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Investigation of Naturally Coloured Cotton of Different Origin – Analysis of Fibre Properties

Abstract
Naturally coloured cotton is naturally pigmented fibre that grows in shades of brown and green. Because the colour is present in the fibres, fabrics made of them do not have to be dyed. The elimination of the dyeing process can save up to one half of the cost of preparing textiles and also lowers disposal costs for toxic dye waste dangerous to human health and the environment. In spite of the economic and ecological benefits resulting from the elimination of the dying process, the application of the naturally coloured cotton in the world textile industry is still limited. The low quality of fibres is considered as the most important reason for the limitation of naturally coloured cotton application. The aim of the work presented was to investigate the quality of naturally coloured cotton of different origin as well as to show the potential of the naturally coloured cotton as an excellent raw material for manufacturing ecological textiles of good quality and attractive design.

Key words: *naturally colored cotton, fibre properties, maturity, length, quality.*

provement of the competitiveness of cotton in the world textile market. First of all research work is carried out in order to improve the quality of cotton varieties as well as to increase the economical effectiveness of cotton production.

The following directions of cotton investigation and development should be mentioned here:
- organic cotton,
- genetically modified cotton,
- naturally coloured cotton.

Organic cotton is grown using methods and materials that have a low impact on the environment [2, 3]. In 2009 organic cotton was grown in 22 countries worldwide. Now it represents 0.76 percent of global cotton production. Due to the positive impact on the environment the cultivation of organic cotton is governmentally supported in many countries.

Genetically modified cotton is an important step in cotton development. Genetically modified cotton crops have been modified to resist insects, which allow to reducing the application of pesticides. In 2007 genetically modified cotton covered a total of 15 million hectares, i.e., 43 percent of the world's cotton area. Most genetically modified cotton is grown in India and the US, but it can also be found in China, Argentina, South Africa, Australia, Mexico, and Columbia [3].

Naturally coloured cotton is naturally pigmented fibre that grows in shades of brown and green. Historical records report the existence of browns with pink and lavender tints. Because colour is

present in fibres, fabrics made of them do not have to be dyed [4 – 8]. Dyeing textile products is one of the most costly steps in fabric finishing due to water and energy consumption, as well as waste production. Dyestuffs used for the textile dying process are still a problem, even with organically grown cotton. Dyes can contain toxic chemicals, and their use and disposal have harmful effects on the environment. The elimination of the dyeing process due to the presence of colour in fibres can save up to one half of the cost of preparing textiles and also saves on disposal costs for toxic dye waste dangerous to human health and the environment. Investigation [9] showed a sudden increase in the heavy metal content in cotton fabrics both after dyeing and printing. The appearance of large quantities of Co, Cu and Cr, as well as an increase in the content of Ni and Zn was observed. It was caused by contamination from reactive and pigment dyestuffs used in the chemical treatment of cotton fabrics.

In spite of the economic and ecological benefits resulting from eliminating the dying process, the application of naturally coloured cotton in the world textile industry is still limited. Reasons for the limitation of naturally coloured cotton cultivation and application are different. Cotton fields need to be located some distance away from white cotton to avoid cross-pollination. Cotton ginning also requires separate technological lines for the ginning process of coloured and white cotton. However, the quality of fibres is considered as the most important reason for the limitation of naturally coloured cotton application. It is commonly

■ Introduction

Cotton is the basic raw material processed in the textile industry all over the world. Due to its excellent natural hygienic and comfort-related properties, cotton is traditionally applied in clothing and other textiles used close to the human skin. The last decades have seen the intensive development of chemical fibres which have displaced cotton and other natural fibres from many segments of application. Nevertheless the share of cotton in the total amount of processed fibres is ca. 30% [1]. Moreover similar to the other areas of textile fibre development, in cotton research we can also observe intensive efforts aimed at the im-

known that the majority of naturally coloured cotton varieties are of lower quality (strength, length, Micronaire, etc.) than the most conventional white cotton [6 – 8]. Due to low quality during the industrial revolution, naturally coloured cotton was replaced by white cotton, which is better processed on industrial looms.

In 1982 in the United States, Sally Fox, a plant breeder, began a research program to improve the length and quality of naturally coloured cotton fibres. By 1988 Fox had developed coloured cotton hybrids with fibres long enough to machine-spin successfully [4, 5]. She cultivated long fibre coloured cotton and created her own patented cotton called "Fox Fibre". Naturally coloured cotton has also been rediscovered in other countries that cultivate cotton. Nowadays it is grown in many countries such as Israel, Brazil, Bulgaria, Peru, Greece, Turkey and the former Soviet Union. Due to different reasons, in the US, being one of the biggest cotton producers in the world, the cultivation of naturally coloured cotton is currently limited. Resistance from growers who are worried that the pollen of natural cotton might drift into their white cotton fields is one of the main reasons for the limited growing of coloured cotton [10].

The share of naturally coloured cotton in the total amount of cotton cultivated worldwide is also slight. Apart from the low quality of fibres, the limited range of colours and colour unevenness, as well as a lack of rules and criteria for the quality classification of naturally coloured cotton can be considered as factors which make the global trade and processing of naturally coloured cotton difficult.

Naturally coloured cotton is underestimated due to the common opinion that it is of low quality, which is not always true. Numerous investigations have proved that naturally coloured cotton can be processed without any problems and textiles made of naturally coloured cotton are characterised by quality comparable with that of textiles made of standard white cotton [7, 11 – 13].

The aim of work presented was to investigate the quality of naturally coloured cotton of different origin as well as to show the potential of naturally coloured cotton as excellent raw material for manufacturing ecological textiles of good quality and attractive design.

■ Materials and methods

Samples of naturally coloured cotton originated from Greece, Turkey, Israel, Brazil, Bulgaria and the US were objects of the investigation, including:
- brown cottons:
  - from Greece – 4 samples marked: GB 1 – GB 4,
  - from Turkey: light brown short – (TLBS), light brown long – (TLBL) and brown – (TB),
  - from Brazil: brown – (BB) and reddish brown – (BRB),
  - from Bulgaria: 2 samples marked: BLB1 and BLB 2,
  - from the US – 2 variants: USB 1 and USB 2,
  - from Israel – IB

- green cottons:
  - from Turkey – TG,
  - from Brazil – BG,
  - from the US – USG,
  - from Israel – IG.

Measurement of the cotton samples was performed by means of methods and devices traditionally used for the measurement of standard white cotton: AFIS (Advanced Fibres Information System) and HVI (High Volume Instrument) [14 - 16].

The appearance of fibres as well as the shape of the fibre cross section were analysed using an electron scanning microscope.

The quality of fibres was assessed by comparing fibre parameters with statistical data gathered in Uster® Statistics [17].

■ Results and discussion

Quality of naturally coloured cotton according to AFIS results

Cotton measurement by means of AFIS included determination of parameters characterising the fibre length and its uniformity, as well as the short fibre content, maturity, immature fibre content, fibre fineness, neps and trash content. Results of measurement of basic fibre parameters by means of AFIS are presented in *Table 1*.

Parameters characterising the contamination of cotton determined by the AFIS are presented in *Table 2* (see page 36).

On the basis of the results obtained, it can be stated that the naturally coloured cottons investigated differ from each other in the range of all parameters measured.

Values of the UQL(w) parameter, which is close to the classer length of fibres, are in the range from 22.6 mm to 29.2 mm (0.89" – 1.15"). Cotton samples of QUL(w) lower than 1" are considered as short-staple cotton. Thus all samples of green cotton and some samples of brown cotton from Brazil, Israel, the US (sample USB 2) and Bulgaria (sample BLB 1) should be classified as short-staple cotton. The longest fibres were shown by
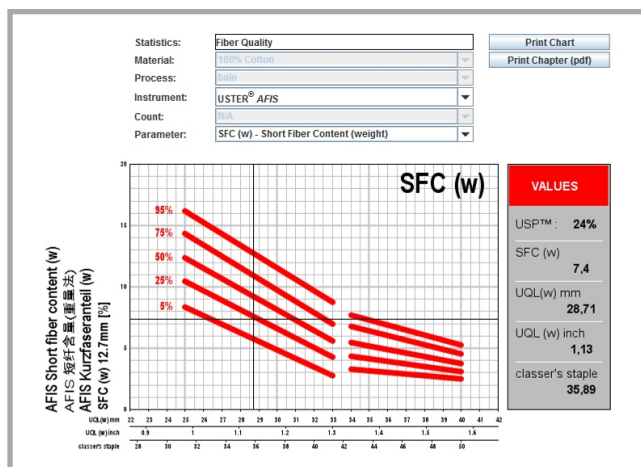
Table 1. Results of measurement of basic fibre parameters by means of AFIS; L(w) – mean length by weight, L(w)CV – length variation by weight, UQL(w) - upper quartile length by weight, SFC(w) - short fibre content by weight, Fine – fibre fineness, IFC - immature fibre content, MR – maturity ratio.

Sample	L(w), mm	L(w)CV, %	UQL(w), mm (in)	SFC(w), %	Fine, mtex	IFC, %	MR, -
GB1	22.7	34.2	27.6 (1.09)	10.8	166	7.0	0.87
GB2	21.4	35.7	25.9 (1.02)	12.3	160	7.7	0.83
GB3	21.8	37.3	27.1 (1.07)	13.9	160	7.7	0.83
GB4	21.7	34.6	26.2 (1.03)	11.0	160	7.4	0.84
TB	23.9	31.8	28.0 (1.10)	7.0	178	5.8	0.92
TLBS	24.3	31.5	28.8 (1.13)	7.4	169	5.8	0.92
TLBL	24.9	31.7	29.2 (1.15)	6.8	166	5.8	0.93
TG	20.2	34.3	24.1 (0.95)	12.2	161	8.6	0.84
BRB	19.8	29.8	22.6 (0.89)	9.2	169	7.8	0.84
BB	19.8	31.0	23.1 (0.91)	11.6	156	10.0	0.78
BG	20.4	38.4	25.4 (1.00)	16.7	142	10.0	0.78
USB 1	24.0	30.9	28.1 (1.11)	6.5	153	8.5	0.84
USB 2	20.3	34.0	24.6 (0.97)	13.7	169	9.4	0.80
USG	20.6	35.0	24.8 (0.98)	13.4	149	10.6	0.75
IB	20.6	33.6	24.5 (0.96)	12.1	163	8.4	0.81
IG	20.1	38.4	24.9 (0.98)	17.3	145	9.7	0.78
BLB 1	21.1	27.8	24.0 (0.94)	6.7	177	5.7	0.90
BLB 2	23.4	29.2	26.5 (1.04)	5.7	161	7.4	0.86

Figure 1. *Example of Uster® Statistic interactive chart [19].*

Table 2. *Cotton contamination according to AFIS; Nep – fibre nep count per gram, SCN – seed coat nep count per gram, Dust – dust count per gram, Trash – trash count per gram, VFM – visible foreign matter.*

Sample	Nep,	SCN,	Dust,	Trash,	VFM,
		g⁻¹			%
GB1	366	24	850	149	2.87
GB2	504	34	1286	278	5.13
GB3	476	18	664	141	2.65
GB4	437	24	976	248	3.86
TB	141	39	1243	99	2.48
TLBS	87	10	404	61	1.10
TLBL	134	17	1126	102	2.61
TG	221	29	3921	440	9.02
BRB	270	20	684	134	4.59
BB	346	26	482	100	2.31
BG	521	35	638	111	3.03
USB 1	271	8	295	16	0.41
USB 2	306	39	402	50	1.99
USG	350	31	1628	188	4.25
IB	336	12	555	68	1.63
IG	565	34	760	148	4.08
BLB 1	116	4	1016	127	2.64
BLB 2	118	5	648	106	2.19

Table 3. *Results of the assessment of the quality level of cotton variants investigated according to Uster® Statistics.*

Cotton variant	Quality level according to Uster® Statistics [19]									
	SFC	Fineness	IFC	MR	Nep	SCN	Dust	Trash	VFM	Mean
GB1	61	48	33	61	79	60	95	> 95	95	70.0
GB2	59	70	36	88	> 95	81	> 95	> 95	> 95	80.7
GB3	93	67	46	88	> 95	34	75	> 95	90	76.6
GB4	44	69	28	86	91	48	> 95	> 95	> 95	73.3
TB	13	13	13	25	5	> 95	> 95	82	85	48.0
TLBS	24	36	17	25	< 5	11	38	51	31	26.1
TLBL	24	46	21	19	6	40	> 95	84	88	47.3
TG	51	70	47	82	23	61	> 95	> 95	> 95	69.8
BRB	14	43	29	82	36	33	77	> 95	> 95	56.7
BB	41	82	77	> 95	60	52	49	83	81	69.2
BG	> 95	> 95	80	> 95	> 95	82	71	90	> 95	90.3
USB 1	8	84	73	82	49	5	23	5	< 5	36.8
USB 2	68	78	65	> 95	48	89	38	39	72	66.1
USG	65	95	86	> 95	62	67	> 95	> 95	> 95	85.2
IB	47	62	42	> 95	58	6	59	57	58	54.1
IG	> 95	> 95	73	> 95	> 95	76	86	> 95	> 95	91.4
BLB 1	< 5	21	5	38	< 5	< 5	> 95	> 95	89	39.4
BLB 2	< 5	66	32	72	< 5	< 5	72	86	78	45.8

light brown cotton from Turkey: TLBS and TLBL.

In order to assess the quality of the cotton variants investigated, the results from AFIS were compared with statistical data published by Uster Technologies [18]. The statistical data are presented in numerical form and in the form of charts. *Figure 1* presents an example of an Uster® Statistic interactive chart. On the abscissa there is the length of fibres expressed by the UQL(w) parameter; whereas on the axis of ordinates –values of the parameter analyzed. Red lines represent the level of quality. An interpretation of the quality level according to Uster® Statistics as follows: if the value of the parameter investigated reaches 5%, it means that only 5% of cotton raw materials worldwide represents this quality level or better; at the other extreme, if the value measured corresponds to the 95% level in Uster® Statistics, it means that 95% of the cotton raw materials produced worldwide is better than this value [18]. In other words a value of 95% means a bad quality of cotton.

Uster® Statistic charts present statistical data for cotton raw materials of a minimal fibre length of 0.95”. Some of the samples investigated are characterised by a fibre length shorter than 0.95”. In order to assess the quality of such cottons their parameters have been compared with values corresponding to fibre length UQL(w) = 0.95”.

Results of the assessment of the quality level of cotton variants investigated according to Uster® Statistics are presented in *Table 3*.

The quality level of the samples of naturally coloured cotton investigated is different depending on the parameter taken into consideration during the quality assessment. Some cotton variants represent a high quality level in the aspect of particular fibre parameters, but at the same time they represent the lowest quality from the point of view of contamination, for instance, the brown cotton of Bulgarian origin, sample BLB 1.

The quality level of the cotton variants investigated in the range of particular parameters is presented in *Figures 2 – 5*. The closer to the graph's center the better the quality. Brown cottons of Greek origin are characterised by good quality in the range of immature fibre content, fibre
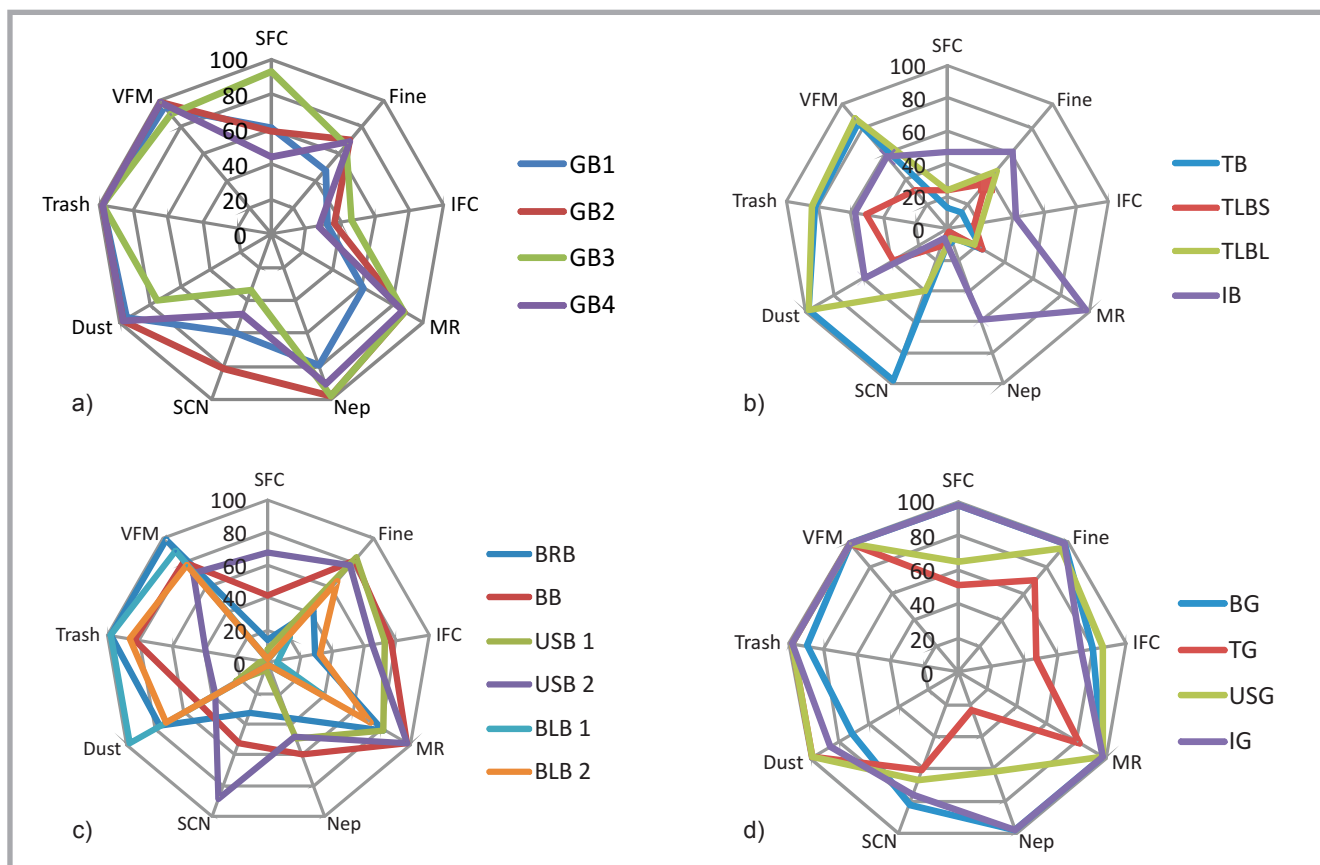
Figure 2. *Quality level according to the Uster® Statistics of brown cotton of: a) Greek origin, b) Turkish and Israeli origin, c) Brazilian, American and Bulgarian origin, d) green cotton.*

fineness and short fibre content (with the exception of sample GB 3), but they are strongly contaminated (*Figure 2*).

Turkish light brown short cotton is characterised by the highest quality level from the point of view of all parameters analysed (*Figure 3*). Almost all parameters represent better quality than the world average quality level. Other brown cotton variants from Turkey are characterised by good fibre properties, but they are strongly contaminated. Brown cotton of Israeli origin is also characterised by good quality, with the exception of fibre maturity (*Figure 3*).

The quality level of brown cotton of Brazilian, American and Bulgarian origin is varies widely depending on the parameters analyzed (*Figure 4*).

The quality of green cottons is generally worse than that of brown cottons. In this group the best quality occurred for cotton of Turkish origin (*Figure 5*).

In order to assess in a complex way the quality level of the naturally coloured cottons investigated, the average quality level was calculated as an arithmetic mean from quality levels according to particular properties.

According to Uster® Statistics, a quality level of 95% is treated equally as that > 95%, as for quality levels of 5% and < 5%. In order to distinguish both levels during calculation of the average quality level the value of 98% was introduced instead of one > 95%, and 2% – instead of < 5%. The results of calculation are presented in *Table 3*.

The highest quality was noted for Turkish light brown short cotton (TLBS). It is characterised by an average quality level of 26.1 according to Uster® Statistics and almost all fibre parameters represent very good or good quality. Only the trash content in TLBS cotton is at an average quality level (51%) in relation to all cotton raw materials processed all over the world. Good quality (average quality level 36.8% and 45.8%) was also noted for US brown cotton sample 1 (USB 1) and Bulgarian brown cotton sample 2 (BLB 2). In the case of both brown cottons mentioned none of the fibre parameters exceeds 95%. It should be emphasised that cottons listed above cotton samples of the best quality are also characterised by

good fibre length compared to middle staple cotton.

An average quality level lower than 50% according to Uster® Statistcs was also noted for Turkish brown cotton (TB) – 48%, Turkish light brown long (TLBL) – 47.3% and Bulgarian brown sample 1 (BLB 1) – 39.4%; however, in the cases mentioned at least one of the fibre parameters analyzed exceeds a level of 95%.

Quality of naturally coloured cotton according to HVI results

By means of the HVI the following cotton parameters were determined [18]:

- Upper half mean length – UHML; mean length by weight of the longer 50% of fibres,
- Uniformity ratio – Un; length uniformity of fibres,
- Breaking strength – Str; breaking force of fibre bundle divided by fibre fineness,
- Breaking elongation of fibre bundle - El,
- Micronaire,
- Area of sample covered by trash particles - Area,
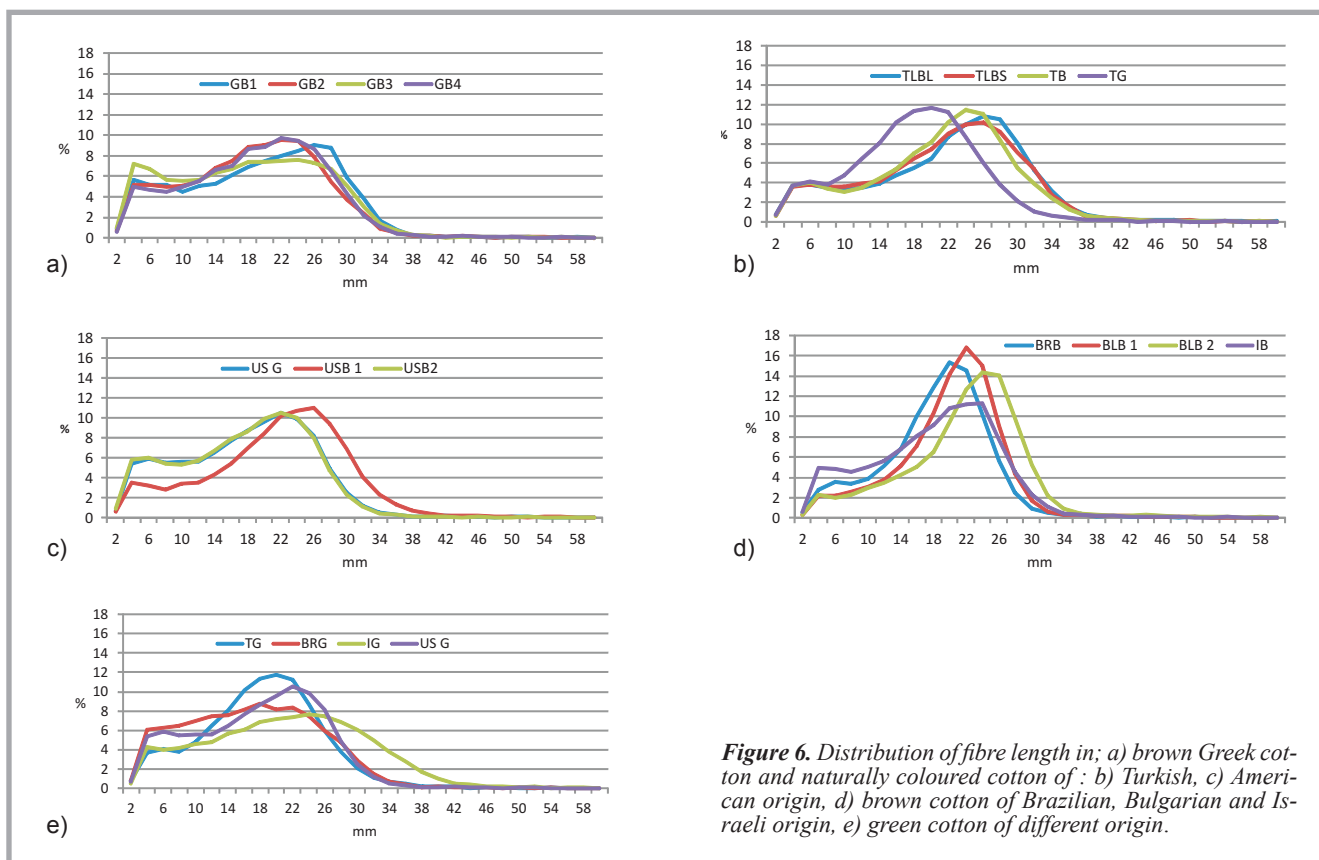- The number of trash particles – Cnt.

Figure 6. Distribution of fibre length in; a) brown Greek cotton and naturally coloured cotton of : b) Turkish, c) American origin, d) brown cotton of Brazilian, Bulgarian and Israeli origin, e) green cotton of different origin.

Results of cotton measurement by means of the HVI are presented in **Table 4**. Due to the small amount of fibres, Brazilian cotton and brown cotton from Israel cannot be measured by the HVI. Therefore only 14 variants of naturally coloured cotton were assessed according to the HVI results.

Classification of cotton from the point of view of parameters measured by the HVI is as follows [18]:
- according to the length uniformity:
  - very low: below 76%
  - low: 77% – 79%
  - average: 80% – 82%
  - high: 83% – 85%
  - very high: above 86%
- according to the breaking strength:
  - very low: below 20.6 cN/tex
  - low: 20.7 – 23.5 cN/tex
  - average: 23.6 – 26.5cN/tex
  - high: 26.6 – 29.4 cN/tex
  - very high: over 29.4 g/tex.
- according to the Micronaire:
  - very fine: below 3.0
  - fine: 3.0 – 3.9
  - average: 4.0 – 4.9
  - coarse: 5.0 – 5.9
  - very coarse: 6.0 and higher.

From the point of view of length uniformity, the majority of cotton variants investigated can be classified into classes: average (8 variants) and low (5 variants). None of them belongs to the classes of very low nor very high.

Contrary to common opinion, the breaking strength of naturally coloured cotton is quite good. Only the breaking strength of green cotton from the US (sample USG) can be assessed as very low (19.6 g/tex). The majority of variants (7 cotton samples) are characterised by a mean breaking strength in the range of 25 g/tex – 27 g/tex, three of which are strong (samples: TLBS, TLBL and BLB 2) and Turkish brown cotton (sample TB) can be assessed as very strong.

On the basis of the Micronaire value very fine fibres were noted in Israeli green cotton (IG). The rest of the cotton samples investigated should be classified as fine or average.

Distribution of fibre properties in naturally coloured cotton

The AFIS provides average values of particular properties of cotton fibres as well as histograms illustrating the distribution of properties measured: length, fineness, maturity, neps and trash. Exploiting this
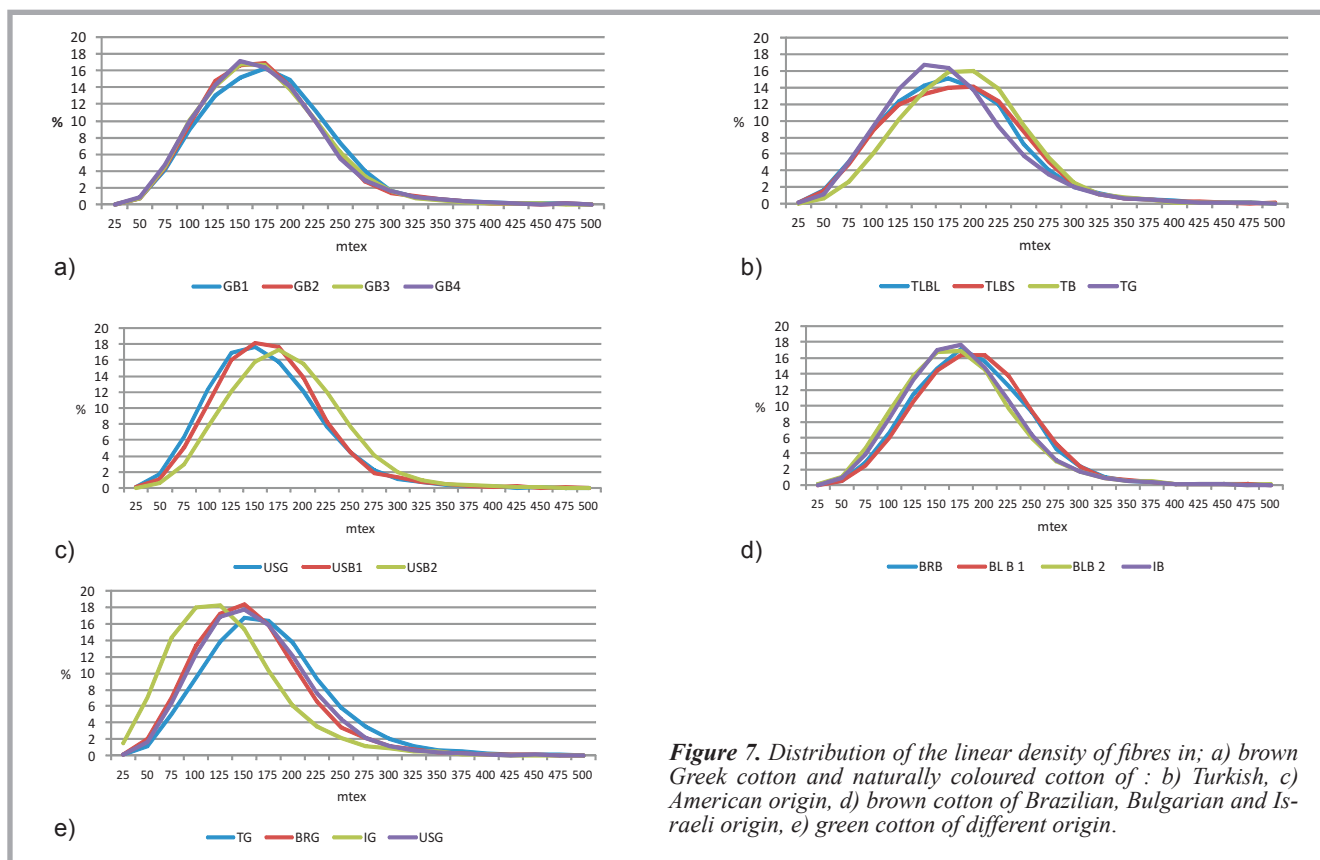
Table 4. Results of cotton measurement by means of the HVI.

Sample	Area, %	Cnt, -	UHML, mm	Un, %	Str, g/tex	El, %	Mic, -
GB1	0.86	286	25.6	81.5	25.9	6.0	4.0
GB2	1.39	311	24.2	80.0	26.9	5.6	3.4
GB3	1.19	279	26.3	80.2	26.2	6.5	3.6
GB4	1.15	274	25.3	79.2	26.1	6.0	3.4
TB	1.97	441	26.6	82.9	30.9	5.9	4.0
TLBS	0.57	192	26.6	82.9	29.2	5.9	4.3
TLBL	1.30	336	28.0	83.7	29.1	5.4	3.9
TG	6.41	715	22.0	79.7	24.1	5.6	3.4
USB 1	5.62	449	26.5	82.4	26.0	6.3	4.0
USB 2	2.22	416	22.0	78.7	21.6	5.9	4.5
USG	1.68	300	22.3	77.5	19.6	5.2	3.0
IG	4.77	423	28.1	79.4	25.3	5.2	2.6
BLB 1	3.03	483	22.2	82.0	25.9	5.9	4.4
BLB 2	0.95	261	23.8	82.9	28.6	5.3	3.7

a)

b)

c)

d)

e)

Figure 7. *Distribution of the linear density of fibres in; a) brown Greek cotton and naturally coloured cotton of : b) Turkish, c) American origin, d) brown cotton of Brazilian, Bulgarian and Israeli origin, e) green cotton of different origin.*

feature of the AFIS, we analysed the distribution of basic fibre properties in the samples of naturally coloured cotton investigated. Due to the big number of cotton variants investigated, the presentation in one graph of the distribution of particular properties in all samples investigated could make them illegible. Thus in the subsequent part of the paper the distribution of particular fibre properties has been presented for selected groups of cottons.

Fibre length

Figure 6.a presents the distribution of the fibre length in brown cotton of Greek origin. It can be seen that the length distributions in samples GB 2 and GB 4 are almost identical, whereas sample GB 3 is characterised by the biggest quantity in classes of the shortest length. The graph for sample GB 1 tends towards longer fibres in comparison to other samples of Greek origin.

In the case of Turkish cotton the fibre length distribution in green cotton differs significantly from that in light brown and brown cotton (**Figure 6.b**). In green cotton the most numerous is class 18 mm – 20 mm, whereas in light brown cotton it is 25 mm – 26 mm and for brown cotton – 23 mm – 24 mm. The quantity of the

shortest classes (2 mm – 8 mm) in Turkish cotton is significantly lower than that in Greek cotton.

Fibre length distribution in US brown cotton sample 2 (USB 2) is almost identical to that in American green cotton. Both are characterised by short fibres, a UQL(w) below 1". They contain many more short fibres than US brown cotton sample 2 (USB 2) (**Figure 6.c**). In USB 2 the most numerous is class 25 mm – 26 mm, whereas in USB 1 and USG the most numerous is class 21 mm – 22 mm.

Brown cottons from Bulgaria stand out from the whole group of the naturally coloured cottons investigated in the range of fibre length distribution. Both BLB 1 and BLB 2 contain far fewer fibres in the shortest classes than other cottons (**Figure 6.d**). In both Bulgarian cottons the quantity of the most numerous classes is 15% or more, whereas in other brown cottons it is ca. 10 %.

The distribution of the fibre length in green cotton varies depending on the cotton origin (**Figure 6.e**). The general tendency is that green cottons contain many more short fibres and the fibre length is more equally distributed than in brown cottons. In Brazilian and Israeli green
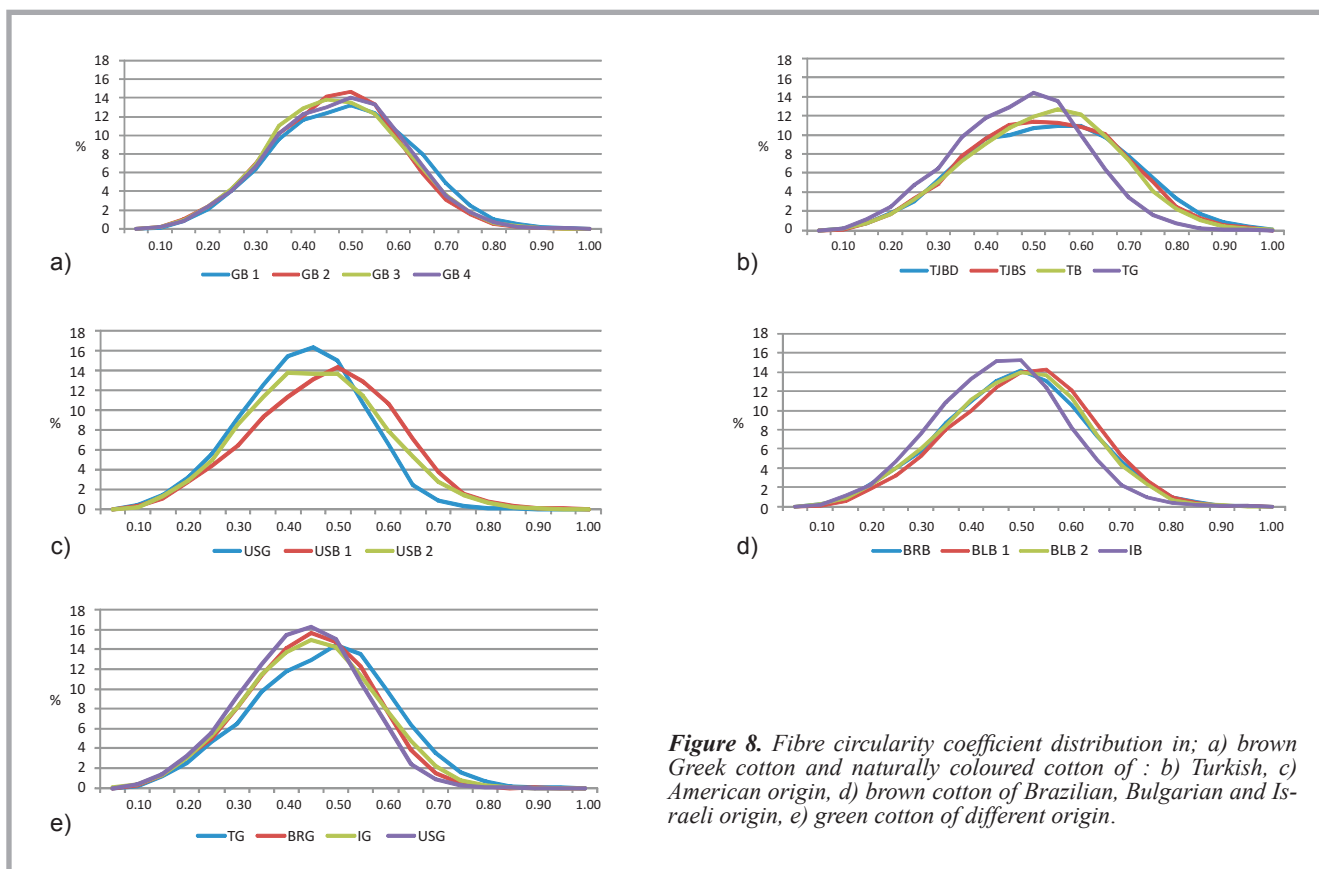
cotton the quantity of the most numerous classes is ca. 8%.

Fineness

In the case of the linear density of fibres, their distribution in brown cotton is not as diversified as that of the fibre length. The distribution of the linear density of fibres is almost identical in brown Greek cottons (**Figure 7.a**). Turkish light brown cottons, both short and long, also have a very similar distribution of fibre fineness (**Figure 7.b**). Turkish brown cotton has a bigger amount of fibres in classes representing thicker fibres. In Turkish brown cotton the most numerous is class 200 mtex, whereas in the case of Turkish green cotton it is class 150 mtex.

The distribution of the linear density of fibres in American brown cotton sample 2 (USB 2) tends towards thicker fibres in comparison to American brown cotton sample 1 (USB 1) and American green cotton (USG) (**Figure 7.c**).

Much bigger differences in the fibre fineness distribution can be observed in the case of green cotton of different origin (**Figure 7.e**). Especially, green cotton from Israel is characterised by a relatively high number of fibres in classes representing thin fibres. The maximum

Figure 8. *Fibre circularity coefficient distribution in; a) brown Greek cotton and naturally coloured cotton of : b) Turkish, c) American origin, d) brown cotton of Brazilian, Bulgarian and Israeli origin, e) green cotton of different origin.*

fibre fineness in Israeli green cotton corresponds to 100 – 125 mtex, whereas in other green cottons – to 125 – 150 mtex.

Maturity

According to the AFIS, the maturity of cotton fibres is expressed by the maturity ratio parameter, which is calculated on the basis of the fibre circularity coefficient, defined as the ratio of the wall
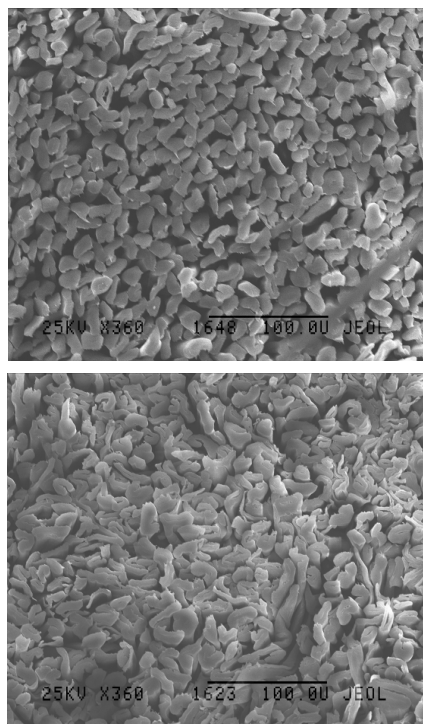
Figure 9. *Microscopic pictures of fibre cross-sections: a) Turkish light brown long (TLBL), b) Turkish green (TG).*
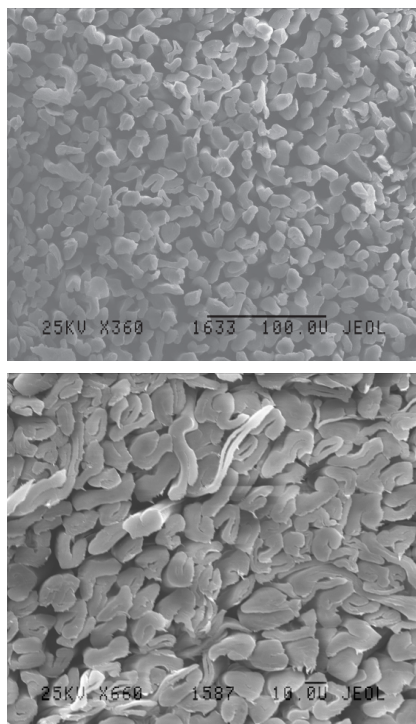
Figure 10. *Microscopic pictures of fibre cross-sections of cottons containing the smallest number of immature fibres: a) Turkish brown (TB), b) Turkish light brown short (TLBS).*
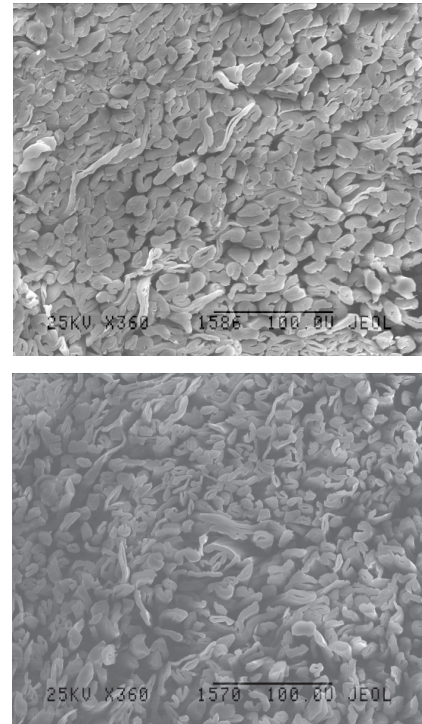

Figure 11. *Microscopic pictures of fibre cross-sections of cottons containing the biggest number of immature fibres: a) American green (USG), b) Israeli green (IG).*

cell area and that of a circle of the same perimeter as the fibre cross-section [20]. The AFIS provides information about the distribution of the circularity coefficient of cotton fibres measured.

The distribution of values of the fibre circularity coefficient in Greek samples of brown cotton is very similar. The most numerous classes represent a circularity in the range of 0.45 - 0.50 (*Figure 8.a*).

A similar situation was observed in the case of brown cotton of Turkish origin. Only Turkish green cotton differs significantly from brown and light brown Turkish cotton. It contains many more immature and dead fibres than brown cottons (*Figure 8.b*).

Naturally coloured cotton of American origin is characterised by a bigger amount of immature fibres than Turkish cotton. We can also notice a significant difference between American green cotton (USG) and American brown cotton; see sample 1, in particular (USB 1) (*Figure 8.c*).

Brazilian and Bulgarian brown cottons are very similar from the point of view of the distribution of the fibre circularity coefficient (*Figure 8.d*). Israeli brown cotton contains many more immature fibres and significantly fewer mature fibres than Brazilian and Bulgarian brown cottons.

Contrary to the fibre length and fineness, green cottons do not differ from each other in the aspect of circularity coefficient distribution. Only the graph representing Turkish green cotton tends towards mature fibres in comparison to the rest of the green cotton variants (*Figure 8.e*). In Turkish green cotton the most numerous class corresponds to the circularity coefficient 0.45 – 0.50, whereas in other green cottons it is 0.40 – 0.45.

A big content of immature and dead fibres in some samples of naturally coloured cotton investigated and differentiation of naturally coloured cotton from the point of view of fibre maturity were confirmed by microscopic observation of fibre cross-sections.

Figure 9 presents a comparison of fibre cross-sections of Turkish light brown long (TLBL) and Turkish green (TG) cotton. Turkish light brown long cotton is characterised by the highest Maturity

Ratio (0.93) and low IFC (5%), whereas Turkish green cotton contains many more immature fibres (IFC = 8.6%), and its Maturity Ratio is 0.84. Microscopic pictures show that Turkish light brown fibres have a thicker wall and a regular elliptical shape of the cross-section, whereas Turkish green cotton contains a majority of fibres with an irregular, flattened shape of the cross-section and a thin fibre wall.

Figure 10 presents microscopic pictures of fibre cross-sections of cottons containing the smallest number of immature fibres: Turkish brown (TB) and Turkish light brown short (TLBS), whereas *Figure 11* shows microscopic pictures of fibre cross-sections of variants containing the biggest number of immature fibres: American green (USG) and Israeli green (IG).

■ Conclusions

The investigation presented did not confirm the common opinion that the quality of naturally coloured cotton is low. On the basis of the results obtained it was noted that the quality of naturally coloured cotton varies significantly depending on the fibre origin. There are some variants of really very poor quality, but there are also some variants of a quality corresponding to the average of white cotton commonly processed all over the world.

Among all samples of naturally coloured cotton subjected to the investigations presented, some of them: Turkish light brown long (TLBL), American brown (USB 1) and Bulgarian brown (BLB 2) are characterised by a quality corresponding to a very good and good quality level according to Uster® Statistics. 44% of the variants of naturally coloured cotton investigated represent an average world quality level according to Uster® Statistics.

Contrary to common opinion, the breaking strength of naturally coloured cotton is quite good. The majority of the cotton variants investigated are characterised by the mean breaking strength, three of which can be classified as strong ones (samples TLBS, TLBL and BLB 2), and Turkish brown cotton (sample TB) can be assessed as very strong.

The length of fibres can be considered as one of the most important quality problems of naturally coloured cotton. Half of the cotton variants investigated are char-

acterised by a UQL(w) equal to 1" or a slightly lower value.

The majority of the variants of naturally coloured cotton investigated can be assessed as contaminated. Nevertheless it is not a serious problem because the contamination can be removed during cotton processing and does not influence the quality of cotton products.

The investigation showed that, in general, the quality of green cotton is lower than that of brown cotton. However, here they are exceptions. Among the cotton variants investigated Turkish green cotton is characterised by significantly better quality in comparison to the green cotton from Brazil, Israel and the US.

Considering the results of measurement by means of the AFIS and HVI, it can be stated that the majority of variants of naturally coloured cotton investigated can be processed in spinning mills without any problems. Due to the fibre length and contamination, naturally coloured cottons should be processed by the open-end spinning system, because OE spinning is less sensitive to the fibre length, its uniformity and fibre contamination than ring spinning technology.

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INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES

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- mass per unit area using small samples
- elasticity of yarns
- breaking force and elongation of fibres, yarns and medical products
- loop tenacity of fibres and yarns
- bending length and specific flexural rigidity of textile and medical products

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Other tests:
- for fibres
  - diameter of fibres
  - staple length and its distribution of fibres
  - linear shrinkage of fibres
  - elasticity and initial modulus of drawn fibres
  - crimp index
- for yarn
  - yarn twist
  - contractility of multifilament yarns
- for textiles
  - mass per unit area using small samples
  - thickness
  - tenacity
- for films
  - thickness-mechanical scanning method
  - mechanical properties under static tension
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  - suture retention strength of medical products
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