	3,6	3,6	3,6	4,3	3,5	4,0	3,5	3,1	4,3
	Strength : Mpsi	76	99	92	82	82	80	88	81	81
	cN/tex	36,9	48,1	44,7	39,9	37,9	38,9	42,8	39,4	39,4
Barberton (dryland)	Micronaire index	3,6	3,4	3,3	4,2	4,1	3,3	4,0	3,4	4,5
	Strength : Mpsi	84	101	90	86	79	84	82	82	87
	cN/tex	40,8	49,1	43,7	41,8	38,4	40,8	39,9	39,9	42,3
Groblersdal	Micronaire index	5,1	4,5	4,5	5,6	5,1	4,6	4,4	4,2	5,6
	Strength : Mpsi	88	100	91	86	81	82	82	88	84
	cN/tex	42,8	48,6	44,2	41,8	39,4	39,9	39,9	42,8	40,8

Van Heerden and Cronje[393] gave the above table for South African grown cottons. More up to date information was published recently[394].

TABLE 54

FIBRE PROPERTIES OF SELECTED WORLD COTTONS[18]

Country and variety	Staple Length		Micronaire	Zero-gauge Tenacity	
	(in.)	mm		(000 lbs.)	cN/tex
Egypt					
Giza 30	1,19	30,2	4,3	92	45
Karnak	1,36	34,5	4,0	103	50
Ashmouni	1,04	26,4	4,7	90	44
Menoufi	1,33	33,8	4,0	98	48
Zagora	1,06	26,9	4,7	88	43
Mexico					
Laguna	1,07	27,2	4,0	76	37
Torreson	1,05	26,7	4,0	76	37
Matamoras	1,02	25,9	4,2	83	40,5
Sonora	1,06	26,9	4,4	81	39,5
Mexicali	1,10	27,9	4,3	91	44,5
Brazil					
North	1,02	25,9	3,9	82	40
South	0,95	24,1	4,0	74	36
Peru					
Pima	1,46	37,1	3,4	94	46
Tanguis	1,25	31,8	4,7	86	42
Acala	1,06	26,9	3,4	82	40

Country and variety	Staple Length		Micronaire	Zero-gauge Tenacity	
	(in.)	mm		(000 lbs.)	cN/tex
Pakistan					
289F	0,96	24,4	4,5	95	46,5
NT	0,97	24,6	4,8	91	44,5
Azad	0,90	22,9	4,8	79	38,5
4F	0,82	20,8	5,3	85	41,5
LSS	0,85	21,6	5,0	87	42,5
Sind Desi	0,70	17,8	7,3	78	38
India					
Oomra	0,70	17,8	6,3	65	31,5
Bengal Desi	0,64	16,3	7,6	71	34,5
Dhollera	0,80	20,3	5,4	77	37,5
Gaorami	0,86	21,8	5,1	92	45
Vijay Broach.	,88	22,4	4,9	92	45
Jarilla	0,82	20,8	5,6	88	43
Sudan					
American	1,31	33,3	4,2	89	43,5
Egyptian	1,30	33,0	3,8	98	48
Short	0,90	22,9	3,1	86	42
U. States					
Arizona 44	1,09	27,7	4,3	85	41,5
Calif. 4-43	1,11	28,2	4,0	85	41,5
DPL 15	1,08	27,4	4,4	82	40

Turkey						**U. States**					
Izmir	1,06	26,9	4,0	80	40	1517C	1,13	28,7	3,8	87	42,5
Adana	1,03	26,2	4,1	92	45	Rowden	0,98	24,9	5,5	86	42
						Coker					
						100W	1,06	26,9	4,4	80	39
French W.						Stoneville					
Africa						2B	1,07	27,2	4,3	80	39
Allen	1,03	26,2	3,6	82	40	Empire	1,07	27,2	4,3	80	39
Mebane T.	0,97	24,6	4,4	80	39	Lankart 57	0,95	24,1	4,0	79	38,5
						Paymaster	0,95	24,1	3,8	69	33,5
						Hibred	0,85	21,6	4,8	79	38,5
						Lockett 140	0,83	21,1	5,0	83	40,5
						Pima S-1	1,42	36,1	3,5	100	49
Iran						**Syria**	1,03	26,2	4,4	84	41
Coker	1,03	26,2	4,1	83	40,5						
American	0,97	24,6	5,1	78	38	**Russia**	1,09	27,7	5,0	83	40,5
Lating	1,10	27,9	3,6	78	38						
Filestani	1,05	26,7	4,3	82	40	**Belg.**					
Paraguay						**Congo**	0,97	24,6	3,6	75	36,5
DPL 12	1,04	26,4	4,1	77	37,5	**Uganda**	1,15	29,2	3,6	82	40
American	0,97	24,6	3,8	81	39,5	**Iraq**	1,04	26,4	3,7	86	42
West Indies						**Greece**	1,03	26,2	4,2	80	39
Sea Island	1,73	43,9	3,0	100	49	**Tanganyika**	1,06	26,9	4,0	82	40
Sans Salvador	1,06	26,9	4,2	71	34,5	**Nicaragua**	1,05	26,7	4,0	73	35,5
Argentina	0,96	24,4	3,7	78	38	**Guatemala**	1,06	26,9	3,9	74	36

Source: *Fibre Properties and Related Marketing Data for Selected World Cotton* (Research Report No. 41. Austin: Cotton Economic Research, The University of Texas 1956).

TRASH AND NON-LINT CONTENT

Cotton grade is determined subjectively by a composite rating of colour, foreign matter and ginning preparation[18]. Foreign matter is referred to as the kinds and amount of leaf, pieces of burrs, bracks, dirt, etc. This constitutes non-lint in lint cottons. The nature of the trash may be as important as its mass in determining grade[198]. Ginning preparation refers to whether the fibres have been damaged or entangled during ginning. Character includes those fibre properties which are not included in either grade or staple length. Generally recognised as components of character are fibre strength, maturity, fineness, spirality and drag. Terms usually used to describe character are hard, normal, soft , weak and perished[18].

During harvesting and ginning, cotton seeds are broken to a lesser or greater degree depending upon the severity of the mechanical action[395, 396]. Seed-coat fragments can adversely affect spinning and can also adhere to the crush rollers on a card[396, 397]. It is also believed[396] that cotton seed oil from seed-coat fragments and seed motes is related to sticking problems in processing.

The non-lint content of a cotton, particularly fine dust (micro-dust) has a particularly adverse affect on rotor (OE) spinning since it builds up in the rotor groove and causes interference with the yarn formation process and increases wear on machine parts. The deposit (dust) found in the rotor consists essentially of fragmented parts of the cotton plant and resembles the trash eliminated by the Shirley Analyser[398]. The hard trash removed during the second passage of cotton through a Shirley Analyser correlates very well with rotor deposit[398].

A seed-coat fragment may be defined as that part of a cotton seed that is broken from either a mature or immature seed during mechanical processing[397]. It is usually black or dark brown and may or may not have fibres or linters attached. A funiculus is the slender stalk of the growing seed by which it is attached to the placenta of the boll. Fragments larger than 5 mm in diameter are removed readily, almost none remaining after two lint cleaners. More than two lint cleaners, during ginning, are not recommended because fibre breakage offsets any slight cleaning effect[397].

Broken fragments of seed or shell can cause trouble in the fabric through the bleeding of colouring matter when wet with an alkaline liquor[399].

"Mote" is a whole undeveloped seed of any size or age, covered with fuzz and short fibres, certain of which bear mature lint fibres[198]. In one study[400] it was found that motes, i.e. seed fragments clinging to the fibres — constitute a major portion of the trash, accounting for 40—75% of the total. In general, the blow room machines preferentially removes impurities other than motes so that there is a progressive increase in the relative concentration of the motes. Different types of beaters vary in their trash extraction capability although the position of a given beater in the sequence of machines appears to be immaterial. At the card, there is a selective mote removal by the flats[400].

Nonlint (or trash) content of cottons is generally determined by means of the Shirley Analyser which separates the lint from the foreign matter[198]. For non-lint determination a 100 g cotton sample is generally passed twice through a Shirley Analyser.

The total non-lint values reported include both visible and invisible loss.

These results are distinguished from total picker and card waste in that practically no fibre is included, whereas textile mill wastes include appreciable amounts of fibre[198]. Test performed in previous years show the following average relationship of Shirley Analyser non-lint to grade[198].

TABLE 55

APPROXIMATE RELATIONSHIP BETWEEN GRADE AND NON-LINT

American Upland Grade	*Code*	*Average non-lint content (%)*
Strict Middling	21	1,8
Middling	31	2,2
Strict Low Middling	41	3,0
Low Middling	51	4,2
Strict Good Ordinary	61	5,4
Good Ordinary	71	6,7

Data source: 4656 American Upland Colour and Trash Survey samples tested from crops of 1971—1975.

The following scale has been developed to represent the average non-lint content for grades of American Pima cotton[198]:

TABLE 56

RELATIONSHIP BETWEEN AMERICAN PIMA GRADE AND NON-LINT

American Pima Grade	**Average non-lint content (%)**
2	2,4
3	2,7
4	3,5
5	4,3
6	5,8
7	7,3
8	9,6
9	10,6

Data source — 1329 American Pima-Color and Trash Survey Samples tested from the crops of 1971—1975.

Non-lint contents of cottons is correlated with grade, classer's length and micronaire[401].

Figure 34 illustrates results obtained by the USDA on about 200 samples drawn from nearly all the cotton producing countries, roughly in proportion to their output[281].

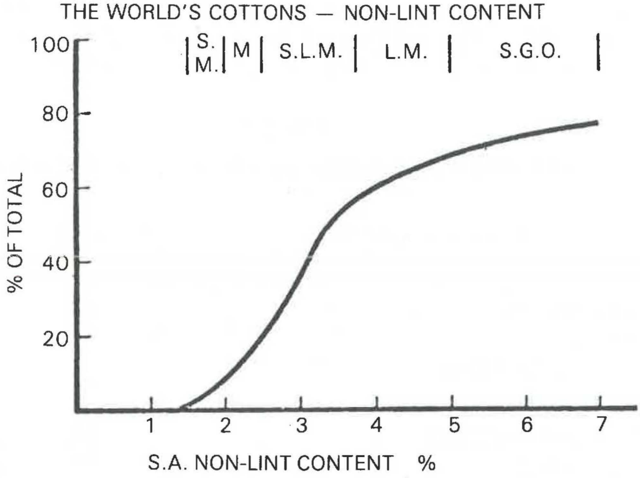


FIGURE 28

Cumulative frequency distribution of Shirley Analyser non-lint content of world cottons[281]

Shirley Analyser trash is also related to cotton grade in the following figure[402]:

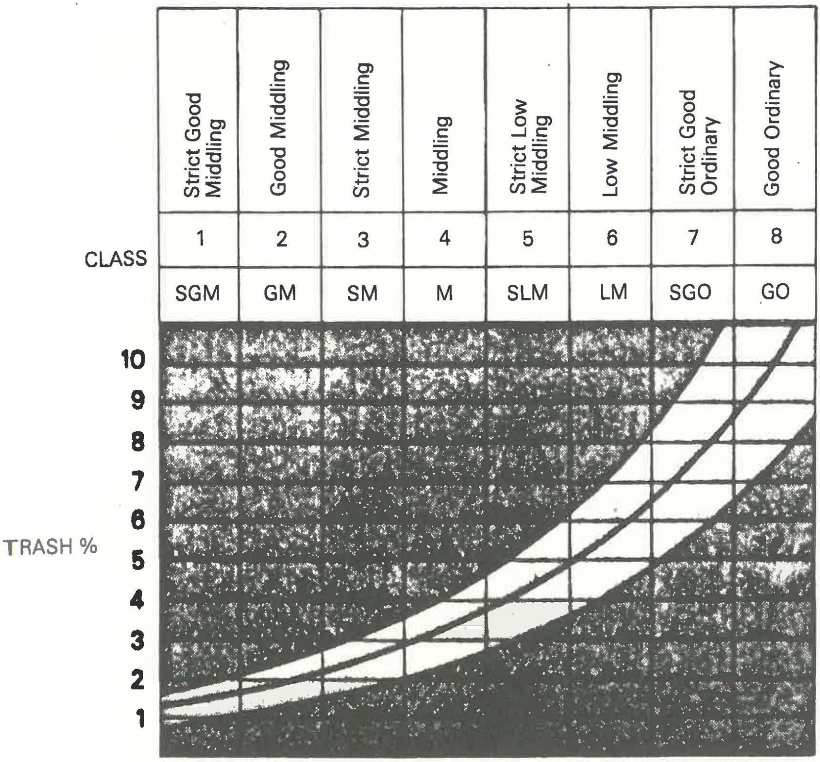


FIGURE 29

Average waste quantities as a function of the class of cotton[402] (Shirley Analyser)

From 1946, when there were no lint cleaners in cotton gins, to 1974, the non-lint content of SLM cotton dropped from 5,2 to 2,8% in spite of harvesting shifting to mechanical picking during this period[404]. The reduction has been ascribed primarily to lint-cleaners and better ginning[404]. In 1979 it was estimated that, in the U.S., some 99% of the gins had one or more stages of lint cleaning, and some 82% had two or more stages[403].

The subjective grade assigned by the classer has been compared with optically measured non-lint content and the following classification of the Universal Standards for American Upland Cottons has been arrived at[151].

TABLE 57

GRADE LIMITS BASED ON OPTICALLY MEASURED NON-LINT CONTENT[151]

	Particulate Count
White Colour Group	
Good Middling	1,8— 3,0
Strict Middling	3,9— 5,2
Middling	6,2— 8,6
Strict Low Middling	14,1—16,7
Low Middling	21,1—26,8
Strict Good Ordinary	21,9—36,3
Good Ordinary	38,5—45,8
Spotted Colour Group	
Strict Middling	5,7— 7,6
Middling	7,5—10,4
Strict Low Middling	21,8—26,6
Low Middling	26,3—31,4
Tinged Colour Group	
Strict Middling	4,3—10,5
Middling	7,2—24,4
Strict Low Middling	9,3—27,1
Low Middling	16,6—37,0

COTTON DUST AND BYSSINOSIS

Other foreign matter is always present outside of the desirable cellulosic fibre produced by the plant itself: leaf, steam and other organic matter, and other elements such as fungi and possibly enzymes of one type or another which we are not completely and fully aware of[405]. All of these materials add up to the causes within the processing and manufacturing operation of the health hazard being called brown lung or byssinosis. No one has as yet absolutely determined the specific causative agents in this rather elusive disease, although it has been linked to micro-organisms (and associated endotoxins) present in the dust liberated from cotton[405a]. Pre-cleaning, including washing, reduces airborn micro-organisms released during carding[405a].

Byssinosis is a chronic respiratory disease induced by the long-term inhalation of the dust produced during the procession of cotton, flax and soft hemp[406]. Initially the disease is characterized by chest tightness and shortness of breath when the worker returns to the processing environment after having been away from the job for a weekend or longer. In later stages, which normally occur after many years exposure, the afflicted individual can suffer loss of respiratory capacity and may become occupationally disabled[406].

Byssinosis, commonly called brown lung disease has been defined as acute and chronic responses in the lung by *some* individuals who have inhaled raw cotton dust[407]. The acute phase was said to be very mild, and it takes a long time for the chronic disease to develop. From the time-of-development viewpoint, this is unlike the characteristics of a carcinogen[407].

As far as the susceptible individuals go, it can range from 1% to 60% of exposed persons, and generally from cotton trash and bract below 15 μm in particle size, so that operations that have the higher incidence are the early stages of yarn manufacture such as opening, picking, carding, drawing and roving. Once these operations are completed, the incidence goes down for spooling, winding, twisting, slashing and weaving, due to the decrease in the amount of cotton dust fall-out. A normal individual exhales 75% to 80% of air in 1 sec., and a decrease of 10% would be considered arbitrarily as a reactor; OSHA uses 5% decrease. The correlation between subjective vs objective symptoms is less than 1%. This was said to be the real problem in diagnosis. Smokers are said to be 600 times more prone to develop byssinosis and persons with asthma or chronic bronchitis are also more prone[407]. The maximum work place concentration of dust allowed in milligrams of dust per cubic metre of air is given below for various countries[408]:

MAXIMUM DUST LEVELS (mg/m³)

Switzerland	1,5 total amount of dust
Fed. Rep. of Germany	1,5 total amount of dust at preparatory machines up to and including card room
USA	1,0 total amount of dust
Great Britain	0,5 total amount of dust exclusive of fibres longer than 2 mm
USSR	4 total amount of dust

Dust levels of 0,2 mg/m^3 have been proposed by OSHA[409].

In 1977 OSHA released its proposed new standards for cotton dust. It proposed that after promulgation, engineering controls be implemented to ensure that cotton dust (measured with a vertical elutriator) does not exceed 0,5 mg/m^3, decreasing to 0,35 mg/m^3 in four years and to 0,2 mg/m^3 in seven years[410].

The designation "total amount of dust" covers all the portions of matter taken in by the measuring appliance without sifting out any components. In

Great Britain all fibres longer than 2 mm are eliminated by means of an interposed screen.

The regulations of the individual countries generally prescribe how the dust sample is to be extracted from the atmosphere. Above all, the aspiration velocity is laid down. For instance it is 1,25 m/s in the Federal Republic of Germany. This velocity of the air is regarded as being equivalent to the rate of respiration. In this way, the penetration of heavy fly into the measuring appliance is avoided. The manner of extraction of dust can lead to considerable variations in the dust concentrations measured.

In cotton spinning mills fibrous particles from the cotton plants are to be found along with non-fibrous fragments such as tiny pieces of stalk, leaf, seedpods, husks and granules. Recently, the proportion of this trash has increased owing to the employment of mechanical picking in the cotton fields. The dust also comprises mineral elements such as quartz granules along with various spores, mould fungus and yeasty substances[408].

Cotton dust, plant parts, gin trash and weed samples have been analysed chemically in an attempt to identify causal agents for byssinosis[411]. A typical bale of strict low middling (SLM) cotton contains about 0,5 to 1,0% bract trash[412]. Leaf-like particles, including bracts, comprise about 70% (by mass) of respirable cotton dust[412].

In one study it was found that the total number of dust particles per-cubic-metre in the card room, airborne cotton dust was drastically reduced by the Shirley Analyser (SA) cleaning at the gin, although the reduction in dust level did not produce a change in the particle-size distribution in the respirable size range (less than 15 μm in diameter)[413]. The respiratory function change of human test subjects when exposed to the cotton dust in the card room was identical for both the SA-cleaned and the normally-ginned cotton. The evidence provided by this experiment indicated that the extreme mechanical cleaning of lint at gins may not of itself be expected to provide relief from byssinotic symptoms among cotton mill workers[413].

The use of single process blow room machinery, all enclosed automated bale opening and cotton feeding procedures will reduce the dust substantially[414]. Oiling while utilising coarse cotton, blending with fine or synthetic fibre reduces the dust hazard. Card machines should be all-enclosed with overhead exhaust hoods and automated exhaust stripping. Air-conditioning seems to be effective in reducing dust greatly in spinning and high speed winding needs an improved ventilation system. Increasing dust load aggravates a decline in lung function in byssinotic and even asymptomatic workers. There seems to be a distinct pattern of decline in function with byssinosis, different from chronic bronchitis[414]. Card production rate signicantly affects dust[415].

A study by Burlington revealed the following with respect to the prevalence of byssinosis in textile plants[416].

TABLE 58

PREVALENCE OF BYSSINOSIS IN TEXTILE PLANTS[416]

Department	**Cotton plants**		**Cotton-manmade blend plants**		**Control plant (no cotton)**	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
Preparation	—	38%	—	20%	—	—
Yarn producing	—	15%	—	4%	—	—
Weaving	—	15%	—	6%	—	—
TOTAL	11-25%	17,6%	6-9%	7,7%	—	1%

The Burlington steam treatment technique is claimed to reduce or even eliminate byssinosis[405].

Treatment of cotton with additives appears to have potential for effective dust control in the textile mill[417]. Additives, used in conjunction with existing air cleaning systems, might provide adequate dust control and thus negate the need for installation of additional expensive air cleaning systems[417]. The mechanism of dust control has not been fully explored. The effectiveness of oil treatment, however, suggests that the dust was fixed to the fibre, by wetting or adhesive action, so that it was not liberated during processing[417].

It has been found[418] that the steaming of cotton lint (subsequent to ginning) reduced ambient dust levels during carding. The steaming operation actually removed dust, decreasing the Shirley Analyser waste from 14% to 10,7%. Steaming had no effect on lint grades but it increased staple length by about 0,8 mm in one sample. Slight tendencies towards yellowness and reduced yarn strength as a result of steaming were observed, however[418]. Attempts are being made to breed cottons with a more closed boll and less total plant matter so as to reduce trash and dust during processing[412].

Various other articles deal with byssinosis and dust, including the reduction of dust[412, 419—422a], particularly by washing the cotton[422].

GENERAL PARTICLE CHARACTERISTICS

The following tables give some details of particle sizes.

TABLE 59

CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS[423]

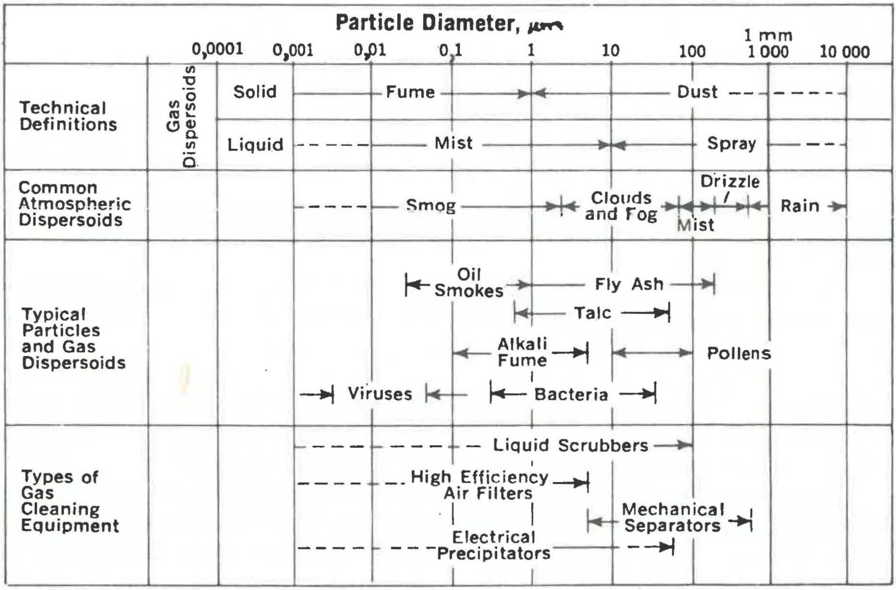
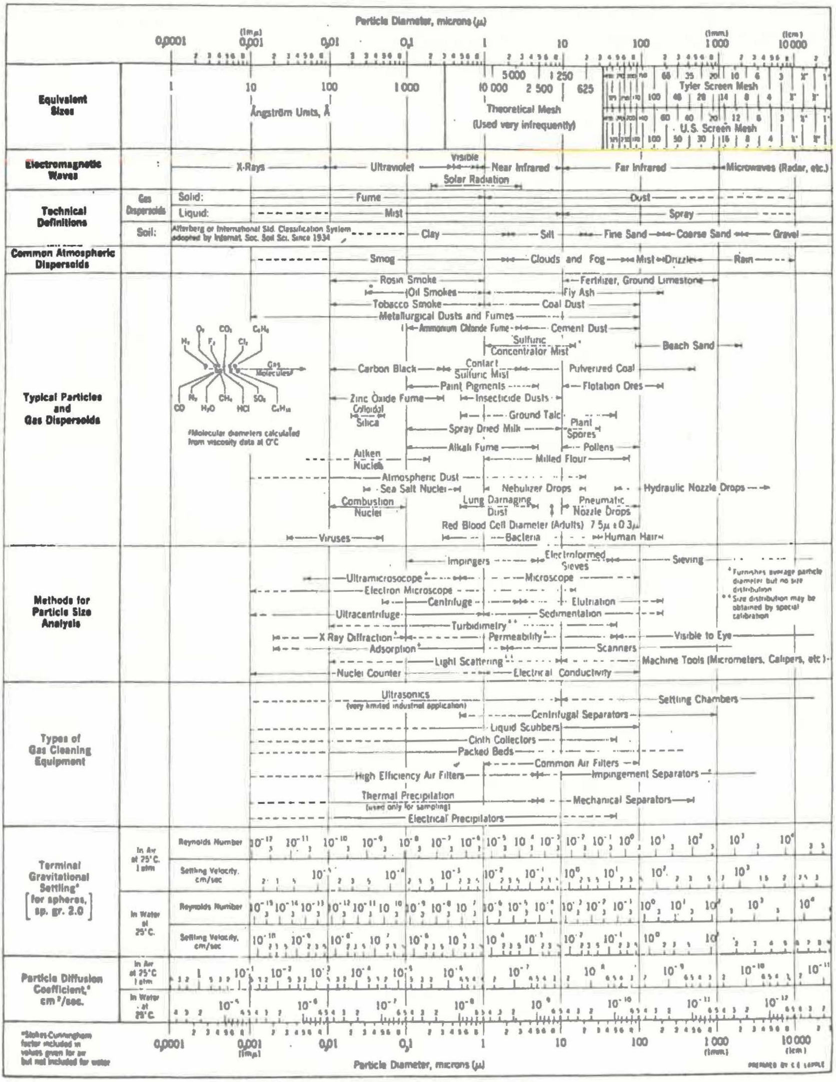


TABLE 60

CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS[424]



Source: Stanford Research Institute

WASTE DURING PROCESSING

The waste produced in a cotton textile mill (see Figure 30) is an important factor in determining the cost of operating and therefore in influencing the profits of the mill[425]. Since cotton goes to market principally in the form of products manufactured by the mills, better control of waste production and increased value of the waste produced are also important to those segments of the cotton industry which supply the raw fibre.

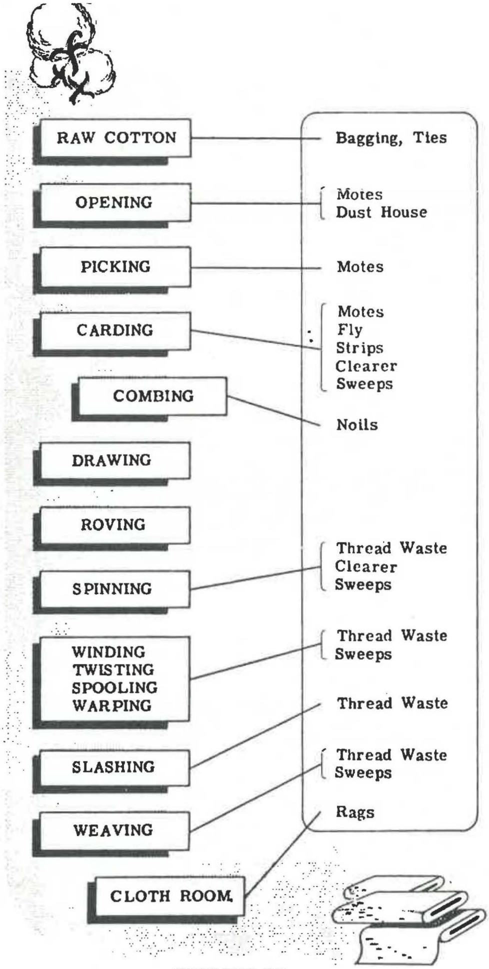


FIGURE 30

Flow chart showing the more important types of cotton waste produced, and their point of origin in the mill[425]

Since trash content is a factor in grade, lower grades of cotton should obviously yield more waste. Staple length also has an influence. Greater percentages of picker and card waste are obtained by processing the longer staples than by processing corresponding grades of shorter staple lengths. Slower doffer speeds are used for the longer staples; this automatically decreases the speed of the feed roll and hence results in a more thorough carding action of the longer staples[425]. The average relationship between grade and manufacturing waste is shown in Table 61.

TABLE 61

AVERAGE PERCENTAGES, PICKER AND CARD WASTE, FOR AVAILABLE GRADES OF COTTON

Grade	Medium and short staples (%)	Long-staple Upland (%)
Good middling	6,3	9,9
Strict middling	7,2	10,9
Middling	8,1	11,9
Strict low middling	9,3	13,1

A percentage of about 4 to 5% of waste may be taken as a mean value in respect of the amount of blowroom and licker-in waste produced[426]. To this must be added about 1,5 to 2% filter waste and flat strips. Utilisable waste consists mainly of flat strips, filterwaste and comber waste which may in fact be re-cycled either as an unmodified waste lot or mixed with raw cotton of a lower grade. Blowroom and licker-in droppings are generally classified as non-utilisable waste[426]. This could be incinerated in the mill's own furnace.

For "middling" cotton the following table indicates the amount of waste occurring at the various machines[427].

TABLE 62

WASTE OCCURRING AT VARIOUS MACHINES[427]

Opening room	approx 3 to 7%
Carding room	approx 3%
Drawframes & flyers	approx 0,5%
Spinning machines	approx 1 to 2 %
Total amount of waste	approx 7,5 to 12,5%
Noils (combing)	10 to 20%

In ring spinning, fly can amount to something like 0,5% of production.

Today waste is increasingly being used, particularly in rotor (OE) spinning and the following tables indicate waste-fibre recovery and usage[428].

TABLE 63

TEXTILE WASTES — FIBRE RECOVERY AND USAGE[428]

TEXTILE WASTES Fibre recovery and usage	**Principal machines for fibre recovery**					**Fibre yield**	**Possible uses**				
Waste category	**none**	**RMS**	**NC**	**VOS**	**VR**	**approx. %**	**Ring spin.**	**Rotor spin.**	**Wadding**	**Upholstery**	**Nonwovens**
1. Fibre waste from ginning plants	–	+	+	–	–	25. . . 50	–	+	+	+	+
2. Fibre waste from cotton cleaning plants	–	+	+	–	–	25. . . 50	–	+	+	+	+
3. Card licker-in and grid waste	–	+	+	–	–	20. . . 40	–	+	+	+	+
4. Card flat strips and suction waste	–	+	(+)	–	–	50. . . 80	(+)	+	+	+	+
5. Lap and web waste from pickers and cards	+	–	–	–	–	100	+	+	+	+	+
6. Cotton comber waste	+	(+)	–	–	–	95. . . 99	+	+	+	+	+
7. Card and drawframe sliver wastes	+	–	–	–	–	100	+	+	+	+	+
8. Roving waste	–	–	–	+	–	98	+	+	+	+	+
9. Yarn waste	–	–	–	–	+	85. . . 95	–	+	(+)	+	+
10. Suction waste	+	–	–	–	–	98. . .100	+	+	+	+	+
11. Cloth waste	–	–	–	–	+	80. . . 90	–	+	(+)	+	+

Waste cleaner WILLOMAT RMS
Waste cleaner NOVACOTONIA NC
Roving waste opener VOS
Combined tearing machine VR

(In brackets — conditionally used)

TABLE 64

TEXTILE WASTES — FIBRE USAGE[428]

TEXTILES WASTES **Fibre usage**	**MIXING COMPONENTS FOR OE-YARNS** **Examples**																
Cleaned or opened virgin or secondary raw material	**tex** **Nm** **Ne**	**125** **8** **5**		**100** **10** **6**		**77** **12** **7**		**71** **14** **8**		**63** **16** **9**		**56** **18** **11**		**50** **20** **12**		**45** **22** **13**	**42** **24** **14**
1. Fibre waste from cotton cleaning plants		10	40	20	30		30		40								
2. Card licker-in and grid waste		10	10		5				10								
3. Fibre waste from ginning plants				20		30	20						40		55		
4. Card flat strips and suction waste		20	10		5	20			10		40						
5. Low grade cotton	%		20	20				20			20						
6. Cotton comber waste				10		20		30		55		70	10	85		100*	100*
7. Waste from man-made fibres production		35		10	50	15		10		10			50		15		
8. Suction waste			20		10				20		20	15		15			
9. Yarn waste		25		20		15	20	30		25	20	15			30		
10. Cuttings from woven and knitted fabrics							30	10	20	10							
	*comber waste from long and extra-long staple cotton																

Waste from various spinning mills was measured on a Shirley Analyser and the percentage of good fibre in the total scutcher waste was found to be between 20 and 45%, depending on quality[427]. The different wastes from spinning mill preparatory machines have a good fibre fraction of between 20 and 70%. Different amounts of waste are recorded by the individual spinning mills, attributable to the use of different raw materials, different machines and differing machine settings[427].

Examination of the wastes revealed that in the flat card strips, in the licker-in waste and in the step cleaner waste, there is the highest percentage of good fibres[427].

When considering the results of the fibre examinations with regard to tuft strength and micronaire value, it was observed that the properties of the good fibres from the step cleaner (normal scutcher waste) are generally speaking, relatively good, whereas with the other machines, quite clear differences in the quality of the various wastes could be discerned. For example, the quality of the card licker-in waste is always inferior to the other wastes.

When comparing the properties of recovered fibres with those of good quality cottons, the fibres are considered as quite acceptable.

Another interesting factor is the fibre length distribution in the fibres recovered from different wastes. There are significant differences in the quality of the various wastes.

Naturally, the fibre length distribution of the recovered fibres depends on the raw material, on the efficiency of the machine and on the machine setting.

In every instance examined, the fibres from the licker-in waste were most inferior and the fibres from the step-cleaner and from the Kirschner beater were the best[427].

The percentage of waste extracted by the picking and carding processes in performing a spinning test provides a measure of manufacturing waste. There is an average relationship between this waste and grade as discussed in the previous section on the grade of cotton. The rate at which the cotton is carded, however, affects the picker and card waste values because the more thorough carding action obtained when the carding rate is decreased extracts a larger quantity of waste. The longer staple cottons are generally carded at a lower rate than the shorter cottons in order to obtain acceptable yarn quality. Tests performed in recent years show the following average relationship of picker and card waste to grade[198]:

TABLE 65

American upland		Average picker and card waste[198]
Grade	Code	Percent
Strict Middling	(21)	5,0
Middling	(31)	5,3
Strict Low Middling	(41)	5,9
Low Middling	(51)	6,9
Strict Good Ordinary	(61)	7,8
Good Ordinary	(71)	8,8

TABLE 66

American Pima	Average picker and card waste
Grade	Per cent
2	7,7
3	7,9
4	8,4
5	8,8
6	9,7
7	10,6
8	12,0
9	12,6

Data source: 4 656 samples of American upland cotton and 1 329 samples of American Pima cotton tested for Shirley Analyser nonlint content from the crops of 1971—75 and picker and card waste calculated from its relationship to Shirley Analyser nonlint content.

It has also been estimated that[429]:
Picker and Card waste = 27,7 – 0,15 (Grade Index) – 4,03 (UHML) – 0,54 (Micronaire)
with a standard error of 0,90%.

By means of this equation only 39% of the variation in picker and card waste could be accounted for.

Under the same operating conditions the amount of waste per flat strip is a good indication of the quality of cotton and of the total amount of waste that is being made at the card, for the flat strip is correlated to the amount of waste that is removed at other points on the card[2]. Such tests are considered essential after grinding or after settings have been changed on the card[2].

EFFECT OF PROCESSING ON FIBRE PROPERTIES

Mechanical processing affects cotton fibre properties[430] to some extent although the wet finishing operations such as bleaching, mercerising and resin-finishing generally alter the fibre mechanical properties more than carding, spinning and weaving[430]. Changes in cotton fibre properties are reflected in the fabric properties[430]. It has been found that lint cleaning at the gin caused a slight but consistent decrease in micronaire reading, the latter changing from 4,81 to 4,76 to 4,75 to 4,74 respectively after zero, one, two and three stages of lint cleaning[431]. The reasons for the decrease in micronaire reading with lint cleaning is not clear although it was suggested[431] that the removal of foreign matter affected the micronaire reading. In one study, processing cotton into yarn appeared to have little effect on the length, crystal alignment and mechanical properties of the fibres, except that elongation decreased, the initial modulus increased and the maturity of the carded cotton was slightly lower[432]. Other workers have, however, reported fibre damage upon processing. An estimate of fibre damage (breakage) during carding by comparing fibre lengths prior to and after carding may be misleading due to fibre stretching and the removal (in the waste) of short fibres[433]. Damage to the fibre walls, however, can be assessed by means of alkali centrifuge values (ACV). Varying the speeds of certain card components did not produce, in selected fibre properties, variations large enough to identify any general region within the card as a possible source of damage[433].

Carding and combing should increase the 2,5% span length and the 50% span length, due to the removal of short fibres[434], although fibre breakage can counteract this. The effect of processing on the 50% and 2,5% span lengths of cotton has been investigated[435]. It was found that in spite of the removal of short fibres during opening and carding these processes reduced both the 2,5% and the 50% span lengths. This indicated some fibre breakage during both opening and carding. On average, opening reduced the two span lengths by 4%, carding reduced them by a further 3% and breaker and finisher drawing each by another 1%. The average span length values for fibres in the roving were about 5% higher than those in the finisher drawframe sliver while those of the fibres in the yarn were approximately 1% higher than those of the fibres in the roving. The 2,5% span length value for the yarns was 4% lower than that for the original cotton mix while the 50% span length was 2% lower[435]. Peirce[399] states that card sliver and cotton lint have very similar length characteristics. There is some breakage in going from lint to card sliver, most of which occurs in the card. This is compensated for by the removal of short fibres. If anything, the fibre length in card sliver is slightly lower than that in the lap; the card does appreciable damage to the fibres but eliminates most of the fibres it breaks. Very little breakages occur in the blowroom[399].

Fibre linear density, as determined after combing, is generally lower than that determined on the material prior to combing, probably due to the fact that combing removes short fibres which tend to be coarser[436].

Elsewhere it is stated, however, that combing not only eliminates shorter fibres but also the finer and immature fibres[437].

In another study on cottons[438], it was found that combing generally increased mean fibre length and decreased the short fibre content.

According to Audivert[209] *et al* (quoting results obtained by Grunder[439]) cotton undergoes small changes in mean fibre length during processing but neither the modal nor the maximum fibre length is altered.

NEPS (see also Micronaire and Maturity)

Neps occur in all ginned cotton[440] (but hardly in unpicked cotton)[360], mechanical operations such as machine picking, handling, drying, cleaning, ginning, lint cleaning and particularly carding producing neps[441, 241]. A nep is generally defined as a definite fibre tangle having a hard central knot or centre sufficiently large to be detected easily[360]. Neps are small knot-like aggregates of tightly entangled cotton fibres normally not larger than a common pin head. Naps are similar to neps but are usually larger, may show seed fragments and are not as closely entangled. Neps are usually associated with immature or fine fibres and are caused by the entangling of these fibres during processing. In spinning, the nep can interfere with the drafting and cause an end breakage[360]. Neps detract from the appearance of fabrics when they are to be dyed or printed because neps absorb dyes differently and appear as spots on the finished material[360]. In yarns, neps are small specks consisting often of a tangle of fibres[213]. The following has been reproduced from an excellent review by Wegener[442]:

Whilst *cotton* neps occur not only in raw cotton, but also in semi-finished products, in the yarn and the finished fabric, the slubs contained in *wool* are formed during its processing. Similarly the slubs found in semi-finished products, yarns and fabrics made from synthetic fibres are mostly formed in the course of processing.

Cotton neps

De Meulemeester, Raes and De Backer[443] subdivide cotton neps in respect of their nature as follows:

(1) Fibre neps (USA: neps). They are the actual neps and consist of entangled fibres which make their appearance as small knots.

(2) Leaf neps (husk neps, USA: neps). They consist of leaf fragments entangled with fibres.

(3) Linters neps (USA: motes). These are conglomerations of normal fibres and linters (frequently of a furry nature) with seed particles.

(4) Neps made up of dead fibres (USA: matted fibres). These are fibre bundles formed from parallel fibres and have a mat yellow gleam. These fibres are dead, adhere to one another, but can be separated.

Depending on the type of cotton neps, mature, immature or dead fibres may occur in them. According to De Meulemeester, Raes and De Backer[443] the fibre neps and leaf neps contain mainly dead fibres, the linter neps both mature as well as immature and dead fibres. Fessmann[444] discovered in the processing neps a considerable share of mature fibres apart from immature and dead fibres (mostly severed fibre tips). Neukirchner[445] discovered that the neps occurring in the cotton card web consisted mainly of dead fibres. Frequently a mature, especially strong fibre (catching device) is the cause for the creation of the nep. Sometimes a sack-shaped deformity of a fibre (fibre collector) forms the centre of the nep.

Airborne fibres of different types (fly) also contribute to the formation of neps. Coalesced fibre entanglements are created as a result of the contents of the lumen escaping; the causes of this could be premature harvesting or damage due to insects. In such cases, the fibres will no longer mature. Coalescence of fibres may also be caused by honeydew (the excretions of aphids). Neukirchner[445] found that a cotton nep consists in most cases of conglomerations of similar fibres. De Meulemeester, Raes and De Backer[466] frequently found fibres with broken-off ends in cotton neps. If a fibre breaks during processing it often rolls itself up and wraps itself around other fibres in the process, thus forming a nep.

The neps contained in cotton have a different dye affinity than the rest of the cotton fibres as a result of their high content of immature and dead fibres. The dying variations can be reduced considerably by mercerization (Fessmann[444], Köb[447], Goldthwait, Wiles and Von Sales[448]).

During processing of the cotton in the spinning mill, neps are both eliminated or disentangled as well as new ones formed. Fessmann[444] gives priority to the elimination of neps in favour of their disentanglement, since the neps contain a large share of dead and immature fibres leading to an unfavourable spinning structure. Up to the last scutcher, the number of neps is progressively reduced, this fact being correlated with the elimination of the impurities contained in the cotton. At the same time new neps are being formed in the processing stages prior to the scutcher, thus increasing the number of neps contained in the cotton. Moreover (according to Ebert[449], Suebius[450] and Hartenhauer[451]), the number of neps is increased in the scutcher.

A processing stage which does reduce neps is the carding process. On the card, more neps are eliminated or disentangled than the number of newly formed ones which are added.

The nep-reducing effect of the card can be considerably increased by a number of measures. However, the realization of many of these measures is frustrated occasionally as a result of the reduction in output connected with them[444, 449—460].

The nep-reducing effect is reduced as the card clothing fills up[447, 451, 461]. Perner and Jung[462] state that the number of neps contained in the card web shortly before the card clothing is cleaned can often be double that of the number of neps in the card web shortly after the card clothing has been cleaned. So far as the elimination of neps is concerned, the use of a tandem card or a second passage through the card will be advantageous. In addition, the use of calendering rollers will reduce the nep content considerably[463, 464]. Normally a card will eliminate a greater percentage of neps, the more neps there are in the lap.

Whilst a further reduction of the number of neps is achieved at the comber[444, 451, 465] the nep content may increase under certain conditions at the draw frames and speed frames. The formation of neps will be encouraged by an insufficient degree of orientation and by the presence of fibre hooks[451, 452, 465]. According to Fessmann[444] the formation of neps during drafting may also be caused by the breaking of excessively long fibres.

The formation of processing neps depends on a number of influences, such as fibre characteristics and parameters peculiar to the particular processing method. There are correlations between the characteristics which affect the formation of neps in cotton, thus indicating that the connection found between the tendency towards the formation of neps and one or the other of the characteristics need not necessarily be causative.

(1) *Fibre fineness*
Finer cotton fibres have a stronger tendency towards nep formation than coarser ones. This does not only apply to processing neps but also to harvesting neps. The reason for the increased tendency of the finer fibres to form neps is the low stiffness of these fibres[248, 443, 451, 452, 457, 466—472].

(2) *Degree of fibre maturity*
In general, the tendency of cotton to form neps increases with a rising share in dead and immature fibres or with a decrease in the average maturity of the fibres, respectively[443, 451, 457, 466, 468, 470, 473].

(3) *Staple length*
The effect of the staple length on the tendency towards nep formation is controversial. De Meulemeester, Raes and De Backer[443] deny any such effect. Hartenhauer[451] states that an increase in the tendency towards nep formation can be correlated to an increase in the staple length of the cotton, since a long-staple cotton frequently has a greater mean fibre fineness than a short-staple one.

(4) *Fibre strength, elongation, elasticity, bending strength*
As the values of these fibre properties decrease, the tendency of the cotton to form neps increases, one of the reasons why broken fibres play a dominant part in the formation of neps[446, 447, 451, 467].

(5) *Nep content of the raw cotton*
A cotton which has a high nep content already at the delivery stage, will also show a tendency towards nep formation during processing[451]. De Meulemeester, Raes and De Backer[443] found a definite correlation between the number of neps in the raw cotton and the number of neps in the card web; however, the neps contained in the card web had a lower mass than those in the raw cotton.

(6) *Origin*
There is a certain dependence of the nep formation on the origin of the cotton. However, even with cottons of the same origin there can be considerable differences with regard to neppiness[443, 444, 457].

(7) *Harvesting*
Sledded and machine-picked cotton has a greater content of dead and immature fibres as well as impurities, such as husk and other residue than

manually picked and snapped cotton. Correspondingly, the tendency towards the formation of neps is greater with machine-picked cotton[444]. Of great importance for a low nep content is the correct time of harvesting (maturity).

(8) *Ginning*
The breaking of fibres favours the formation of neps. Roller ginning machines have a gentler action than saw-tooth ginning machines. Of importance in their effect on nep formation are correct air condition, the cleaning process and the intensity of mechanical treatment[444, 470].

(9) *Moisture content of the material*
With increasing moisture content the tendency of the cotton to form neps also increases.

(10) *Fibre impurities*
With increasing fibre impurities, such as husk, leaf and stalk particles, the tendency towards nep formation increases in the cotton.

(11) *Fibre orientation and fibre hooks*
With a low degree of fibre orientation in the fibre band the formation of neps is encouraged. Fibre hooks may be regarded as the preliminary stage in the formation of processing neps. This applies especially to the processing stages following the carding. High drafts encourage nep formation.

(12) *Fibre separation in the cotton*
With a satisfactory degree of fibre separation, the formation of neps is reduced. But too high a moisture content may upset the result[474, 475]. Fibre separation by means of plucking should be aimed at. A fibre-destroying separation (saw tooth action on clamped bundles of fibres) only increases the tendency of the cotton to form neps.

(13) *Processing of the cotton by means of beaters*
Too intensive a beating action and too many beaters as well as too high a feed to the beaters all encourage the formation of neps. High beater speeds should be avoided. The Crighton opener gives good results with regard to the elimination of neps[451, 452, 460]. It has been proved that the use of Kirschner beaters in opening machines leads to the creation of fewer neps than that of triple bar beaters.

(14) *Interruptions of the air flow or air turbulence in the conveying ducts*
Occurrences of this kind encourage nep formation[451, 452].

(15) *Spin finishes*
Depending on their type, they may reduce or increase formation of neps in comparison with untreated cotton[476].

(16) *Spinning processes*
According to investigations carried out at the Shirley Institute[477] OE yarns (BD 200—20 tex) contain fewer neps than ring-spun yarns made from carded cotton, but approximately the same amount of neps as ring-spun

yarns of average quality made from combed cotton. According to Kirschner and Kleinhansel[478] OE yarns (BD 200) are superior or at least equivalent to ring-spun yarns of similar quality so far as nep content is concerned.

In order to keep the formation of neps during the processing of the cotton to a possible minimum, the following general rules apply:

1. A low intensity and frequency of processing should be aimed at.
2. The machines should be set correctly, kept in a good state of repair and free from rough places.
3. The fibres should contain few impurities and not have too high a moisture content.
4. The fibres should have satisfactory orientation. The compression of fibres and formation of fibre hooks should be avoided as far as possible.

CARDING AND NEPS

Neps in cotton yarns may originate from machine picking, ginning, opening and cleaning and particularly from the carding operation[241]. Improper settings and excessive beating and over-heating of the cotton are known to increase neps. Neps in card web increase with decreasing micronaire, particularly below a micronaire of about 4 (3 also mentioned)[241]. The cottons are frequently broken during cleaning and particularly in the carding process. Some of the neps in the card web are worked out in the drawing and spinning processes, but additional neps and imperfections are often produced in these processes.

The number of neps in the card web, however, is a good indication of the yarn appearance grade to be expected, except when grassy cotton or immature cotton with seed-coat fragments attached are used[241]. It appears risky to use cottons with micronaire values below about 3,5.

High nep count and a cloudy web are often indicative of poor carding[438], poor cards frequently being responsible for nep formation[479], while good cards can actually reduce the number of neps. Neps increase from the raw cotton to the picker stage after which it may be decreased at the card, the drawing operations gradually increase the number of neps[479]. The cotton comes from the boll with about 30 neps/g and from the gin with about 270 neps/g and it reaches the card with about 495 to 525 neps/g . An excellent card may reduce the neps to about 90 neps/g while an average card can reduce it to about 165 neps/g . Dividing the neps/g by 5 approximates the neps per 100 sq. inches of card web.

Card efficiency can be defined as follows in terms of nep removal:

$$\text{Card Efficiency} = \frac{\text{Lap neps/g} - \text{Web neps/g}}{\text{Lap neps/g}} \times 100$$

It appears that 90 neps/g are subtracted from the web neps. Variations due to stripping cycle are about 75 neps/g, that due to variations in grinding cycle about the same, that due to cotton fineness about 90 neps/g and that due to variations in card efficiency about 270 neps/g[479]. There is a close relation between neps in the card web and those in the yarn, although there are more neps in carded yarn than in the card sliver. The following table allows a rating of the frequency of neps in a card sliver.

TABLE 67

NUMBER OF NEPS PER HUNDRED SQUARE INCHES OF CARD WEB (PRODUCTION RATE 4,5 kg/hr)

NUMBER*	RATING
1 to 15	Low
16 to 30	Average
31 to 45	High
> 46	Very high

(100 square inch = 645 cm^2)
*Multiplying by 5 approximates neps/g .

In one study on 8 mills, from 36 to 108% of the neps in the lap were still in the card sliver[480].

A direct relationship appears to exist between card web neps and minority hooks[481]. As minority (leading) hooks in the card web increase so do yarn imperfections[480]. It has been postulated that the same mechanism which increases minority hooks in card sliver also increases card web neps[481, 482].

For cottons that nep easily, low doffer speeds are generally required[481].

Cottons with a low fibre friction and high recovery from compression transfers from card cylinder to doffer more easily than cottons with high fibre friction and low recovery from compression[235]. As the micronaire decreases the sliver mass should be reduced particularly at high production rates[235].

Finer and longer cotton fibres are more prone to nep formation[479]. Although fibre length and fineness influence neppiness the proportion and distribution of thin-walled (immature) fibres contribute more to fabric defects than do either of these other fibre properties[483, 484]. Nep formation has also been found to increase linearly as the percentage of the higher elongation cotton in a blend increased, indicating that nep formation decreases with an increase in stiffness[375].

The effect of carding rate on yarn properties appears to depend upon the micronaire of the cotton, although yarn imperfections generally increase with increasing carding rate[235]. The card production rate can also affect yarn quality as illustrated in the following figure[485]:

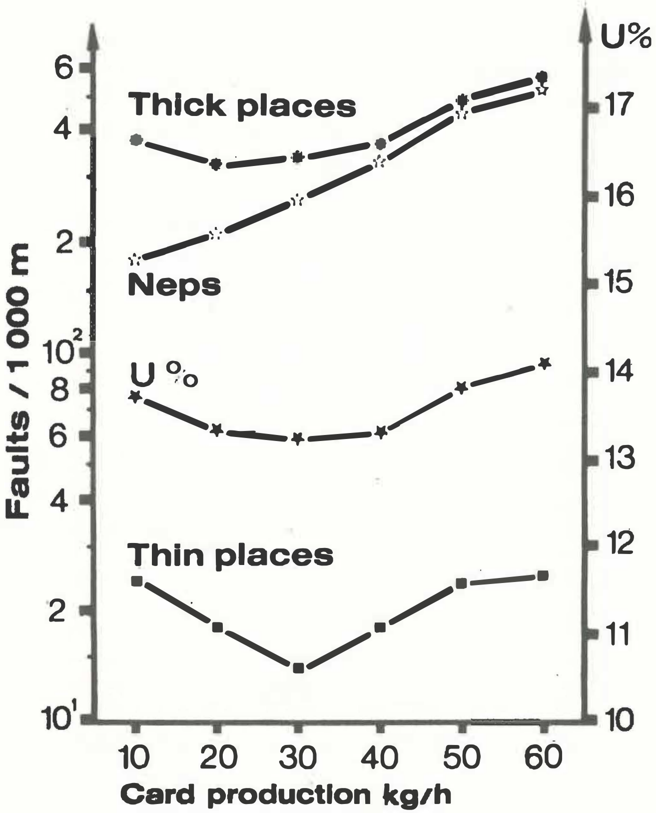


FIGURE 31
Effect of card production rate on yarn quality

Although increasing carding rate sometimes increase yarn imperfections and decrease yarn grade[486] this is not always the case as the following table shows:

TABLE 68

QUALITY COMPARISON BETWEEN HIGH-PRODUCTION AND STANDARD CARDS WITH VARIOUS COTTONS[487]

No.	Material	Micronaire	Card type	Production kg/h	Tex	Yarn Results					Remarks
						Imperfections			Tenacity (cN/tex)	Irregularity* (U%)	
						Neps	Thick places	Thin places			
1	Semi-first assortment from America, Brazil and noils	3,75	standard high production	5,0 20,0	30 30	253 70	239 45	347 52	13,6 13,9	15,0 11,5	
2	50% American 17,5mm 50% Turkish 17,5mm	4,2	standard high prod.	6,0 20,0	30 30	437 314	533 381	148 94	13,1 13,2	13,7 14,0	
3	South Brazil	3,3	standard high prod.	6,0 20,0	30 30	1 008 416	714 451	107 127	11,9 11,4	15,0 14,6	
4	First assortment American 17,5mm	4,44	standard high prod.	3,5 20,0	20 20	184 138	341 194	102 24	12,7 13,0	15,0 14,1	
5	American 17,5mm	4,48	standard high prod. high prod.	5,0 25,0 30,0	20 20 20	146 85 88	174 22 25	2 — 1	11,0 12,5 12,5	14,1 13,1 13,2	
6	Mako	3,95	standard high prod.	3,0 14,0	10 10	197 193	360 131	298 85	17,8 17,4	13,4 11,1	Comb-out 14%
7	Giza	3,17	standard high prod. high prod.	4,0 12,5 21,0	10 10 10	45 21 32	95 9,1 13,9	43 2,0 4,7	22,0 22,1 22,0	10,5 10,9 10,9	Comb-out 18,5%
8	Sudan	3,75	standard high prod. high prod.	4,0 17,5 25,0	12 12 12	63 30 46	52 42 31	178 160 165	17,3 17,2 17,6	12,1 12,4 11,6	Comb-out 18,5%
9	Peru Pima	3,77	standard high prod.	3,0 14,0	7,5 7,5	28 26	55 25	21 6	19,3 19,3	13,2 14,0	Comb-out 20% Comb-out 18%
10	Karnak	3,65	standard high prod.	2,4 12,0	7,5 7,5	16 13	41 44	19 19	20,3 19,8	13,1 13,3	Comb-out 24%
11	Karnak	3,22	standard high prod.	2,0 14,0	6,5 6,5	116,7 70,4	135 51	162 39	20,4 20,4	15,0 12,7	Comb-out 18%

*To convert to CV multiply by 1,25

EFFECT OF FIBRE PROPERTIES ON YARN PROPERTIES

It has been claimed[488] that, under the classification system then used for cotton the price of cotton poorly reflects its processing quality because of the great emphasis placed on grade factors (colour and trash) which have very little effect on spinning quality. Trash has its greatest effect on manufacturing waste and to a much lesser extent on yarn and fabric appearance, i.e. trash is mainly a mass loss[163]. Colour has very little effect on processing quality other than the colour of the yarn and dyeing behaviour[488].

Mixing cottons of different colours can affect the appearance of dyed materials. Cottons that are low grade because of weather damage or excess trash content increase manufacturing waste and decrease processing efficiency[489].

Over the past fifty years or more, literally hundreds of articles have been published on the subject of the relationship between yarn and fibre properties. Although high correlations and accurate predictive relationships were often arrived at in a particular study, as yet no relationship has been universally accepted for predicting the cotton yarn properties from those of the fibre. It is possible that with all the modern instruments available which allow the various fibre properties to be measured quickly and accurately, together with the advanced computer technology, a general relationship between yarn and fibre properties may soon be arrived at. Nevertheless, to do this it may be necessary to measure a wider range of fibre properties, for example, wax content, than those routinely measured now.

Yarn strength measurements are claimed to provide a reliable evaluation of fibre spinnability[245, 247] and quality[490].

It appears that as the cultivar changes so the order and amount of variation in yarn strength which is explained by specific fibre property changes[491]. Hence the accuracy of predictive equations will be affected by environment and cultivar environment interaction. It is stated that these factors make empirical approaches of dubious value, where-as a statistical approach is recommended.

Lawson *et al*[492] state that in a study of the contribution of cotton fibre properties to yarn strength the prediction on cottons from a single growing season is high although over environments or years the prediction was not very good. They therefore conclude that, factors other than the usually measured fibre properties of length, strength and fineness must be involved in the yarn strength. One such factor was thought to be fibre cohesion within the yarn[492].

It is more important to closely control fibre length distribution in a cotton mix than either strength or micronaire reading, within practical ranges[493], although Aldrich[494] found that when two cottons differing significantly in length and strength were blended, the yarn and fabric properties generally agreed well with the values predicted from the weighted means of the components.

For a normal range of micronaire reading, strength and short fibre content, processing performance *prior to spinning* is not appreciably affected by the various fibre properties[197, 493]. For ring-spun yarns the fibre characteristics that have the greatest effect on yarn strength are strength, length and fineness, in that order[495].

Fine fibres, except for extreme fineness, are assets to yarn strength and spinning production rate.

Cotton yarn irregularity is affected more by fibre length than by fibre linear density[496, 497] with the CV of cotton fibre length or length uniformity also affecting yarn irregularity[496, 498].

Louis *et al*[495] found that, for medium staple cottons, fibre strength affected yarn strength most, followed by fibre length. Ramey *et al*[345] found a better correlation between yarn strength and fibre properties for ring yarns than for rotor yarns[345].

Cotton length is considered the principal determinant of ring yarn and fabric strength[163]. Long fibres tend to produce more imperfections (called neps), during carding; therefore the longer staple cottons are normally subjected to low carding rates and to a combing operation which removes the neps and a large percentage of short fibres and which also aligns the fibres[163]. Length distribution has a large effect on the appearance, strength and uniformity of both yarn and fabric, short fibres being particularly disadvantageous. Fibre length and length distribution are the major determinants of processing efficiency, with length more than any other fibre property determining the limiting count which can be spun (see Part II). Generally, long fibres produce fewer end breakages and can be spun at higher processing speeds and require less twist to achieve maximum yarn strength. Fibre length is closely related to fineness[163]. Length uniformity ratio is also a good indicator of spinning performance (e.g. ends down and production rate) and yarn quality, but is secondary to 2,5% span length[488].

Cotton fibre length and fineness are regarded as of paramount importance for efficient ring-spinning performance[495].

An increase in short fibres (<10 mm) degrade yarn strength, uniformity and appearance[493], yarn strength decreasing by about 1% for each 1% increase in short fibres[493], the effect being greatest for fine yarns and lower twists. It also adversely affects spinning performance[147, 493]. Increases in short fibre content also decreased the tensile and tear strength and flex abrasion of print cloth[493]. It has been concluded that the 2,5% span length and uniformity ratio were preferred for explaining yarn irregularity[498].

Elsewhere it was stated that yarn uniformity appears to be affected by processing variables rather than by fibre properties although the 50% span length and the fibre fineness (or micronaire) were the most important in predicting end breakages and these were followed in importance by bundle strength and elongation[495].

Nevertheless, within practical ranges, yarn linear density and twist and spindle speed often affect spinning end-breakages more than do the fibre properties[197].

The calculated cost of an end break is quite small and varies, according to country, raw material, etc., within the range of approx. 3 to 20 US cents[499, 500].

Micronaire has a much greater effect on spinning quality than grade[488]. Micronaire affects yarn appearance more than any other fibre property[495]. All other factors being constant, finer fibres produce more regular and stronger yarns, although the effect of fineness on strength is generally secondary to that of fibre length. Neps have been found to decrease rapidly and yarn strength slightly, with increasing micronaire. Yarn uniformity decreases slightly with either extra-fine or extra-coarse micronaire[493]. It has been stated[483] that, if all other fibre properties remain constant, an increase in micronaire increases end breakages during spinning, decreases yarn strength and improves yarn appearance with the effects increasing in magnitude as the yarns become finer. Trash content can, however, overshadow these effects particularly for coarser yarns[501].

Cottons with high micronaire readings (5 and higher) adversely affect spinning performance and yarn strength but improve neps and yarn appearance grade[493]. Micronaire reading of 4,0 to 4,2 is a suitable compromise between the use of low micronaire for higher strength yarns and high micronaire for better yarn appearance[493] (i.e. fewer neps)[163]. Low micronaire fibres are generally carded at slower speeds. Fine, but mature fibres, can be spun with reduced end-breakage rates[163]or at higher speeds[493].

Cotton fineness is more important in rotor than in ring spinning, with the reverse being true for fibre-strength[303], the effects being attributed to differences in the fibre arrangement and alignment in the yarns. Strong rotor yarns can be obtained by using low micronaire, strong cottons, with fibre length and uniformity appearing to be of secondary importance[502].

Fine and strong cottons improve the yarn strength and spinning performance in both ring and rotor spinning[303].

Vaughn and Rhodes[503] reported that a short staple cotton with a low micronaire (3,3) produced a stronger yarn than a medium staple 4,3 micronaire cotton. Fibre fineness also affects the roving and yarn twist required to obtain optimum properties processing efficiency[493].

Within varieties, micronaire does not appear to bear a consistant relationship to bundle tenacity[247, 504].

It has been shown that the neps in cotton yarn affect the yarn appearance grade most, the effect of thin and thick places being slight[436, 505]. Nevertheless the corrolation between the frequency of neps and yarn appearance grade is not very good either. Combing greatly improves yarn evenness and strength and greatly reduces imperfections. Particles of foreign matter are also counted as neps by the Uster Imperfection Indicator[436]. Fibre length characteristics are regarded as important factors governing the imperfections in yarns[436].

Uster yarn evenness is closely related to the frequencies of thick and thin places for combed cotton yarns[505]. Uster normally records more neps for rotor than for ring yarns, but since fewer neps are generally apparent on rotor yarns it could be that the Uster is counting wrapper fibres[506].

Fibre strength has no appreciable affect on processing efficiency[163], yarn evenness or appearance but is linearly correlated with yarn strength[197, 493].

Strength is often regarded as a substitute for length in obtaining a strong end product[163].

Fibre strength does not appear to affect the twist required for maximum yarn strength and it has little effect on ends down[493]. At low twist yarns spun from cotton with a Pressley of 99 000 psi (48,5 cN/tex) averaged from 35 to 40% stronger than yarns spun from a cotton with a Pressley of 82 000 psi (40 cN/tex). As the twist increased so the difference in the strength of these yarns decreased until at the highest twist the difference ranged from 12 to 20%[493].

It is widely accepted that cotton bundle tenacity at ⅛″ (3,2 mm) gauge gives a better measure of yarn strength than the bundle tenacity at zero-gauge (i.e. Pressley).

In one case, 93% of the variation in yarn strength could be explained in terms of upper half mean length, fibre tensile strength and fineness[18]. As a general rule for a world-wide prediction of yarn strength based on the specific fibre characteristics the following components take effect relatively[202]:

Fibre length	
2,5% Span Length and Uniformity Ratio	39%
Fineness (Micronaire)	18%
Fibre strength (cN/tex)	20%
Unexplained factors	23%
Yarn strength	100%

In a study[495] on 79 medium staple length cottons it was found that the Fibrograph 50% span length generally correlated better with the end breakages during spinning and the yarn evenness and tensile properties than the 2,5% span length. In simple correlation analysis, micronaire reading and maturity had practically no correlation with any yarn property or with end breakage rate. Skein breaking strength and single thread strengths were almost perfectly correlated although their variations (CV's) were not. When carrying out multiple correlation analysis it was found that the 50% span length was superior to the 2,5% span length in explaining yarn strength and end breakage results with the uniformity ratio almost as good as the former. It was, therefore, suggested that the 2,5% span length results should be used as a guide for machine settings while the 50% span length should be used for predicting yarn quality and spinning performance. In general, about 80% of the observed variation in yarn strength and end breakage results could be explained in terms of 50% span length, fineness (or micronaire), 3,2 mm (⅛″) gauge strength and bundle elongation[495]. Cotton fineness, length, strength, maturity and grade under ideal conditions explain about 80% of the variation in cotton fibre spinning quality[373].

Under certain conditions as much as 96% of the variation in yarn strength could be explained in terms of bundle tenacity (⅛″), 50% span length, etc.[491]

Bogdan[507] arrived at the following equation for CSP:

$$CSP = \frac{160}{1 + BM^2} \left[\frac{P}{C} \left\{(1 - 10^{-0,13(M-T)^2}\right\} - F\right]$$

where

B is the *fibre* obliquity parameter

P is the intrinsic yarn-strength parameter

C is the cotton count (Ne)

M is the *twist multiplier* (English cotton system)

T is the ineffective twist multiplier

F is the drafting parameter

$B = 0,014$

$T = 4,5 - 0,15\,P$

$F = 2,1/(P - 8)$

Every cotton has to be spun to at least one count so as to establish P[507].

From results of 200 micro-spinning tests of 90 widely different cottons it has been concluded that yarn breaking tenacity was highly correlated with 2,5% span length, Stelometer tenacity and micronaire, correlations of the order of 0,9 or higher were obtained for 12,5, 17 and 25 tex yarns[240].

Ramey *et al*[345] processed 42 different cottons into 12 and 27 tex ring yarns and 27 tex rotor yarns. Fibre length and strength explained most of the observed variation in yarn strength. Tenacity at ⅛″ gauge on its own explained nearly 80% of the observed variation in the strength of all the yarns with either upper half mean length or mean length explaining some 50% of the observed variation. Micronaire did not significantly affect yarn tenacity. Fibre extension also had a small negative effect on yarn tenacity but neither micronaire nor fibre fineness or maturity (Arealometer A and N values) had a significant effect[345].

Fibre elongation is closely related to yarn elongation although the degree of correlation is influenced by yarn twist, yarn number and fibre length[493]. High fibre elongation produces yarns of high elongation but its effect on other yarn properties and end breakages is small. Its effect on finished fabric elongation is also small. It has a small effect on end breakages during spinning, the higher the elongation the lower the end breakages. It has been found[489] that instrumental analysis of fibre properties accounted for 85% of the variation in break factor, 81% in spinning production rate at 40 ends down per 1 000 spindle hours, 78% in manufacturing waste and 36% in yarn appearance. Corresponding values for classer's measurements were 47, 58, 34, 43 and 26% respectively[489].

The strength of raw cotton yarns can often be increased perceptibly by solvent extraction of the natural fibre wax, or by kier-boiling which achieves the same result[508]. Conversely, the addition of wax lowers yarn strength. Vincent[509] explained that treatment of yarn with dilute sulphuric acid prior to kier-boiling increases the strength of the finished yarn.

The following graph relates skein strength (CSP) to the staple ratio (staple length/fibre linear density) for 10 tex carded yarns spun from different Egyptian cottons[510].

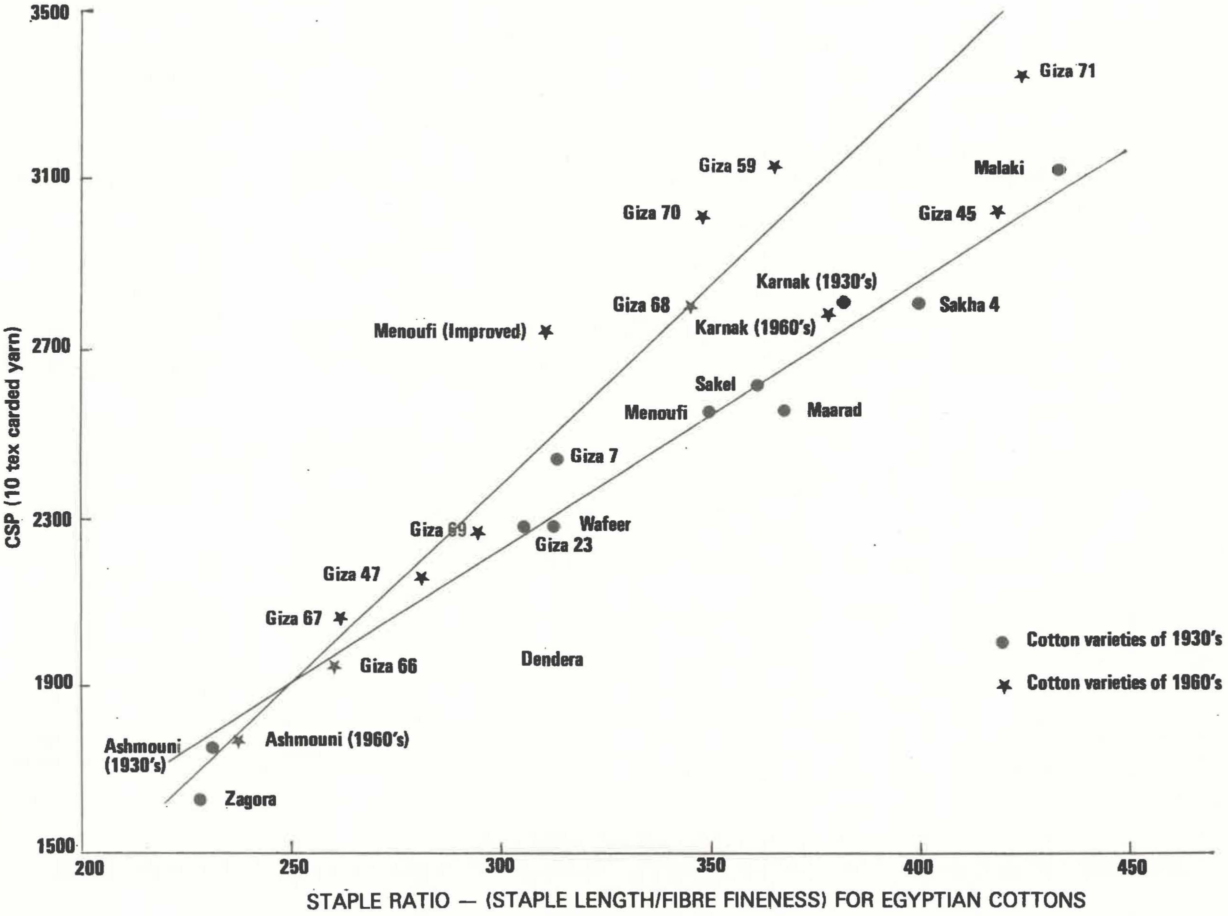


FIGURE 32

Relation of skein strength to the staple ratio[510]

The following table give some general properties for U.S. cottons as well as the corresponding yarns.

TABLE 69

PERFORMANCE LEVELS OF US COTTONS, YARN COUNT SPUN AND USUAL RANGE OF FIBRE PROPERTIES

Performance level	Representative varieties		Yarn tex	Nominal Staple Length		Micronaire reading	Fibre Tenacity at (⅛″) 3,2 mm gauge (cN/tex)
				(in.)	(mm)		
1	Central & West Texas & Oklahoma	Lankart 57 Western stormproof	18—73	15/16—1	(23,8—25,4)	3,2—4,6	17—19
1a	High Plains of Texas	Gregg 35, Paymaster 202	18—73	15/16—1	(23,8—25,4)	3,2—4,0	19—21
1b	West Texas	Lankart XX 571 Lockett 4789A Paymaster IIIA	14—73	31/32—1 1/16	(24,6—27,0)	3,2—4,6	19—21
* 2	Imperial Valley Arizona Lower Rio Grande Valley Rain Belt	Coker 201 Deltapine 16 Stoneville 213	10—73	1 1/32—1 1/8	(26,2—28,6)	3,8—4,8	18—20
2a	Rain Belt	Coker 310	10—30	1 3/32—1 5/32	(27,8—29,4)	3,8—4,8	19—21
2b	San Joaquin Valley of California	Acala SJ-1	10—21	1 3/32—1 5/32	(27,8—29,4)	3,8—4,5	21—23
3	West Texas New Mexico & Arizona	Acala 1517	7,4—21	1 1/8—1 3/16	(28,6—30,2)	3,2—4,0	22—24
** 4	West Texas New Mexico & Arizona	Pima S-3 Pima 4	4,9—15	1 3/8—1 1/2	(34,9—38,1)	3,2—4,0	27—30

* Bread-and-Butter type

** Sewing thread mainly but also for fine yarns

The following two tables may be used as a guide to cotton yarn CSP and elongation (extension). It may be noted that yarn elongation is highly correlated with fibre elongation with an increase in elongation reducing breakages during weaving[198].

TABLE 70

Kind of yarn, staple length group and description	**CSP for the specified Cotton counts***	
Carded yarns:		
Short staple group:	**8s(74)**	**22s(27)**
Low	2144—2304	1738—1914
Average	2312—2472	1936—2112
High	2480—2640	2134—2310
Medium staple group:	**22s(27)**	**50s(12)**
Low	1892—2156	1300—1600
Average	2178—2442	1650—1950
High	2464—2728	2000—2300
Long staple group:	**22s(27)**	**50s(12)**
Low	1980—2332	1350—1750
Average	2354—2706	1800—2200
High	2728—3080	2250—2650
Combed yarns:		
Long staple group:	**22s(27)**	**50s(12)**
Low	2376—2728	1800—2200
Average	2750—3102	2250—2650
High	3124—3476	2700—3100
Extra-Long staple group:	**50s(12)**	**80s(7,4)**
Low	3050—3150	2560—2720
Average	3200—3300	2800—2960
High	3350—3450	3040—3200

Data source: 317 short staple, 1565 medium staple, 194 long staple and 100 extra-long staple lots of cotton tested from the crops of 1971—1975.

*Yarn tex given in parenthesis.

TABLE 71[198]

Kind of yarn, staple length group and description	Yarn elongation in per cent for the Specified yarn counts*	
Carded yarns:		
Short staple group:	**8s(74)**	**22s(27)**
Low	6,4—7,0	5,3—5,9
Average	7,1—7,7	6,0—6,6
High	7,8—8,4	6,7—7,3
Medium staple group:	**22s(27)**	**50s(12)**
Low	5,2—5,8	3,6—4,2
Average	5,9—6,5	4,3—4,9
High	6,6—7,2	5,0—5,6
Long staple group:	**22s(27)**	**50s(12)**
Low	5,4—5,8	4,1—4,5
Average	5,9—6,3	4,6—5,0
High	6,4—6,8	5,1—5,5
Combed yarns:		
Long staple group:	**22s(27)**	**50s(12)**
Low	5,9—6,3	4,5—4,9
Average	6,4—6,8	5,0—5,4
High	6,9—7,3	5,5—5,9
Extra-Long staple group:	**50s(12)**	**80s(7,4)**
Low	5,2—5,4	4,5—4,7
Average	5,5—5,7	4,8—5,0
High	5,8—6,0	5,1—5,3

Data source: 317 short staple, 1565 medium staple, 194 long staple and 100 extra-long staple lots of cotton tested from the crops of 1971—1975.

*Cotton count, with yarn tex given in parenthesis.

Louis *et al*[511, 512] have related the lea and single thread strength of cotton yarns.

The optimal amount yarn twist for the raw material in question can be calculated in advance from the principle fibre properties. As an example which does not claim general validity, however, the following formula is given for the critical degree of twist[217]:
Tex Twist Factor = 53,2 – 0,66 x (2,5% Span Length in mm) + 1,52 x (micronaire).

It has been stated that the twist factor (K) for maximum yarn strength can also be calculated as follows[513, 514]:

$$K = 2{,}72 + \frac{615{,}6}{L^{1{,}85}}$$

where L is classer's staple length in mm .

K is English cotton system (to convert to tex twist factor multiply by 9,6).

Louis and Fiori[515] obtained the following empirical formula for predicting the twist factor required for maximum yarn skein strength (Tmax). The results were based on data collected for American medium staple cottons.

$$T_{max} = 56{,}5 + 2{,}39\,(\text{micronaire}) - 1{,}6\,(50\%\ \text{Span Length in mm}) - 0{,}16\,(\text{Tenacity in cN/tex at } 1/8''\ \text{gauge}) - 0{,}37\,(\text{Bundle Extension})$$

$n = 60$; $r = 0{,}89$.

T_m is the tex twist factor. To obtain English cotton twist factor multiply by 0,104.

The following table has been given for relating yarn twist required for maximum strength to the upper half mean length[2]. It appears that the upper-half mean length has been replaced by, and is approximately equivalent to, the 2,5% span length, while the mean length has been replaced by the 50% span length.

TABLE 72

RELATIONSHIP BETWEEN UPPER-HALF MEAN LENGTHS AND TWIST MULTIPLIERS FOR MAXIMUM YARN STRENGTH[2]

Upper Half Mean Length* (Fibrograph)		English Cotton Twist Multiplier	Tex Twist Factor	Upper Half Mean Length* (Fibrograph)		English Cotton Twist Multiplier	Tex Twist Factor
in.	mm			in.	mm		
0,62 and shorter	< 15,7	5,35	51,2	0,98-1,01	24,9-25,7	4,10	39,2
0,63-0,66	16 -16,8	5,15	49,3	1,02-1,05	25,9-26,7	4,05	38,8
0,67-0,70	17 -17,8	5,00	47,9	1,06-1,09	26,9-27,7	3,95	37,8
0,71-0,74	18 -18,8	4,85	46,4	1,10-1,13	27,9-28,7	3,90	37,3
0,75-0,78	19,1-19,8	4,70	45,0	1,14-1,16	29 -29,5	3,85	36,8
0,79-0,82	20,1-20,8	4,60	44,0	1,17-1,20	29,7-30,5	3,80	36,4
0,83-0,86	21,1-21,8	4,45	42,6	1,21-1,24	30,7-31,5	3,75	35,9
0,87-0,89	22,1-22,6	4,35	41,6	1,25-1,28	31,8-32,5	3,70	35,4
0,90-0,93	22,9-23,6	4,25	40,7	1,29-1,32	32,8-33,5	3,65	34,9
0,94-0,97	23,9-24,6	4,20	40,2	1,33-1,36	33,8-34,5	3,60	34,5

*Very nearly equal to 2,5% Span Length

ℓ = 2,5% span length (mm)
and

$$U = \text{uniformity ratio (i.e. } \frac{50\% \text{ Span Length}}{2,5\% \text{ Span Length}} \text{ x } 100)$$

with CSP = (310 − Count) x $\sqrt{FQI_6}$ for carded yarns.

The proliferation of units must be noted here in that maturity coeffic (M_C) and not maturity ratio (M) is used, the yarn count is the English Co Count (Ne), the 50% Span length is used in place of the 2,5% span length the bundle tenacity is expressed in gf/tex. To convert gf/tex to cN/tex m ply by 0,98. Moreover micronaire is used and not fibre linear density.

The equation for carded yarns was also found[534] to apply to com yarns. The general belief that the fibre parallelisation achieved through co ing would significantly contribute to yarn quality was not supported. following relationship was derived for combed yarns.

$$CSP = (310 - \text{count})\ (1 + \frac{W}{100} \sqrt{FQI_6}\ )$$

where W is the comber waste in % and the other symbols are as before. I pears therefore that the CSP increases by 1% for every 1% increase in cor waste. Some FQI_6-values required for different CSP levels are given b (assuming a comber waste of 10%)[534]:

TABLE 73

FQI_6-VALUES REQUIRED TO OBTAIN CERTAIN CSP LEVELS

(10 tex) 60's combed		(7,5 tex) 80's combed		(6 tex) 100's combed	
CSP	**FQI_6**	**CSP**	**FQI_6**	**CSP**	**FQI_6**
1600	34	1900	56	2000	75
1700	38	2000	63	2100	83
1800	43	2100	69	2200	91
1900	48	2200	76	2300	99
2000	53	2400	90	2400	108

$$FQI_6 = \frac{(50\% \text{ Span Length}) \text{ x} \begin{pmatrix}\text{Bundle Strength} \\ \text{in gf/tex at 3 mm}\end{pmatrix} \text{ x} \begin{pmatrix}\text{Maturity} \\ \text{Coefficient}\end{pmatrix}}{(\text{Micronaire value})}$$

In another article[507, 535] it is stated that the rate of increase of skein strength is 0,8% for every 1% of comber noil removed, i.e. the skein strength will be 8% higher if 10% of comber noil is removed than if no noil is removed (i.e. than that of the *carded* yarn). If no information on comber noil is available a conservative value of 12,5% can be assumed, i.e. generally combed yarns should be about 10% stronger than a carded yarn spun from the same cotton[535].

Elsewhere it is stated that for each 2% change in the amount of comber waste removed there is a 1% change in yarn strength[495].

Subramanian *et al*[536] suggested a fibre quality index:

$$FQI_7 = \frac{\ell\sqrt{SSo}}{\sqrt{HH_S}}$$

where ℓ = effective length in 32nds
S and So are bundle strengths at ⅛" and zero-gauge (gf/tex).
H is actual fibre fineness
H_S is standard fibre fineness } in mtex

Once again using the more widely accepted fibre properties and metric units we can write:

$$FQI_8 = \frac{\ell\sqrt{SSo}}{\sqrt{HH_S}}$$

where ℓ now becomes the 2,5% span length or the staple length (in mm)
S and So are the ⅛" and zero-gauge bundle tenacities in cN/tex
H is the actual fibre fineness (in mtex)

and $H_S = \frac{H}{M}$ is the standard fibre fineness (in mtex),

i.e. the fineness the cotton would have at a maturity ratio (M) of *one*.

Iyenger and Gupta[537] suggested that CSP can be approximated by either:

$$FQI_9 = \frac{L - 10}{\sqrt{m}} \times S$$

or

$$FQI_{10} = \frac{L - 10}{\sqrt{f}} \times S \times U$$

where L is the mean length (mm)
f is in this case the actual fibre fineness and
S is the fibre bundle tenacity at 3,2 mm (⅛") gauge.

The following cotton fibre quality index has been used[538, 539], for the contributions of the fibre length and fineness to CSP:

$$FQI_{11} = \frac{\text{Staple Length}}{\text{Fibre mtex}}$$

tings of the cages, with apron drafting, can also cause short slubs. "Crackers" are mainly due to excessively long fibres[545].

An increase in spinning draft (i.e. keeping roving tex constant but reducing the yarn tex) from 14 to 28 causes a significant increase in the number of yarn faults. At the same yarn linear density doubling the draft (from 15 to 30) increased the number of disturbing faults by a factor of about 5, mainly due to more fly being generated at the higher draft. Increased cage opening settings increased yarn irregularity and faults significantly. More so for carded than combed yarns.

Taking an overall view of the different spinning systems, it appears that regular cleaning, particularly at the spinning frame, should reduce the total number of faults in the yarn by something like between 50% and 75%. Fly-type faults can be reduced by a half without incurring too high costs in terms of cleaning. Fly in the processing prior to spinning result in slubs in the yarn[545].

The following table is a guide to typical spinning end-breakage frequencies. The 50% values may be taken as "average" values.

TABLE 75

USTER STATISTICS — EXPERIENCE VALUES FOR END-BREAK FREQUENCY AT RING SPINNING MACHINES (PROVISIONAL)[547]

Distribution of Spinning Mills Worldwide (in %)	**End-breaks per 1 000 spindle hours**		
	Combed cotton (100% cotton)	**Carded cotton (100% cotton)**	**Worsted (100% wool)**
10	12	14	38
50	23	28	75
90	48	58	150

YARN LINEAR DENSITY VARIATION

Generally, a measure of yarn linear density (count) variation is obtained by weighing say a 100 metre length of yarn from each of at least 20 spinning tubes.

The CV between bobbins (CV_B) has a bearing on weft bars whilst CV within bobbins ($CV_W\%$) affect general appearance of a fabric[548]. A difference of 7% in yarn count (linear density) can result in a weft stripe in a sensitive fabric construction, a difference of 10% nearly always leads to a visible weft stripe. Similar trends occur for knitted fabrics. Accordingly the total variation (CV_T) of the yarn count should not exceed 3%. It appears that CV of count (based upon 100 m lengths) should preferably be kept below about 2,5% (2% should be aimed at)[548]. Worldwide averages CV of count (linear density) based upon 100 metre lengths of yarn are 2,4% for combed cotton[549] and 3,0% for carded cotton[549].

REFERENCES

1. Groz-Beckert Nadelfabriken Pamphlet (1976).
2. Grover, E. B. and Hamby, D. S., Handbook of Textile Testing and Quality Control, Textile Book Publishers Inc. (Interscience New York, 1960).
3. *Text Asia,* **10** (11), 124 (Nov., 1979).
4. Gutknecht, T., *Intern. Text. Bull.* (Spinning), No. 3, 329 (1978).

4a. *Text. Asia,* **10** (9), 231 (Sept., 1979).

5. *L'Industrie Text.,* No. 1095, 1096 (Dec., 1979).
6. *Cotton Int.,* p. 257 and 258 (1980).
7. *Textile Organon,* **50** (6) (June, 1979).
8. *Text. Month,* 60 (March 1980).
9. *Amer. Text. (K/A Edition), AT-9* 38 (April, 1980).
10. Albrecht, W., *Text. Asia,* **10**, 140 (Dec., 1979).
11. Mehta, P. C., *Text. Inst. Industr.,* **17** (3), 95 (1979).
12. Van Winkle, T. L., Edeleanu, J., Prosser, E. A. and Walker, C. A., *American Scientist,* **66**, 280 (1978).

12a. Koedam, H. E., *De Tex. Textilis,* 116 (March, 1980).

13. The Knitter, *AT-9,* 10 (Jan., 1980).
14. Collins, K. J., Evans, R. B. and Barry, R. D., *Economics, Statistics & Cooperative Service,* Washington (June, 1979).
15. *Canad. Text. J.,* **96,** 24 (Nov., 1979).
16. *Int. Text. Bull.,* No. 1, 92 (1980).
17. Koedam, H. E., *Knitt. Times,* **48,** 16 (6 Aug., 1979).
18. Luan, D. C., Ph.D. Thesis, University of Texas (Cotton Economic Research, (Oct., 1959).
19. Shroff, J. J., *Colourage,* **14** (12), 25 (9 June, 1977).
20. Arnold, M. H., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.23 (1969).

20a. Cornish-Bowden, M. E. quoted by Billett, R., *Farmer's Weekly,* **14** (28 Nov., 1979).

21. Wakeham, H., *Text. Res. J.,* **26,** 925 (1956).
22. Lord, E., *J. Text. Inst.,* **47,** T209 (1956).
23. Chytiris, T., *Melliand Textilber.,* **58,** 789 (1978).
24. "Better Cottons", USDA Research Administration, Beltsville, Md. (Sept., 1947).
25. Ono, Y., "Studies on the Cotton Fiber as the Material for Cotton Spinning, Part I, Japan Cotton Text Inst. Ozaka, (Japan, 1958).
26. Rollins, M. L. and Tripp, V. W., *Text. Res. J.,* **24,** 345 (1954).
27. Morton, W. E. and Hearle, J. W. S., "Physical Properties of Textile Fibres", Heinemann and The Textile Institute (1975).
28. Kerr, T., *Protoplasma,* **27,** 229 (1937).
29. Berriman, L. P., *Text. Res. J.,* **36,** 272 (1966).

30. Berriman, L. P. and Benedict, H. M., *Text. Res. J.*, **33**, 1026 (1963).
31. DuPré, M., *Text. Res. J.*, **29**, 151 (1959).
32. Hertel, K. L. and Lawson, R., *Text. Bull.*, **94** (5), 23, 63 (1968).
33. Compton, J., Martin, W. H., Word, B. H. and Barber, R. P., *Text. Res. J.*, **25**, 58 (1955).
34. Balls, W. L., "Studies of Quality in Cotton", Macmillan, London (1928).
35. Berriman, L. P., *Text. Res. J.*, **33**, 1027 (1963).
36. Williams, J. L., Sugg, H. and Ingram, P., *Text. Res. J.*, **46**, 434 (1976).
37. Eckberg, R., Ingram, P. and Williams, J. L., *Text. Res. J.*, **46**, 508 (1976).
38. Ingram, P., Eckberg, R. and Williams, J. L., *Text. Res. J.*, **46**, 587 (1976).
39. Eckberg, R. P., Ingram, P. and Williams, J. L., *Text. Res. J.*, **46**, 629 (1976).
39a. Rousselle, M-A. and Nelson, M. L., *Text. Res. J.*, **50**, 103 (1980).
40. Rowland, S. P., Nelson, M. L., Welch, C. H. and Hebert, J. J., *Text. Res. J.*, **46**, 194 (1976).
41. Kassenbeck, P., *Text. Res. J.*, **40**, 330 (1970).
42. The Versatility of Cotton, *Int. Inst. Cotton Publication.*
43. Sloan, W. G., Hoffman, M. J., Robinson, H. M., Moore, H. B. and Cooper, S., *Amer. Dyest. Rep.*, **52**, P.412 (1963).
44. Mock, U., *Melliand Textilber.* (Eng.Ed), **2**, 769 (1974).
45. Lennox-Kerr, P., *Text. Industr.*, **134** (10), 57 (Oct., 1970).
46. Mauersberger, H. R., Ed., Textile Fibres 5th Ed., New York, Wiley (1948).
47. Patel, G. S. and Patil, N. B., *Text. Res. J.*, **45**, 168 (1975).
48. Lord, E., *J. Text. Inst.*, **55**, T69 (1964).
49. Pearson, N. L., *Text. Res. J.*, **20**, 152 (1950).
50. Balls, W. L., "Development and Properties of Raw Cotton", London, A. C. Black Ltd., (1915).
51. Marsh, P. B., Barker, H. D., Kerr, T. and Butler, M. L., *Text. Res. J.*, **20**, 288 (1950).
52. Burkitt, F. H. and Heap, S. A., *Amer. Dyest, Rep.*, **61**, 58 (June, 1972).
53. Neelakantan, P., *Text. Res. J.*, **47**, 178 (1977).
54. Culp, T. W., Harrell, D. C. and Kerr, T., *Beltwide Cotton Production Res. Conf.*, p.103 (1976).
55. Raes, G. and Fransen, T., *Text. Res. J.*, **24**, 1000 (1954).
56. Hessler, L. E., Towery, J. D. and Power, B. K., *Text. Res. J.*, **24**, 1010 (1954).
57. Hertel, K. L., *Text. Res. J.*, **27**, 571 (1957).
58. Meredith, R., *J. Text. Inst.*, **36**, T107 (1945).
59. Virgin, W. P. and Wakeham, H., *Text. Res. J.*, **26**, 177 (1956).

60. Pillay, K. P. R. and Shankaranarayana, K. S., *Text. Res. J.*, **31**, 515 (1961).
61. Chytiris, T., *Text. Res. J.*, **31**, 175 (1961).
62. Calkins, E. W. S., *Text. Res. J.*, **31**, 176 (1961) and Iyengar, R. L. N., *Text. Res. J.*, **31**, 177 (1961).
63. Jones, D. M., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.73 (Paris, 1969).
64. Muhlethaler, K., *Bio-Chem. Biophys. Acta,* **3**, 15 (1949).
65. Tripp, V. W., Moore, A. T. and Rollins, M. L., *Text. Res. J.*, **21**, 886 (1951).
66. Roelofsen, P. A., *Bio-Chem. Biophys. Acta,* **7**, 43 (1951).
67. Hock, C. W., Ramsey, R. C. and Harris, M. J., *J. Research Natl. Bur. Standards,* **26**, 93 (1941).
68. Kerr, T., *Text. Res. J.*, **16**, 249 (1946).
69. Sisson, W. A., *Contrib. Boyce Thompson Inst.*, **9** (3), 239 (1938).
70. Wiegerink, J. G., *Text. Res. J.*, **9**, 357 (1939).
71. Wakelyn, P. J., Loewenschuss, H. and Roark, B. A., *Text. Res. J.*, **42**, 597 (1972).
72. Altschul, A. M., Lyman, C. M. and Thurber, F. H. in "Processed Plant Protein Foodstuffs", Ed. A. M. Altschul, New York Academié Press, p.485 (1958).
73. Tharp, W. H., in "Cottonseed and Cottonseed Products", Ed. A. E. Bailey, New York Interscience, p.144 (1948).
74. Tripp, V. W., Moore, A. T. and Rollins, M. L., *Text. Res. J.*, **21**, 886 (1951).
75. Tharp, W. H., in "Cottonseed and Cottonseed Products", Ed. A. E. Bailey, New York Interscience, p.121 (1948).
76. Bailey, A. E., Ed. in "Cottonseed and Cottonseed Products", New York, Interscience, p.365 (1948).
77. Balls, W. L., *Proc. Roy. Soc.,* (London), B90, 542 (1919).
78. Kassenbeck, P., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.455 (Paris, 1969).
79. Ingram, P., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.519 (Paris, 1969).
80. Raes, G., Fransen, T. and Verschraege, L., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.475 (Paris, 1969).
81. Kulshreshtha, A. K., Chudasama, V. P. and Dweltz, N. E., *J. Appl. Pol. Sci.*, **20**, 2329 (1976).
82. Sridharan, V., *Colourage,* **23**, 31 (9 Dec., 1976).
83. Johnson, A., Maheshwari, K. C. and Miles, L. W. C., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.577 (Paris 1969).
84. Du Bois, W. F., *Melliand Textilber.*, **55**, 1002 (1974).

85. Ward, K., *Text. Res. J.*, **20**, 363 (1950).
86. Hermans and Weidinger, *J. Polymer Sci.*, **4**, 135 (1949).
87. Mark, H. F., Gaylord, N. G. and Bikales, N. M. (Eds.), Encyclopaedia of Polymer Science and Technology, Vol.3, p.135 (1965).
88. Davidson, G. F., *J. Text. Inst.*, **18**, T175 and T275 (1927).
89. Nickerson, *Ind. Eng. Chem.*, **33**, 1022 (1941); **34**, 85 and 1480 (1942); **37**, 1115 (1945); **38**, 299 (1946).
90. Conrad and Scroggie, *Ind. Eng. Chem.*, **37**, 592 (1945).
91. Philipp, H. J., Nelson, M. L. and Ziifle, H. M., *Text. Res. J.*, **17**, 585 (1947) and **18**, 149, 155 (1948).
92. Hermans and Weidinger, *J. Appl. Phys.*, **19**, 491 (1948).
93. Hermans, "Contribution to the Physics of Cellulose Fibers", New York, Elsevier, p.50 (1946).
94. Magne, Portas and Wakeham, *J. Am. Chem. Soc.*, **69**, 1896 (1947).
95. Frilette, H. and Mark, *J. Amer. Chem. Soc.*, **70**, 1107 (1948).
96. Liang, C. Y. and Marchessault, R. H., *J. Polymer Sci.*, **37**, 385 (1959).
97. Weiss, A. H., *Text. Res. J.*, **42**, 526 (1972).
98. Staudinger, H. and Feuerstein, K., *Ann.* **526**, 72 (1936) — quoted in ref. 46.
99. Bhujang, K. S. and Nanjundayya, C., *Text. Res. J.*, **25**, 137 (1955).
100. Kling, Dr., *De Tex-Textilis,* No. 12, 38 (Dec., 1976).
101. Merkenich, K. and Kling, A., *Textil-Praxis Int.*, **34**, 1388 and 1497 (1979).
102. McCall, E. R. and Jurgens, J. F., *Text. Res. J.*, **21**, 19 (1951).
103. Zeisel, S. in "Rohstoffe des Pflan-zenreiches", Leipzig (1926).
104. Manudhane, R. G., *Colourage,* **22**, 63 (15 May, 1975).
105. Hamby, D. S., The American Cotton Handbook, Vol. 1, *Interscience Publ.*, p.72 (1965).
106. Kearney and Schofield as quoted in ref. 46.
107. Geake as quoted in ref. 46.
108. Fargher and Probert as quoted in ref. 46.
109. Zerbe, C., "Mineralöle und verwandte produkte" (1952).
110. Rollins, M. C., in "The Cotton Handbook", Vol. I, Ed., D. S. Hamby, New York, Interscience, p.70 (1965).
111. Guthrie, J. D. in "Chemistry and Chemical Technology of Cotton", Ed. K. Ward Jr., New York, Interscience, p.1 (1955).
112. Heyn, A. N. J., *Text. Res. J.*, **20**, 771 (1950).
113. Moss, E., *Britt. J. Appl. Phys. Suppl.*, **I**, 19 (1951).
114. Pandey, S. N. and Iyengar, R. L. N., *Text. Res. J.*, **40**, 1053 (1970).
115. Hadwich, F., *Indian Text. J.*, **89**, 45 (June, 1979).
116. Abbott, G. M. and Robinson, G. A., *Text. Res. J.*, **47**, 199 (1977).
117. Viswanathan, A., *J. Text. Inst.*, **64**, 553 (1973).
118. Knecht, E., *J. Text. Inst.*, **2**, 22 (1911).

119. Adcock, A., *Text. J. Austr.*, **49**, 34 (Sept., 1974).
120. Fargher, R. G., Hart, L. R. and Probert, M. E., *J. Text. Inst.*, **18**, T29 (1927).
121. Mehta, H. U., Gupta, K. C. and Bhatt, V. R., *Text. Res. J.*, **46**, 356 (1976).
122. Varghese, J., Pasad, D. M. and Dixit, S. R., *Indian J. Text. Res.*, **3**, 61 (Sept., 1978).
123. Egerton, G. S. and Fisher, K. M., *Text. Res. J.*, **41**, 789 (1971).
124. Weiner, L. I., *Text. Res. J.*, **32**, 524 (1962).
125. Starvakus, E. J. and Platt, M. M., *Text. Industr.*, **124** (10), 141 (1960).
126. Varghese, J., *Indian Text. J.*, **87**, 151 (March, 1977).
127. Varghese, J. and Pasad, D. M., *Amer. Dyest. Rep.*, **67**, 39 (April, 1978).
128. Grant, J. N., Kingsbery, E. C. and Tsoi, R. H., *Text. Res. J.*, **33**, 839 (1963).
129. Becher, D., *SAWTRI Cotton Symposium* (May 1974).
130. Grimes, Mary A., *Text. Res. J.*, **22**, 637 (1952).
131. Nerurkar, S. K., *Indian Text. J.*, **89**, 95 (Nov., 1979).
132. Mangialardi, G. J., *Text. Res. J.*, **49**, 476 (1979).
133. Baker, R. V., Columbus, E. P. and Laird, J. W. (U.S. Dept. of Agric.), U.S. Dept. of *Agri.*, Agri. Research Service, Washington, D.C., Jan., 1977, p.19 Tech. Bull. No. 1540.
134. Lyons, D. W. and Hatcher, J. D., *Text. World*, **124**, 56 (March, 1974).
135. Cook, J. M., *Text. Res. J.*, **26**, 534 (1956).
136. Shete, D. G. and Sundaram, V., *Cotton Development*, **3**, No.4, 3 (1974).
137. Harmancioglu, M., *Textil-Praxis*, **34**, 1466 (1979).
138. Williams, S. and Towery, J., *Cotton*, **109**, 110 (April, 1945).
139. Lord, E., *J. Text. Inst.*, **47**, T16 (1956).
140. Griffin, A. C., *Text. Res. J.*, **49**, 123 (1979).
141. Nelson, M. L., Andrews, F. R. and Grant, J. N., *Text. Res. J.*, **29**, 260 (1959).
142. Leitgeb, D. J. and Wakeham, H., *Text. Res. J.*, **24**, 1047 (1954).
143. Baker, R. V., *Cotton Intern.*, 80 (1976).
144. Wigington, J. T., *Cotton*, **105**, 62 (July, 1941).
144a. Baker, R. V., *Cotton Ginners Journal* and *Yearbook* (March, 1968).
145. *Southern Text. News*, **31** (1975).
146. Clark, S. P., *J. Amer. Oil Chem. Soc.*, **53**, 684 (Nov., 1976).
147. Mikula, G. W., SABS Symposium: Quality Assurance in Modern Textiles, Pretoria (1974).
148. Simon, S. A. and Harmon, C., *Text. Res. J.*, **24**, 12 (1954).
149. Wright, J. W., *Textil-Praxis*, **25**, 72 (1970).
150. Gangli, B., *Textil-Praxis*, **25** (2), 69 (1970).

151. Barker, R. L. and Lyons, D. W., *Text. Res. J.*, **47**, 289 (April, 1977).
152. Lyons, D. W. and Barker, R. L., *Text. Res. J.*, **46**, 135 (1976).
153. Berkley, E. E., *Text. Res. J.*, **27**, 712 (1957).
154. Berkley, E. E., Kennamer, H. G. and Powell, S., *Cotton Trade J. Intern. Ed.* (1954).
155. Nickerson, D. and Tomaszewski, J. J., *Text. Res. J.*, **28**, 485 (1958).
156. Nickerson, D., *Text. Res. J.*, **34**, 645 (1964).
157. Marsh, P. B., Merola, G. V. and Butter, M. L., *Text. Res. J.*, **28**, 95 (1958).
158. Lawson, R., Ewald, P. R. and Ramey, H. H., *Text. Res. J.*, **45**, 698 (1975).
159. Sankov., E. A., *Tekhnol. Tekstil. Promys.*, **123** (3), 26 (1978).
160. Barker, G. L. and McClendon, R. W., *Beltwide Cotton Res. Conf.*, p.122 (1976).
161. Marsh, P. B., Merola, G. V. and Simpson, M. E., *Text. Res. J.*, **23**, 831 (1953).
162. Nickerson, D., as quoted by Simon and Harmon in Ref. 148.
163. Clegg, G. C., *J. Text. Inst.*, **31**, T49 (1940).
164. Munchi, V. G., Proc. "Lecture Series on Spinning", The Textile Association of India, p.8 (1975).
165. Wyatt, B. G., *Text. Res. J.*, **42**, 474 (1972).
166. Roberts, C. W. and Cheung, P. S. R., *Text. Res. J.*, **48**, 91 (1978).
167. Hook, C. W., *Text. Res. J.*, **20**, 141 (1950).
168. Marsh, P. B., Guthrie, L. R. and Butler, M. L., *Text. Res. J.*, **21**, 565 (1951).
169. Hall, L. T. and Elting, J. P., *Text. Res. J.*, **21**, 580 (1951).
170. Marsh, P. B., Bollenbacher, K., Butler, M. L. and Merola, G. V., *Text. Res. J.*, **24**, 31 (1954).
171. Marsh, P. B., *Text. Res. J.*, **25**, 739 (1955).
172. Wakeham, H., Stickley, H. and Spicer, N., *Text. Res. J.*, **24**, 1037 (1954).
173. Waters, W. T. and Phillips, J., *Text. Res. J.*, **31**, 608 (1961).
174. De Gruy, I. V. and Carra, J. H., *Text. Res. J.*, **47**, 91 (1977).
175. Venkatesh, G. M. and Dweltz, N. E., *Text. Res. J.*, **45**, 230 (1975).
176. Belser, R. B. and Taylor, J. L., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.111 (Paris, 1969).
177. Tijskens, M. M., *Melliand Textilber.*, **56**, 222 (1975).
178. Cocoros, C. B., *Amer. Text. Rep./Bull.*, **AT-5**, 16 (Nov., 1976).
179. Parker, R., *Amer. Text. Rep./Bull.* **AT-3**, 48 (May, 1974).
180. Sheehan, W. C., Bailey, T. L. W. and Compton, J., *Text. Res. J.*, **23**, 736 (1953).
181. Whitwell, J. C. and Schwenker, R. F., *Text. Res. J.*, **23**, 175 (1953).
182. Balasubramanian, N. *Text. Res. J.*, **39**, 155 (1969).

183. Desai, R. L., *Text. Res. J.*, **39**, 882 (1969).
184. Lee, J. S. and Finkner, M. D., *Text. Res. J.*, **38**, 1044 (1968).
185. Marsh, P. B., Barker, H. D., Kerr, T. and Butler, M. L., *Text. Res. J.*, **20**, 297 (1950).
186. Goldthwait, C. F. and Robinson, H. M., *Text. Res. J.*, **28**, 120 (1958).
187. Roberts, C. W., Cheung, P. S. R. and Perkins, H. H., *Text. Res. J.*, **48**, 91 (1978).
188. Roberts, C. W., Koenig, H. S., Merrill, R. G. and Cheung, P. S. R., *Text. Res. J.*, **46**, 374 (1976).
189. Hadwich, F., *Melliand Textilber.*, **42**, 487 (1961).
190. Talpay, B. M., *Melliand Textilber.*, **49**, 641 (1968).
191. Perkins, H. H., *Text. Industr.*, **135** (3), 49 (1971).
192. Cheung, P. S. R., Roberts, C. W. and Perkins, H. H., *Text. Res. J.*, **50**, 55 (1980).
193. Perkins, H. H., *Text. World,* **120**, 49 (July, 1970).
194. Nickerson, D. and Tomaszewski, J. J., *Text. Res. J.*, **28**, 528 (1958).
195. Wyatt, B. G., *Text. Industr.*, **140**, 144 (Oct., 1976).
196. Prier, H. W. and Sasser, P. E., *Text. Res. J.*, **42**, 410 (1972).
197. Rusca, R. A., *Text. Mach. Soc. Japan Symp.* (15 July, 1970).
197a. Hunter, L., Textiles: Some Technical Information and Data, Part II SAWTRI Special Publication "Wol 47" (1978).
198. Summary of Cotton Fiber and Processing Test Results for Crop of 1977, *USDA Publication* (Aug., 1978).
199. Williams, J. F., Vlases, G. and Fielding, H., *Text. Res. J.*, **20**, 719 (1950).
200. Textile Terms and Definitions, 5th Edition, p.83 (1963).
201. Wakeham, H., *Text. Res. J.*, **25**, 422 (1955).
202. Preysch, M., *Spinlab Publication* (Zurich, November, 1970).
203. Simpson, J., Corley, J. R. and Schnabel, G. G., *Text. Res. J.*, **27**, 812 (1957).
204. White, E., *Proc. Textile Quality Control Ass.* (1966).
205. Prakash, J., *Text. Res. J.*, **34**, 857 (1964).
206. Manual for Uster Spectrograph, Part III.
207. Cotton Testing Service Tests, Available Equipment and Techniques, and Basis for Interpreting Results, *USDA Publication* (May, 1970).
208. *American Cotton Gr.*, **12**, 18 (July, 1976).
209. Audivert, R. and De Castellar, M. D., *J. Text. Inst.*, **63**, 356 (1972).
210. Woo, J. L., *J. Text. Inst.*, **58**, 557 (1967).
211. Wesson, M. J., "Physical Textile Testing", W.R.C. Smith Publishing Co., Atlanta, Georgia, p.27 (1951).
212. Sundaram, V. and Iyengar, R. L. N., Handbook of Methods of Tests for Cotton Fibres, Yarns and Fabrics published by Cotton Technological Research Laboratory (Bombay, 1968).

213. Prentice, A. N. "Cotton", Longman Group Ltd., (London, 1972).
214. Lord, E. and Underwood, C., *Emp. Cotton Gr. Rev.*, **35**, 26 (1958).
215. Lord, E., *J. Text. Inst.*, **33**, T205 (1945).
216. Köhler, S., *J. Text. Inst.*, **25**, T141 (1934).
217. Preysch, M., *Intern. Text. Bull. (Spinning)*, No. 2, 299 (1979).
218. Mehta, P. C., Mehta, R. D. and Modi, J. R., *Text. Res. J.*, **32**, 77 (1962).
219. Tallant, J. D. and Fiori, L. A., *Text. Res. J.*, **31**, 866 (1961).
220. Tallant, J. D. and Fiori, L. A., *Text. Res. J.*, **30**, 792 (1960).
221. Merchant, V. B., *Text. Res. J.*, **32**, 610 (1962).
222. Tallant, J. D., Fiori, L. A. and Legendre, D. C., *Text. Res. J.*, **29**, 687 (1959).
223. Tallant, J. D., Fiori, L. A. and Sands, J. E., *Text. Res. J.*, **32**, 50 (1962).
224. Artzt, P., *Intern. Text. Bull. (Spinning)* No. 4, 139 (1978).
225. Tallant, J. D., Fiori, L. A., Herschel, W. L. and Castillon, A. V., *Text. Res. J.*, **33**, 1005 (1963).
226. Srikantaiah, G., *Indian J. Text. Res.*, **3**, 129 (1978).
227. Hertel, K. L., *Text. Industr.*, **125** (6), 105 (1961).
228. Hertel, K. L. and Craven, C. J., *Text. Industr.*, **124**, 103 (July, 1960).
229. Spinlab USA, Model 183 Digital Fibrograph and Model 192 Fibrosample, p.20 (July, 1961).
230. Prakash, J., *Text. Res. J.*, **32**, 244 (1962).
231. Nayar, S. G. and Pai, S. B., *J. Text. Ass.*, **36** (3), 142 (1975).
232. Gordon, H. B., *Text. World*, **64**, 39 (1923).
233. Perkins, H. H. and Bargeron, J. D., *USDA Publication* 0-270-132 (1978).
234. Markezich, A. R., *Text. Res. J.*, **41**, 789 (1971).
235. Simpson, J. and Fiori, L. A., *Text. Res. J.*, **41**, 691 (1971).
236. Nolen, N. N., *Text World*, **124**, 95 (Dec., 1974).
237. Prakash, J. and Iyengar, R. L. N., *Text. Res. J.*, **35**, 90 (1965).
238. Lord, E., "The Origin and Assessment of Cotton Fibre Maturity" (Technical Research Division of IIC).
239. Brenner, F. C. and Scocca, P. M., *Text. Res. J.*, **26**, 899 (1956).
240. Tarrin, J. C. and Gutknecht, J., *L'Industrie Textile*, No. 1016, 756 (Oct., 1972).
241. Marth, C. T., Arthur, H. E. and Berkley, E. E., *Text. Res. J.*, **22**, 561 (1952).
242. Leitget, D. J. and Wakeham, H., *Text. Res. J.*, **26**, 543 (1956).
243. Perkins, H. H., *Text. Industr.*, **135** (3), 49 (1971).
244. Ramey, H. H., Lawson, R. and Worley, S., *Text. Res. J.*, **47**, 885 (1977).

245. El-Hattab, H. E., El-Shaer, M. H. and Soliman, M. H., *Text. Res. J.*, **42**, 655 (1972).
246. Turner, A. J. and Venkataraman, V., *J. Text. Inst.*, **25**, T1 (1934).
247. El-Hattab, H. E., El-Shaer, M. H. and Samra, A. M., *Text. Res. J.*, **42**, 650 (1972).
248. Regnery, W., *Text. Res. J.*, **22**, 49 (1952).
249. Marth, C. T., Arthur, H. E. and Berkley, E. E., *Text. Res. J.*, **22**, 561 (1952).
250. Simpson, J., *Text. Res. J.*, **42**, 661 (1972).
251. Fiori, L. A., Louis, G. L. and Sands, J. E., *Text. Res. J.*, **29**, 706 (1959).
252. Fiori, L. A., Louis, G. L. and Sands, J. E., *Text. Res. J.*, **30**, 926 (1960).
253. Mayne, S. C., Mathews, W. T. and Berkley, E. E., *Text. Res. J.*, **30**, 268 (1960).
254. Chatterjee, R. and Arora, R. K., *Text. Res. J.*, **44**, 327 (1974).
255. ICI Technical Information Leaflet D1551.
256. Hadwich, F., *Int. Text. Bull. (Spinning)* No. 1, 13 (1975).
257. Woo, J. L. and Postle, R., *Text. Res. J.*, **48**, 68 (1978).
258. ASTM D1442-75.
259. Dischka, V., *J. Text. Inst.*, **49**, T631 (1958).
260. Du Bois, W. F. and Van de Riet, D. F., *Text. Res. J.*, **24**, 265 (1954).
261. Iyengar, R. L. N., *Indian J. Agric. Sci.*, **11**, 866 (1941).
262. Lord, E., *Empire Cotton Gr. Rev.*, **25**, 180 (1948).
263. Peirce, F. T., *Report of 3rd E.C.S.C. Conference*, p.138 (1938).
264. Peirce, F. T. and Lord, E., *J. Text. Inst.*, **30**, T173 (1939).
265. Neelakantan, P., *J. Text. Inst.*, **66**, 332 (1975).
265a. Goldthwait, C. F. and Sloan, W. G., *Text. Res. J.*, **31**, 434 (1961).
266. Ohno, Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.157 (Paris, 1969).
267. Lord, E., *J. Text. Inst.*, **48**, T37 (1957).
268. *Colourage*, **24**, 44 (28 April, 1977).
269. Furvik, N. B., *'J Soc. Dyers Col.*, **74**, 299 (April, 1958).
270. Fourt, L. and Rutherford, M. B., *Text. Res. J.*, **24**, 67 (1954).
271. Prakash, J., Oka, P. G. and Iyengar, L. N., *Text. Res. J.*, **38**, 52 (1968).
272. Lee, J. S. and Finkner, M. D., *Text. Res. J.*, **36**, 547 (1966).
273. Anon, *Colourage*, **23**, 38 (5 Feb., 1976).
274. Anon, *Text. Topics*, **11** (2) (Oct., 1973).
275. Pearson, N. L., *Text. Res. J.*, **25**, 124 (1955).
276. Stephens, S. G., *Text. Res. J.*, **47**, 526 (1977).
277. Hawkins, W. P., Duckett, K. E. and Henry, Z. A., *Tennessee Farm and Home Science*, 20 (Jan-March, 1975).

338. Orr, R. S., Humphreys, G. C. and Grant, J. N., *Text. Res. J.,* **22,** 89 (1952).
339. Preston, J. H. and Nimkar, M. V., *J. Text. Inst.,* **40,** 674 (1949).
340. Collins, G. E., *J. Text. Inst.,* **30,** 46 (1939).
341. ASTM-D1444-72
342. ASTM-D629
343. Heckert, W. W., *Text. Res. J.,* **27,** 719 (1957).
344. *Text. Topics,* VI (5) (Jan., 1978).
345. Ramey, H. H., Lawson, R. and Worley, S., *Text. Res. J.,* **47,** 685 (1977).
346. Nanjundayya, C., *Text. Res. J.,* **26,** 682 (1956).
347. Brown, H. M., *Text. Res. J.,* **24,** 251 (1954).
348. Pascu, E., *Text. Res. J.,* **21,** 287 (1951).
349. *Text. Industr.,* **142,** 64 (Oct., 1970).
350. Lawson, R., *Text. Res. J.,* **34,** 725 (1964).
351. Rouse, J. T., *Text. Res. J.,* **34,** 908 (1964).
352. Orr, R. S., Weiss, L. C. and Grant, J. N., *Text. Res. J.,* **25,** 939 (1955).
353. Manual of Instruction for Stelometer (Spinlab Knoxville, USA).
354. Suessen Pocket Book (Spindel-Fabriek Suessen).
355. Dexter, L., *Text. Res. J.,* **24,** 587 (1954).
356. Raes, G., Fransen, T. and Verschraege, L., *Ann. Sci. Text. Belges.,* No. 4, 322.
357. Fiori, L. A., Brown, J. J. and Sands, J. E., *Text. Res. J.,* **24,** 503 (1954).
358. Fiori, L. A., Brown, J. J. and Sands, J. E., *Text. Res. J.,* **26,** 296 (1956).
359. *Text. Industr.,* **119** (4), 116 (1955).
360. Rouse, J. T., *Text. Res. J.,* **24,** 498 (1954).
361. Landstreet, C. B., *Proc. Seventh Cotton Improvement Conference,* Greenville and Stoneville, Miss. U.S.A (Oct., 1954).
362. Ruppenicker, G. F., Kingsbery, E. C. and Bouquet, N. A., *Text. Res. J.,* **47,** 239 (1977).
363. Sands, J. E., Fiori, L. A. and Brown, J. J., *Text. Res. J.,* **30,** 389 (1960).
364. Krasny, J. F. Sookne, A. M. and Stam, P. B., *Text. Res. J.,* **32,** 258 (1962).
365. *Text. Industr.,* **143,** 80 (Sept., 1979).
366. Freiber, E. "Die Chemie der Pflanzenzellwand", Berlin Springer-verlag, p.378 (1957).
367. Wakeham, H. and Spicer, N., *Text. Res. J.,* **21,** 187 (1951).
368. Lawson, R. and Ramey, H. H., *Text. Res. J.,* **47,** 249 (1977).
369. Lawson, R., Ramey, H. H. and Jones, J. B., *Text. Res. J.,* **49,** 433 (1979).

370. Venkatesh, G. M., *Text. Res. J.*, **45**, 813 (1975).
371. Stephens, S. G., *Text. Res. J.*, **48**, 407 and 431 (1978).
372. Hertel, K. L. and Craven, C. J., *Text. Res. J.*, **26**, 479 (1956).
373. Fiori, L. A., Sands, J. E., Little, H. W. and Grant, J. N., *Text. Res. J.*, **26**, 553 (1956).
374. Du Bois, W. F. and Van de Riet, D. F., *Text. Res. J.*, **36**, 97 (1966).
375. Louis, G. L., Fiori, L. A. and Sands, J. E., *Text. Res. J.*, **31**, 43 (1961).
376. Waters, W. T., Phillips, J. and Fiori, L. A., *Text. Res. J.*, **36**, 1004 (1966).
377. Louis, G. L., Fiori, L. A. and Sands, J. E., *Text. Res. J.*, **31**, 478 (1961).
378. Rees, W. H., *J. Text. Inst.*, **39**, T131 (1948).
379. *Amer. Rep/Bull*, **AT-1**, No. 6, 40 (1972).
380. Farrow, B., *J. Text. Inst.*, **47**, T58 (1956).
381. Peirce, F. T., *J. Text. Inst.*, **14**, T7 (1923).
382. Skelton, J., *J. Text. Inst.*, **58**, 366 (1967).
383. Chauhan, R. S., Shah, N. M. and Dweltz, N. E., *J. Text. Inst.*, **71**, 18 (1980).
384. Belser, R. B. and Taylor, J. L., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.111 (Paris, 1969).
385. Hertel, K. L., Duckett, K. E. and Lawson, R., Premier Symposium International de la Recherche Textile Cotonniére, Paris, p.139 (Paris, 1969).
386. Simpson, J. and Fiori, L. A., *Text. Res. J.*, **44**, 813 (1974).
387. Mody, R. K. and Subramanian, P. V., *Text. Digest*, 177 (Dec., 1971).
388. Duckett, K. E. and Cheng, C. C., *Appl. Polym. Symp.*, No. 27, 317 (1975).
389. Ewald, P. R., *Appl. Polym. Symp.*, No. 27, 345 (1975).
390. Seshan, K. N., *J. Text. Inst.*, **69**, 214 (1978).
391. Lawson, R., Ramey, H. H. and Krowicki, R. S., *Text. Res. J.*, **46**, 715 (1976).
392. Lennox-Kerr, P., *Text. Industr.*, **134**, 57 (Oct., 1970).
393. Van Heerden, H. G. and Cronje, C. J., *S.A. Textiles*, **22**, 83 (Nov., 1974).
394. Hunter, L., Spencer, J. D. and Gee, E., *SAWTRI Techn. Rep.* No. 460 (1980).
395. Watson, H. and Helmer, J. D., Progress Report ARS 42-107, Agricultural Research Service, Beltsville, Maryland (1964).
396. Perkins, H. H., *Text. Res. J.*, **41**, 559 (1971).
397. Mangialardi, G. J. and Shepherd, J. V., *Text. Res. J.*, **39**, 11 (1969).
398. Van Alphen, W. F., *Melliand Textilber,* (Eng.Ed.), 359 (May, 1978).

399. Peirce, F. T., Kelly, J. F. and Coleman, M. H., *J. Text. Inst.*, **46**, T78 (1955).

400. Anon, *Colourage*, **24**, 44 (28 April, 1977).

401. Rusca, R. A., Little, H. W. and Gray, W. H., *Text. Res. J.*, **34**, 61 (1964).

402. Danielowski, G., *Canad. Text. J.*, **94**, 51 (Nov., 1977).

403. Towery, J. D. and Baker, R. V., *Text. Res. J.*, **49**, 127 (1979).

404. Sasser, P., Jones, J. K. and Slater, G. A., Agro-Industrial Report, **3** (3), (April, 1976).

405. Anon, *Amer. Textiles Rep/Bull* **AT-3**, 48 (Sept., 1974).

405a. Fischer, J. J., *Text. Res. J.*, **50**, 93 (1980).

406. Brown, D. F., McCall, E. R., Piccolo, B. and Tripp, V. W., American Industrial Hygiene Association Journal **38**, 3/77, p.107 (1977).

407. Whitworth, J. W., *Sources Resources*, **1977/4**, 20 (1977).

408. Mandl, G., Dust in Spinning Mills, *Rieter Publication* (1976).

409. Anon, *Text. World*, **127**, 35 (June, 1977).

410. Anon, *Text. Industr.*, **141**, 9 (Feb., 1977).

411. Mittal, D. K., Fornes, R. E. and Gilbert, R. D., *Text. Res. J.*, **49**, 364 (1979).

412. Allen, K., *Progressive Farmer*, 52 (Jan. 1980).

413. Griffin, A. C., Hatcher, J. D. and Cocke, J. B., *Text. Res. J.*, **47**, 129 (1977).

414. Kamat, S. R., Kale, S. C. and Dangwal, S. K., *Indian Text. J.*, **87**, 73 (Sept., 1977).

415. Cocke, J. B. and Perkins, H. H., *Amer. Text. Rep./Bull.*, **AT-7**, 12 (Sept., 1978).

416. *Text. World*, **121**, 31 (May, 1971).

417. Cocke, J. B., Perkins, H. H. and Bragg, C. K., *Amer. Text. Rep./Bull.* **AT-6**, 43 (March, 1977).

418. Taylor, W. E. and Sasser, P. E., *Beltwide Cotton Res. Conf.*, 125 (1976).

419. *Canad. Text. J.*, **96** (4), 93 (April, 1979).

420. Welty, R. E., Gilbert, R. D. and Fornes, R. E., *Text. Res. J.*, **47**, 38 (1977).

420a. Perkins, H. H. and Cocke, J. B., *Text. Industr.*, **142**, 92 (Nov., 1978).

421. Brown, D. F. and Berni, R. J., *Text. Res. J.*, **47**, 152 (1977).

422. *Text. Res. J.*, **50**, 61—96 (1980).

422a. Mandl, G., *Melliand Textilber.*, **61**, 305 (1980).

423. Northrup, H. and Turner, W. F., *Text. Chem. Col.*, **7**, 60/22 (April, 1975).

424. Domingues, G. S., *Text. Industr.*, **139**, 77 (April, 1975).

425. Dockray, G. H., Meadows, B. and Smith, L., *Text. Res. J.*, **20**, 684 (1950).

426. Binder, R., *Text. Mfr.*, **76** (2), 10 (1976).
427. Al Ali, R. and Schenek, A., *Textil-Praxis Int.*, **34** IX and 1459 (1979).
428. *Text. Asia,* **10**, 68 (Nov., 1979).
429. Webb, quoted in Ref. 18.
430. Lebenfeld, L, *Text. Res. J.*, **27**, 473 (1957).
431. Mangialardi, G. J., *Cotton Gin and Oil Mill Press,* 14 (Oct., 1975).
432. Grant, J. N., Morlier, O. W., Scott, J. M., *Text. Res. J.*, **22**, 682 (1952).
433. Honold, E. and Brown, R. S., *Text. Bull.*, **93** 1 (Dec., 1967).
434. Gupta, D. K., H-Kish, M. and El-Shiekh, A., *Text. Res. J.*, **47**, 428 (1977).
435. Anwar, M. S., *Pakistan Text. J.*, 7 (July/Aug., 1973).
436. *Proc. Eleventh Techn. Conf.* (ATIRA, BTRA and SITRA), **2**, 1 (1969).
437. Du Bois, W. F. and Van de Riet, D. F., *Text. Res. J.*, **24**, 265 (1954).
438. Srinathan, B., Ramanathan, S., Sundaram, V. and Parthasarathy, M. S., *Indian Text. J.*, **86**, 87 (May, 1976).
439. Grunder, H. R., *Text. Industr.*, **132** (6), 93 (1968).
440. Orcutt, P. L. and Wakeham, H., *Text. Res. J.*, **23**, 614 (1953).
441. Shepherd, J. V., *Text. Res. J.*, **28**, 579 (1958).
442. Wegener, W., *Textil-Praxis,* **35**, 111 and 130 (1980).
443. De Meulemeester, D., Raes, G. and De Backer, G., *Ann. Sci. Text. Belges,* **2**, 39 (1953).
444. Fessmann, E. R., (1932).
445. Neukirchner, A., *Textil-Praxis,* **23**, 403 (1968).
446. De Meulemeester, D., Raes, G. and De Backer, G., *Ann. Sci. Text.* **2**, 14 (1954).
447. Koeb, H., *Textil-Praxis,* **10**, 11 and 324 (1955).
448. Goldthwait, Ch. F., Wiles, R. L. and von Sales, V. R., *Amer. Dyest. Rep.*, **15**, 544, 574 (1961) and *Textil-Praxis,* **17**, 405 (1962).
449. Ebert, H., *Spinner und Weber,* **75**, 311 (1957).
450. Suebius, M., *Mell. Textilber.*, **36**, 548 (1955).
451. Hartenhauer, H. P., *Textil-und-Faserstofftechnik,* **5**, 603, 645 (1955), *Deutsche Textiltechnik,* **8**, 52, 114 (1958).
452. Bogdan, J. F., Feng, I. Y. T. and Newell, W. A., *Text. World,* **102**, 87 (1952).
453. Kaufmann, G., *Textil-Praxis,* **12**, 652 (1957).
454. Kaufmann, D., *Textil-Praxis,* **12** 1077 (1957); **13** 149 (1958).
455. Kaufmann, D., *Textil-Praxis,* **16**, 1093, 1193 (1961); **17**, 13, 111, 216, 326, 437, 539, 646, 760, 885, 982, 1094 and 1207 (1962).
456. Fujino, K. and Itani, W., *Text. Mach. Soc.*, Japan, **8**, No. 4, 1 (1962).
457. Schenkel, E., *Textil-Praxis,* **12**, 631 (1957).
458. Juengling, P., *Textil-Praxis,* **17**, 980 (1962).

459. Wegener, W. and Peuker, H., *Verkürzte Baumwollspinnerei, Lapp-Verlag,* Mönchengladbach, (1965).
460. Herzog, A. and Koch, P. A., *Mell. Textilber.*, **16**, 413, 561, 617, 689 (1935); **17**, 1, 101, 169, 285, 377, 453, 533, 613 (1936); **18**, 429, 505, 593, 701, 785 (1937); **19**, 157, 245, 337, 425 (1938).
461. Ghosh, G. C., Wakankar, V. A. and Bhaduri, S. N., *Indian Text. J.*, **72**, 73, 80 (1961).
462. Perner, H. and Jung, G., *Deutsche Textiltechnik,* **11**, 61 (1961).
463. Loecker, R., *Zeitschrift für die gesamte Textilindustrie,* **62**, 592 (1960).
464. Juengling, P., *Textil-Praxis,* **16**, 1000 (1961).
465. Leunenschloss, J. and Wagner, H., *Textil-Praxis,* **13**, 767 (1958).
466. Souther, R. H., *Text. Res. J.*, **28**, 582 (1958).
467. Morgan, W. V., *J. Text. Inst.*, **51**, T998 (1960).
468. Pryor, L. D. and Elting, J. P., *Text. Res. J.*, **28**, 575 (1958).
469. Marth, C. T., Arthur, H. E. and Berkley, E. E., *Text. Res. J.*, **22**, 561 (1952).
470. Blaschke, K., *Textil-Praxis,* **10**, 1213 (1955).
471. Markezich, A. R., Tallant, J. D. and Worner, R. K., *Textil. Res. J.*, **28**, 570 (1958).
472. Schnitzler, G., *Bull. Inst. Text., France,* **24**, No. 146, 81 (1970).
473. Rudnick, E. S., *Text. World,* **102**, No. 2, 169, 260 (1952).
474. Jener, J., *Textil-und-Faserstofftechnik,* **3**, 364 (1953).
475. Simon, E., *Textil-und-Faserstofftechnik,* **3**, 361 (1953).
476. Wegener, W., *Forschungsberichte des Landes Nordrhein-Westfalen,* Nr. 818, Westdeutscher Verlag Köln und Opladen, (1959).
477. Break Spinning, Shirley Institute, Manchester. The Cotton Silk and Man-Made Fibres Research Association.
478. Kirschner, E. and Kleinhansl, E., *Textil-Praxis,* **25**, 599, 644, 723 (1970).
479. Souther, R. H., *Text. Res. J.*, **24**, 495 (1954).
480. Van Dalfsen, J. W. and Zaat, J. C. A., *Text. Res. J.*, **24**, 1003 (1954).
481. Simpson, J., *Text. Res. J.*, **42**, 590 (1972).
482. Simpson, J., De Luca, L. B. and Fiori, L. A., *Text. Res. J.*, **37**, 504 (1967).
483. Markezich, A. R., Tallant, J. D. and Worner, R. K., *Text. Res. J.*, **28**, 570 (1958).
484. Crewther, W. G. and Dowling, L. M., *Text. Res. J.*, **31**, 14 (1961).
485. Douglas, K. (Ed.), *Uster News Bulletin* No. 17 (May, 1971).
486. Stigter, D., *Text. Res. J.*, **42**, 657 (1972).
487. Wolf, B., *Int. Text. Bull. (Spinning)* No. 2, 115 (1972).
488. Burley, S. T., Bragg, C. K. and La Ferney, P. E., *Summary Proc. "Cotton Quality and Processing Conference"*, p.11 (1971).
489. Shanklin, E. H., Bragg, C. K. and Burley, S. T., *Ibid,* p.4 (1971).

490. Iyengar, R. L. N. and Gupta, A. K., *Text. Res. J.*, **44**, 492 (1974).
491. Sourady, A. S. E., Worley, S. and Smith, L. S., *Text. Res. J.*, **44**, 301 (1974).
492. Lawson, R., Worley, S. and Ramey, H. H., *Text. Res. J.*, **47**, 755 (1977).
493. Rusca, R. A., *Cotton Gr. Rev.*, **47**, 206 (1970).
494. Aldrich, DeV., *SAWTRI Techn. Rep.* No. 299 (May, 1976).
495. Louis, G. L., Fiori, L. A. and Leitz, L. A., *Text. Bull.*, **94**, 43 (April, 1968).
496. Balasubramanian, N. and Iyengar, R. L. N., *J. Text. Inst.*, **55**, T377 (1964).
497. Balasubramanian, N. and Iyengar, R. L. N., *Indian Text. J.*, **71**, 561 (1961).
498. Ukidve, A. V., Sundaram, V. and Oka, P. G., *Text. Digest,* No. 3, 115 (1971).
499. Felix, E., *Intern. Text. Bull.* (Spinning), No. 2, 313 (1979).
500. Douglas, K., quoted by Lennox-Kerr, P., *Text. Asia,* **11** (2), 71 (Feb., 1980).
501. Newton, F. E., Burley, S. T. (Jr.) and La Ferney, P. E., *Text. World,* **116**, 80 (March, 1966).
502. *Text. Topics,* **3** (6) (Feb., 1975).
503. Vaughn, E. A. and Rhodes, J. A., *Am. Soc. Mech. Eng.*, **76-Tex-7**, 1 (1976).
504. Hancock, N. I., *J. Amer. Soc. Agron.*, **36**, 530 (1944).
505. Patel, C. K., Shelat, B. R. and Radakrishnan, T., *Textile Trends,* **43** (Jan., 1964).
506. Chisholm, B. A., in "Rotor Spinning, Technical and Economic Aspects", E. Dyson, Ed., Textile Trade Press, Textile Book Service (Plainfield 1975).
507. Bogdan, J. F., *Text. Res. J.*, **37**, 536 (1967).
508. Knecht, E. and Hall, W., *J. Soc. Dyers Col.,* **34**, 220 (1918).
509. Vincent, P. D., *Shirley Inst. Mem.*, **3**, 125 (1924).
510. Merzban, M. A., *Cotton Intern.*, 126 (1972).
511. Hamby, D. S., Stuckey, W. C. and Gast, B., *Text. Res. J.*, **30**, 435 (1960).
512. Louis, G. *et al, Text. Industr.*, **128**, 71 (1964).
513. Weiss, L. G., Tsoi, R. H., Sands, J. E. and Grant, J. N., *Text. Res. J.*, **34**, 605 (1964).
514. Campbell, M. E. quoted in the above ref. and *Text. World,* **109** (7), 35 (1950).
515. Louis, G. L. and Fiori, L. A., *Proc. Cotton Res. Clinic,* 35 (1967).
516. Pillay, K. P. R., Seshan, K. N. and Venkatesan, N., *Proc. Eleventh Techn. Conf.* (ATIRA, BTRA and SITRA), **1**, 90 (1970).

517. Hafez, O. M. A., *Text. Res. J.,* **48,** 701 (1978).
518. Louis, G. L. and Fiori, L. A., *Text. Bull.* 1 (July, 1967).
519. Hafez, O. M. A., *Proc. Int. Symp. Cotton Text. Res.* (Paris), p.185 (1969) and Du Bois, W. F., *J. Text. Inst.,* **62,** 403 (1971).
520. *Cotton Trade J.,* **42,** 4, Sec. 2, 20 (1962).
521. Pillay, K. P. R., *Text. Res. J.,* **41,** 11, 16 (1971).
522. Jain, P. S., *Text. Res. J.,* **41,** 88 (1971).
523. Mack, C. H. and Hobart, S. R., *Text. Res. J.,* **42,** 1 (1972).
524. Graham, J. S. and Taylor, R. A., *Text. Res. J.,* **48,** 286 (1978).
525. Stewart, R. E. and Parsons, L. E., *Text. Res. J.,* **19,** 283 (1949).
526. Schultz, E. F., Little, H. W., Tallant, J. D. and Fiori, L. A., *Text. Res. J.,* **31,** 872 (1961).
527. Burley, S. T., *Text. Res. J.,* **29,** 696 (1959).
528. Fiori, L. A. and Louis, G. L., *Text. Industr.,* **127,** 66 (Oct., 1963).
529. Balasubramanian, N., Trivedi, G. K. and Bhanot, B. N., *BTRA Scan,* **6,** 5 (Sept., 1975).
530. Louis, G. L., *Text. Industr.,* **125,** 76 (Oct., 1961).
531. Jain, P. S., *Proc. Eleventh Techn. Conf.* (ATIRA, BTRA and SITRA), **1** 70 (1969).
532. Brown, J. J., Howell, N. A., Fiori, L. A., Sands, J. E. and Little, H. W., *Text. Res. J.,* **27,** 332 (1957).
533. Khanna, R. C., *Indian Text. J.,* **86,** 177 (August, 1976).
534. *SITRA Newsletter,* **16,** 7 (Sept./Oct. 1975).
535. Bogdan, J. F., *Proc. "Cotton Res. Clinic",* 30 (1967).
536. Subramanian, T. A., Ganishi, K. and Bandyopadhyay, S., *J. Text. Inst.,* **65,** 307 (1974).
537. Iyengar, R. L. N. and Gupta, A. K., *Text. Res. J.,* **44,** 492 (1974).
538. Abou Sehly, A. A. H., Tallant, J. D. and Worner, R. K., *Text. Res. J.,* **27,** 73 (1957).
539. Brown, C. H., "Egyptian Cotton", Leonard Hill, London, p.102 (1953).
540. Youssef, A. A. and Hafez, O. M. A., *Text. Mfr.,* **80,** 286 (1954).
541. *SITRA Newsletter,* **17** (1976).
542. Balasubramanian, N., *J. Text. Inst.,* **66,** 45 (1975).
543. Anderson, S. L. and Foster, G. A. R., *J. Text. Inst.,* **46,** T551 (1955).
544. Ratnam, T. V., Seshan, K. N. and Govindarajulu, K., *J. Text. Inst.,* **65,** 61 (1974).
545. Douglas, K. (Ed.), *Uster News Bulletin,* No. 21 (Nov., 1973).
546. Mueller, H., *"Symp. Quality Assurance in Modern Textiles* (Pretoria, 1974).
547. Douglas, K. (Ed.), *Uster News Bulletin* No. 27 (Aug., 1979).
548. Douglas, K. (Ed.), *Uster News Bulletin* No. 24 (Nov., 1976).
549. Douglas, K. (Ed.), *Uster News Bulletin* No. 23 (Aug., 1975).

Published by
The South African Wool and Textile Research Institute,
P.O. Box 1124, Port Elizabeth, South Africa,
and printed in the Republic of South Africa
by Nasionale Koerante Beperk, P.O. Box 525, Port Elizabeth.