ASSESSMENT OF NEW BULGARIAN AND FOREIGN COTTON VARIETIES BY APPLYING OF CLUSTER ANALYSIS

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Abstract

The aim of this study was to assess the productivity and fiber quality of modern Bulgarian and some foreign cotton varieties in comparison with the standard cultivars, as well as the genetic distance between them by applying the method of cluster analysis. Eleven Bulgarian varieties, four Turkish and one Macedonian were included in a trial carried out in 2008 and 2009. It was established that the Bulgarian varieties resulted from two differently purposeful breeding programs differed mainly in fiber length, fineness and lint percentage. The cluster analysis based on the varieties agronomic and fiber technological properties confirmed the genetic differences between them. In a complex evaluation the varieties Darmi and Helius were the best and surpassed Chirpan-539 (the standard for earliness and productivity) in seed cotton yield and had higher index of earliness than it. The variety Helius combined its higher productivity with comparatively high lint percentage, the variety Darmi – with longer fiber than the standards. The Macedonian variety 5140 in our climatic conditions was inferior to the standard Chirpan-539 in seed cotton yield by 4.8 % and in lint percentage by 2.6 %. The Turkish varieties were late in maturity. Because of their lower yields and latens in maturity, they are not suitable to be introduced as commercial varieties. However, they distinguished by bigger bolls, longer fiber and higher lint percentage, and set up higher the first fruit-branch then the Bulgarian ones, and in this respect they proved to be very valuable as initial material for the Bulgarian cotton breeding. The cluster analysis provides useful additional information about the similarity and genetic distance of genotypes. The Bulgarian varieties were genetically distant from the Turkish ones.

Key words: *cotton, G. hirsutum L., varieties, cluster analysis, productivity, fiber properties*

1. INTRODUCTION

The first Bulgarian cultivar - № 38 had naked seeds and it was obtained by means of selection in a native population. The intraspecific hybridization was the principal method used long years in the cotton breeding. The basic cotton varieties for our country were created by this method. Among them Nos. 2362, 3279, 4521, Pavlikeni-73 and Chirpan-433 were of grater importance (Milkovski et al., 1972). Significant progress in this direction was achieved with the creation and adoption of cultivars Beli izvor, Garant and Ogosta (Bozhinov, 1979). The earliness of cultivars was of the greatest importance in cotton breeding programs. Koynov (1981, 1984) reported about cotton varieties obtained from the interspecific hybridization of *Gossypium hirsutum L.* × *G. barbadense L.* species.

The cotton production in Bulgaria is based solely on Bulgarian cotton cultivars. Bulgarian cotton constitutes a specific ecological group - *Proles Bulgaricum* of the *Gossypium hirsutum L.* species and in the world range the Bulgarian cultivars are distinguished with exceptional earliness (Bozhinov, Dimitrova, 1974). Bulgaria is on the northern border for cotton distribution and for that reason earliness is of prime importance.

The native and foreign cultivars constitute the cotton genetic resources which are kept in Cotton and Durum Wheat Research Institute and at present number 764 patterns from the species: *G. hirsutum L., G. barbadense L., G. herbaceum L., G. arboreum L.* and five wild species, among them: *G. thurberi Tod, G. davidsonii Kell and G. sturtianumi Willis* (Dimitrova et al., 2004 a).

At present the cotton breeding in Bulgaria is focused on development of early cultivars with high genetic potential for yield over 4500-5000 *kg/ha* and cultivars with improved fiber quality. Intraspecific hybridization within the *G. hirsutum L.* species and experimental mutagenesis are used in breeding of early and high productive varieties. In breeding of cultivars with improved fiber quality is used interspecific hybridization of the species *G. hirsutum L. × G. barbadense L.*

Last years a large number of varieties were created. The most important were Chirpan-539, Chirpan-603, Beli Iskar and Beli Lom, possessing high genetic potential for yield (Bozhinov et al., 1996, 2004), Avangard-264, Perla-267 and Vega with improved fiber quality (Koynov, Stoilova 1996; Stoilova, Saldzhiev, 2000, 2005).

As a result of successful breeding six new cotton varieties – Veno, Trakia, Helius, Natalia, Darmi and Kolorit, resulting from two differently purposeful cotton breeding programs, were approved by the IASAS (Exclusive Agency for Variety testing, Approbation and Seed control) in 2007 and 2008.

Grouping of cultivars on the base of separate traits or complex of traits allows to a significant degree to facilitate their usage in the cotton breeding programs.

Many researchers have studied the genetic and environmental variation by means of methods, which allow the grouping of genotypes and environments by similarity. Methods, which have been successfully used in the plant breeding programs, are the cluster and the principle component analyses (Dechev, 1997; Pecetti and Annicchiarico, 1998; Atanassov et al., 2007; Roytchev, 2007; Roytchev et al., 2007).

In cotton these analyses have been limitedly applied (Steven Brown, 1991; Lloyd May et al., 1995; Kalsy et al., 1995; Tatineni et al., 1996; Patil et al., 1999; Valkova, Dechev, 2003; Stoilova, Dechev 2003 a, b; Dimitrova et al., 2004 a, b, c; Stoilova et al., 2005).

It is considered that the clusters are genetically distant and the usage of parents relevant to different clusters in one breeding program can prove to be very effective.

The aim of this study was to assess the productivity and fiber quality of modern Bulgarian and some foreign cotton varieties in comparison with the standard cultivars, as well as the genetic distance between them by applying the method of cluster analysis.

2. **MATERIAL AND METHODS**

The varieties Chirpan-539, Veno, Trakia, Helius, Avangard-264, Perla, Natalia, Darmi, Colorit, (Bulgarian), 5140 (Macedonian), Nazili-84/5, Nazili-663, Nazili-954 and Barut-2005 were included in a trial, carried out in 2008 and 2009, in 4 replications and harvested plot of 20 m^2, with a sowing design 60×10×1. As standards were used Bulgarian cultivars Chirpan-539 (for productivity) and Avangard-264 (for fiber quality). The Bulgarian varieties resulted from two differently purposeful breeding programs: Chirpan-539, Veno, Trakia and Helius resulted from breeding for high productivity, the others – from breeding for fiber quality. The varieties were evaluated on the grounds of the obtained data for the most useful agronomic traits – September and total yields, boll weight, fiber length measured by *"butterfly"* method and fiber lint percentage. Technological fiber properties as micronair (cotton finesse), strength, length, uniformity and elongation were measured with HVI (High Volume Instrument) by BTEX in Bourgas.

For the data statistical processing was used statistical program ANOVA. Hierarchical cluster analysis was applied for the grouping of genotypes (Ward, 1963).

3. RESULTS AND DISCUSSION

The years of study were characterized the following way: 2008 was hot in temperature supply and middle dry in rainfall (Table 1). Rainfall sum of 261 *mm* was similar to that for of many years period but it was very irregularly distributed during the cotton vegetation period. Thus in July and August (during the flowering and boll formation period) the rainfall sum was 38.9 *mm,* which was by 56.6 *mm* below average annuals. At the beginning of the vegetation period (in June) the development of cotton passed over under enough rainfall supply. The strong and prolongation drought during the period of flowering and boll formation – the second part of July and August, gave strong negative effect on yield and fiber length. Rainfall in September did not permit the cotton picking to be made in time and caused strong fiber fall on the ground and changed for the worse its quality; 2009 in temperature supply was also hot and dry. Temperature sum during the vegetation period (May - September) was 3264 ^{o}C, which was by 138 ^{o}C more than the average value for of many years period. Rainfall sum was 211 *mm*, by 47 *mm* below average of many years.

Table 1. Meteorological characterization of the cotton vegetation period in 2008-2009 compared to of many years period for the region of Chirpan

Years	Months							Σ/Average VI-VIII
	IV	V	VI	VII	VIII	IX	V-IX	
An average monthly air temperature, ^{o}C								
2008	12.9	16.8	21.2	23.1	25.6	18.5	21.1	23.3
2009	11.9	18.3	21.6	24.2	23.4	19.0	21.3	23.1
1928-2007	11.9	16.9	20.8	23.3	22.3	18.7	20.4	22.1
Temperature sum, $\Sigma\ ^{o}C$								
2008	386	521	637	717	793	555	3223	2147
2009	357	569	648	751	725	571	3264	2124
1928-2007	357	524	624	722	694	561	3126	2035
Rainfall, *mm*								
2008	65.9	35.8	95.4	35.5	3.4	90.9	261	134
2009	16.6	15.6	14.4	88.7	34.6	58.0	211	138
1928-2007	44.9	62.4	65.7	54.0	41.5	34.4	258	161
Hydrothermal Coefficient - HTC (by Savinov)								
2008	1.71	0.69	1.50	0.50	0.04	1.64	0.81	0.62
2009	0.47	0.27	0.22	1.18	0.48	1.02	0.65	0.65
1928-2007	1.26	1.19	1.05	0.75	0.60	0.61	0.82	0.79

The initial development of cotton passed over under extremely insufficient humidity security – 14.4 *mm* in June compared to 65.7 *mm* for a long term period. Independently of higher average monthly temperatures the cotton growth was strongly depressed. The rainfall in July of 88.7 *mm*, which was by 34.7 *mm* above the norm, promoted for the cotton development restoration and gave positive effect on the flowers accumulation and balls retention. The drought in August during the period of ball formation, in combination with the average-monthly higher temperature than that of many years period, accelerated the passing of this stage and caused strong shortening of cotton vegetation period. In 2009 the cotton matured at the end of August. In our country under normal climatic conditions the

cotton matures in the second part of September. The rapidly passing of the flowering-maturity phase reflected extremely unfavorably on the fiber length formation as the negative effect was stronger expressed for the more qualitative varieties which have longer vegetation period than the others.

The Bulgarian cotton varieties were the earliest and in 2008 matured about 7-9th of September (data are not given here). The Macedonian variety 5140 had also good earliness and matured with the Bulgarian. The Turkish varieties matured 15 to 30 days later than the Bulgarian ones. Among the Turkish Barut-2000 was the earlier than the others, but and this variety late in maturity more than 15 days compared to Bulgarian varieties. The September yield characterizes the earliness of varieties and it is used as a criterion for earliness. This year as a result of higher temperature in August (an average monthly 25.6 ^{o}C compared to 22.3 ^{o}C for of many years period and temperature sum by 112 ^{o}C higher) the Bulgarian cotton varieties and the Macedonian variety matured in September. The first picking was made in the beginning of September and the second one – at the end of this month.

The yields obtained were in conformity with the earliness (Table 2). The highest seed cotton yield was obtained from Darmi, which realized average yield of 2395 *kg/ha* and insignificantly surpassed the standard Chirpan-539 by 10.3 *%*, followed by Natalia - 2283 *kg/ha*, by 5.1 *%* over the standard. The Macedonian variety 5140 realized 2240 *kg/ha*, by 3.1 *%* over the standard. All Turkish varieties yielded 33.6 to 49.7 *%* less than the standard variety – Chirpan-539. Among them the highest yield of 1442 kg/ha (66.4 *%* compared to the standard) was accounted for Barut-2005. The statistical processing of data showed high significance of differences between all Turkish varieties and the standard.

Table 2. Agronomic and technological properties of studied varieties in 2008

Variety	Seed cotton yield *kg/ha*	In percent to Chirpan-539	Early September yield *kg/ha*	In percent to Chirpan-539	Boll weight *g*	Fiber length *mm*	Lint percentage %
Chirpan-539	2172	100.0	2048	100.0	5.5	26.3	40.9
Beli Iskar	2135	98.3	1987	97.0	5.5	25.7	39.4
Veno	1763	81.2^{0}	1627	79.4^{0}	5.4	26.1	40.5
Trakia	2145	98.7	2046	99.9	5.1	25.4^{0}	39.4
Helius	2234	102.8	2135	104.2	5.4	25.6	39.4
Avangard-264	2171	99.9	2122	103.6	5.1	28.3^{+++}	35.7^{000}
Perla	2158	99.3	2083	101.7	5.0^{0}	27.3^{+}	37.8^{000}
Natalia	2283	105.1	2171	106.0	5.3	27.3^{+}	38.8^{00}
Darmi	2395	110.3	2308	112.6	5.3	28.1^{+++}	38.3^{00}
Colorit	2211	101.8	2136	104.2	5.7	27.3^{+}	37.7^{000}
Vega	2254	103.8	2198	107.3	5.7	27.9^{+++}	37.1^{000}
5140	2240	103.1	2135	104.2	5.4	26.4	38.5^{00}
Barut-2005	1442	66.4^{000}	1070	52.2^{000}	5.7	29.6^{+++}	43.6^{+++}
Nazili-84/5	1236	56.9^{000}	783	38.2^{000}	5.5	28.7^{+++}	46.1^{+++}
Nazili-663	1112	51.2^{000}	703	34.3^{000}	6.6^{+++}	29.5^{+++}	45.2^{+++}
Nazili-954	1093	50.3^{000}	547	26.7^{000}	5.4	$28.6^{++=}$	43.8^{+++}
GD 5 %	350	16.1	319	15.6	0.5	0.9	1.5
GD 1%	467	21.5	426	20.8	0.7	1.2	2.0
GD 0.1 %	612	28.2	557	27.2	0.9	1.6	2.7

The data for the first picking (in the beginning of September) were more demonstrative than those for the seed cotton yield. While from Chirpan-539 yield of 2048 *kg/ha* was obtained, in Avangard-264 it was 2122 *kg/ha*, in all Turkish varieties yields were from 47.8 to 73.3 *%* lower than that of the standard variety Chirpan-539. These results confirmed the high latens in maturity of Turkish varieties and unreliability of their yields. At the 1st picking the highest yield was obtained from Darmi – 2308 *kg/ha*, by 12.6 *%* over the standard. The Macedonian variety 5140 showed also high yield at the first picking - 2135 *kg/ha*, which was by 4.2 *%* over the standard.

As for boll weight, the best values were seen in the Turkish variety Nazili-663 – 6.6 *g* which exceeded the Bulgarian ones (5.0-5.7 *g*) by 0.9 to 1.6 *g*. The Macedonian variety 5140 had ball weight of 5.4 *g*. In respect of lint percentage the Turkish varieties were the best (43.6 - 46.1 *%*). They exceeded significantly the Bulgarian varieties and the Macedonian one. The varieties Avangard-264, Perla and Colorit had low lint percentage.

The longest fibers (28.6-29.6 *mm*) were found in Turkish varieties which surpassed in fiber length the standard variety Chirpan-539 by 1.7 to 2.6 *mm* and Avangard-264 – by 0.4 to 1.3 *mm*. For the Bulgarian cotton varieties the fiber length measured by "butterfly" varied from 25.4 *mm* to 28.3 *mm*. The varieties Beli Iskar, Veno, Trakia, Helius and the standard cultivar Chirpan-539 had short fiber (25.4-26.3 *mm*) and high lint percentage (39.4-40.9 *%*). The other varieties and the standard cultivar Avangard-264 distinguished with longer fiber (27.3-28.3 *mm*), but they had lower lint percentage (35.7-38.8 *%*). Among them the longest fiber was found for Avangard-264 – 28.3 *mm*, followed by Darmi – 28.1 *mm* and by this trait they were close to Turkish varieties Nazili-84/5 and Nazili-954 (28.6-28.7 *mm*). The Macedonian variety 5140 had short fiber - 26.4 mm and was equal with the Bulgarian ones with short fiber.

The varieties and standards were clustered by five traits on the base of data in table 2. The dendrogram presented on Fig. 1 showed that the genotypes divided into two basic clusters. The first cluster included all Bulgarian varieties and the Macedonian one. The second cluster included all Turkish varieties.

The varieties from the first basic cluster subdivided into two smaller clusters and each of them subdivided into still smaller. It means that genetic differences between varieties existed at the smallest levels of division. The varieties Beli Iskar, Veno, Trakia and Helius were in one cluster together with the standard cultivar Cirpan-539. These varieties as well as Chirpan-539 resulted from the breeding program for earliness and productivity. They were obtained by intraspecific hybridization within the *G. hirsutm L.* species (Cirpan-539, Veno, Beli Iskar, 5140) and experimental mutagenesis (Trakia, Helius), and distinguished by high lint percentage but they had short fiber. The variety Helius was genetically very similar to Beli Iskar.

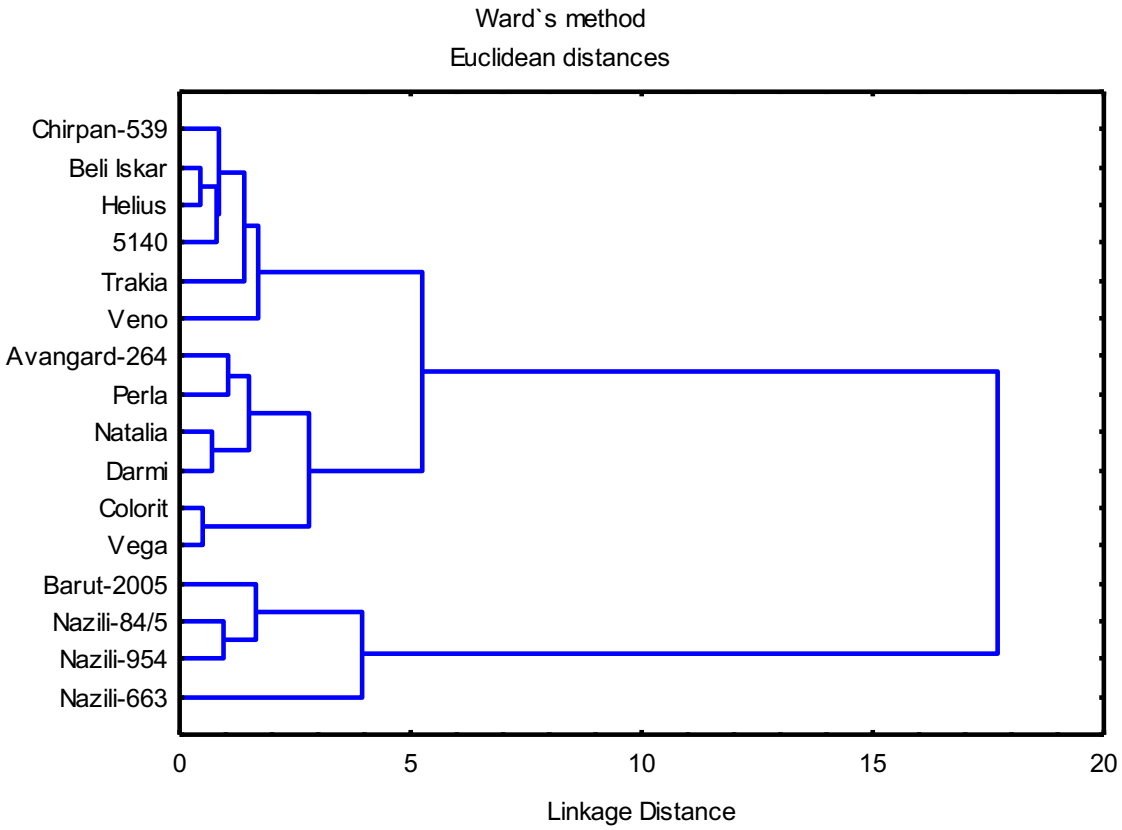

Figure 1. Dendrogram of cluster analysis of 16 cotton varieties by 5 traits based on the data in 1998

The other cluster included Avangard-264 (standard for fiber quality), Perla, Veno, Darmi, Colorit and Natalia. These varieties resulted from the fiber quality breeding and possessed longer fiber and lower lint percentage than the other Bulgarian varieties. The cultivar Avangard-264 was created by interspecific hybridization of the species *G. hirsutum L. x G. barbadense L.*, the others were obtained from crosses of stabilized lines (*G. hirsutum L. x G. barbadense L.)* with *G. hirsutum L.* cultivars. Genetically very similar were Avangard-264 and Perla, Vega and Colotit, Darni and Natalia. The last two varieties possess drought resistance and perform well in dry years, whilst Vega and Colorit realize better in wet years. From the Turkish variety Nazili-84/5 and Nazili-954 were found to be very similar. Barut-2005 showed some genetic distance from these two, it had better earliness, higher September and total seed cotton yields. The variety Nazili-663 with the biggest ball weight and the highest lint percentage combined with long fibre formed separate group.

In 2009 as a result of higher average temperatures during May-August and the strong drought in the beginning of the cotton vegetation period and in August (ball formation period) the Bulgarian varieties and the Macedonian variety matured at the end of August and in the beginning of September. The Turkish varieties matured 12-20 days later. The varieties Helius and Beli Iskar realized the highest seed cotton yields of 2108-2109 *kg/ha* and insignificantly exceeded the standard cultivar Chirpan-539 by 3.7 *%*, followed by Darmi – 2072 *kg/ha*, by 1.9 *%* over the standard (Table 3). The variety Veno was equal with the standard while the other Bulgarian cotton varieties insignificantly were inferior to it by 1.8 to 8.5 *%*. The Macedonian variety 5140 realizes 1764 *kg/ha* and was significantly inferior to the standard by 13.3 *%*. All Turkish varieties were inferior to the standard – Chirpan-539 by 25.5 to

40.8 %. Among them Barut-2005 showed again the highest seed cotton yield – 1516 *kg/ha* (74.5 % of the standard).

Table 3. Agronomic and technological properties of studied varieties in 2009

Variety	Seed cotton yield *kg/ha*	In percent to Chirpan-539	Early September yield *kg/ha*	In percent to seed cotton yield	Boll weight *g*	Fiber length *mm*	Lint percentage %	Height of 1-st sympodium *cm*
Chirpan-539-st.	2034	100.0	1699	83.5	5.0	24.9	41.5	15.8
Beli Iskar (800)	2109	103.7	1972^{++}	93.7	5.1	25.6^{+}	40.0^{000}	15.1
Veno (127)	2047	100.6	1935^{+}	94.5	5.1	24.6	39.6^{000}	14.3
Trakia (240)	1997	98.2	1910^{+}	95.6	5.1	24.9	39.7^{000}	15.0
Helius (288)	2108	103.6	2021^{++}	95.9	5.1	25.0	40.1^{000}	15.6
Avangard-264-st.	1935	95.1	1861	96.2	5.1	26.9^{+++}	38.3^{000}	14.7
Perla (267)	1862	91.5	1750	94.0	5.4^{++}	26.6^{+++}	38.8^{000}	15.2
Natalia (361)	1985	97.5	1885^{+}	95.0	5.1	27.3^{+++}	39.0^{000}	15.7
Darmi (364)	2072	101.9	1972^{++}	95.2	5.1	27.3^{+++}	39.7^{000}	15.7
Colorit (409)	1898	93.3	1787	94.1	5.2	26.1^{+++}	39.3^{000}	16.4
Vega (412)	1897	93.3	1748	92.1	5.0	26.7^{+++}	39.8^{000}	15.8
5140	1764	86.7^{0}	1640	93.0	5.5^{+++}	25.4	38.3^{000}	15.0
Barut-2005	1516	74.5^{000}	847^{000}	55.9	5.7^{+++}	26.7^{+++}	43.0^{+++}	17.9^{+}
Nazili-84/5	1391	68.4^{000}	684^{000}	49.2	5.3^{+}	25.3	43.2^{+++}	20.1^{+++}
Nazili-663	1096	53.9^{000}	575^{000}	55.6	6.0^{+++}	25.8^{++}	45.0^{+++}	22.5^{+++}
Nazili-954	1058	52.0^{000}	450^{000}	42.5	5.7^{+++}	27.1^{+++}	42.7^{+++}	24.9^{+++}
GD 5 %	21,2	10.4	18.7		0.3	0.6	0.8	2.1
GD 1%	28,3	13.9	25.0		0.4	0.8	1.0	2.9
GD 0.1 %	37,1	18.2	32.8		0.5	1.0	1.4	3.7

The first picking was made in the beginning of September and from the standard variety Chirpan-539 was obtained yield of 1699 *kg/ha*, from Avangard-264 (the standard for fiber quality) - 1861 *kg/ha*. At the 1st picking all Turkish varieties were inferior to the standard Chirpan-539 in yields by 44.1 to 57.5 %. The varieties Helius (2021 *kg/ha*), Beli Iskar, Darmi (1972 *kg/ha*), Veno (1935 *kg/ha*) and Natalia (1885 *kg/ha*) showed the highest yields at the 1st picking and significantly surpassed the standard variety Chirpan-539 by 10.9 to 18.9 %. The other Bulgarian varieties surpassed the standard by 2.9-9.5 % while the Macedonian variety insignificantly was inferior to it by 3.5 %. The index for earliness (early September to total seed cotton yield) was very demonstrative for the Turkish cotton latens in maturity. The Bulgarian varieties as well as Macedonian variety realized 83.5 to 96.2 % of their seed cotton yield at the first picking, while the Tirkish ones realized 42.5-55.9 %.

As for ball weight the Turkish variety Nazili-663 had again the highest ball weight – 6.0 *g* while for the Bulgarian varieties it was 5.0-5.4 *g*, and for the Macedonian variety - 5.5 *g*. The varieties Nazili-663, Nazili-954, Barut-2005, 5140 and Perla showed significantly higher boll weight than that of the standard.

The Turkish varieties had the highest indices for the fiber lint percentage (42.7-45.0 %) and by this trait they surpassed all Bulgarian varieties and the Macedonian variety. Of the Bulgarian varieties the highest lint percentage was found for Chirpan-539 – 41.5 %, the others significantly stood behind it.

The longest fiber (27.1-27.3 *mm*) was found for Natalia, Darmi and Nazili-954. The Bulgarian varieties had fiber length from 24.6 to 27.3 *mm*. The varieties Beli Iskar, Veno, Trakia, Helius and the standard cultivar Chirpan-539 had short fiber (24.6-25.6 *mm*) and high lint percentage (39.6-44.5 *%*). The other varieties and the standard cultivar Avangard-264 were with longer fiber (26.1-27.3 *mm*) and lower lint percentage (38.3-38.8 *%*). Among them the longest fiber was found for Natalia and Darmi.

In 2009 the flowering-maturity period passed rapidly as a result of small rainfall in combination with high temperatures and caused strong shortening of the vegetation period which reflected extremely unfavorably on the fiber length, especially on the more qualitative varieties with longer fiber. In 2009 the Turkish varieties Barut-2005 and Nazili-84/5 had by 2.9 and 3.9 *mm* shorter fiber than in 2008, for the Bulgarian varieties the fiber length was less by 1.7 – 2.1 *mm*.

All Turkish varieties distinguished by high setting of the first fruit brunch (first sympodium) about 17.9 – 24.9 *cm*. The height of first sympodium setting for the Bulgarian cotton varieties was about 14.3-16.4 *cm*. The height below 13 *cm* is considered to be critical for mechanization picking of cotton.

The varieties and standards were clustered by six traits on the base of data in table 3. The dendrogram presented on Fig. 2 showed that the genotypes divided into two basic clusters. The clustering in 2009 was similar to that in 2008.

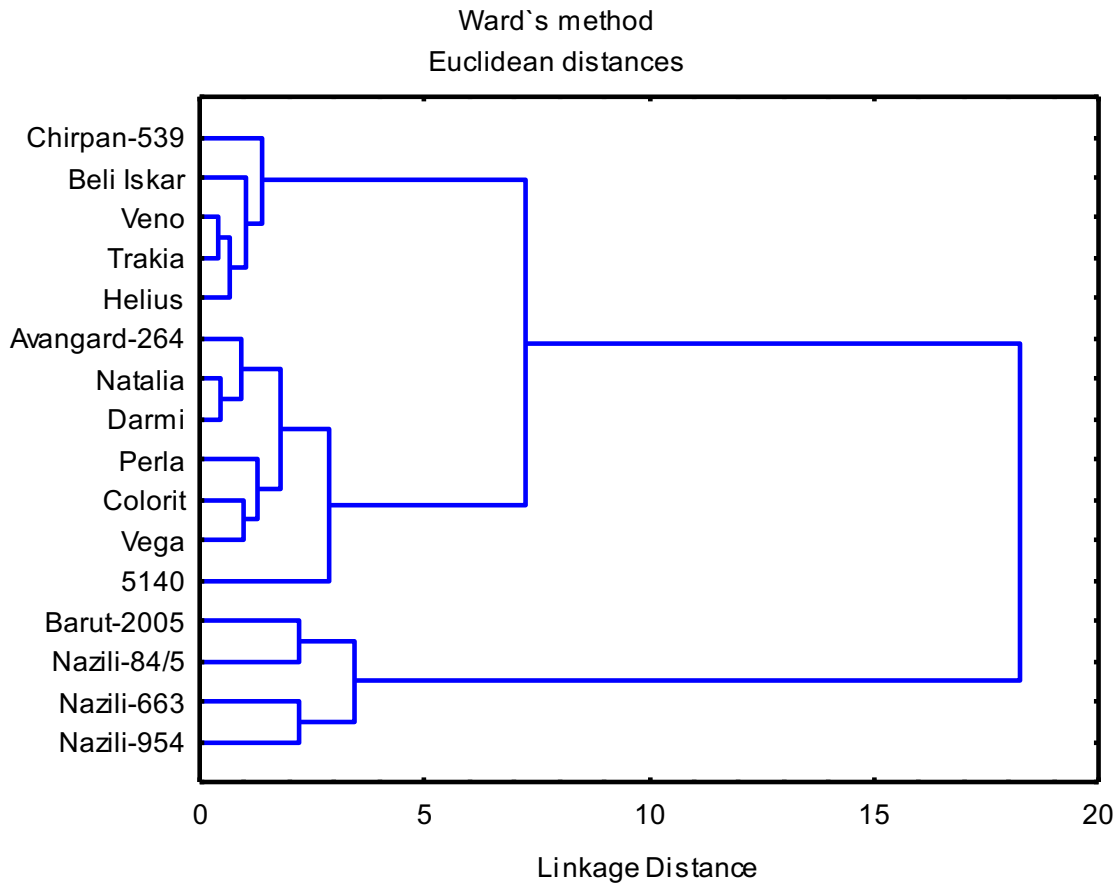

Figure 2. Dendrogram of cluster analysis of 16 cotton varieties by 6 traits based on data in 2009

The first basic cluster included all Bulgarian varieties and the Macedonian one, while the second cluster included all Turkish varieties. In one cluster with Cirpan-539 (standard for earliness and productivity) were the varieties Veno, Beli Iskar, Helius, Trakia and 5140. Genetically very similar were Veno and Trakia. The variety 5140 due to its lower early September and total seed cotton yields formed separate group.

The other cluster included Avangard-264 (standard for fiber quality), Perla, Natalia, Darmi, Colorit and Vega. Genetically very similar were Natalia and Darni, Colotit and Vega. Of the Turkish varieties Barut-2005 and Nazili-84/5, Nazili-663 and Nazili-954 were very similar, too.

The clustering of varieties in 2009 confirmed the genetic remoteness of Bulgarian varieties from the Turkish ones and the genetic differences within the Bulgarian varieties which clearly separated into two subgroups depending on the breeding directions.

The two-factor analysis of variance for the most important agronomic traits showed that the effect of genotypes was highly significant for all studied traits (Table 4). Therefore, it was concluded that the tested varieties had shown the genetic diversity in terms of these traits. The genotype variation had the greatest relative share in the total variation – from 43.5 % (in ball weight)) to 86.8 % (in September yield) (followed by total seed cotton yield - 83.3 %). This means that the phenotype manifestation of traits depended on the genotype of varieties in the greatest degree.

Table 4. Two-way factor dispersion analysis of data for the varieties agronomic and technological properties in 2008-2009

Sources of variation	Degree of freedom	Sum of squares	Sum of squares, %	Dispersion	F-experimental
September yield					
Cultivars - A	15	395982.3	86.8	26398.8	77.6^{+++}
Years - B	1	13842.0	3.0	13842.0	40.7^{+++}
Interaction A×B	15	11102.7	2.4	740.2	2.2^{+}
Error	93	31636.7	6.9	340.2	
Seed cotton yield					
Cultivars - A	15	181760.0	74.3	12117.3	30.5^{+++}
Years - B	1	6690.5	2.7	6690.5	16.8^{+++}
Interaction A×B	15	13025.5	5.3	868.4	2.2^{+}
Error	93	37007.0	15.1	397.9	
Boll weight					
Cultivars - A	15	10.8	43.5	0.72	7.4^{+++}
Years - B	1	1.1	4.4	1.09	11.3^{++}
Interaction A×B	15	3.4	13.6	0.22	2.3^{++}
Error	93	9.0	36.1	0.09	
Fiber length					
Cultivars - A	15	125.1	49.0	8.34	28.0^{+++}
Years - B	1	63.3	24.8	63.3	212.3^{+++}
Interaction A×B	15	37.7	14.8	2.51	8.4^{+++}
Error	93	27.7	10.9	0.30	
Lint percentage					
Cultivars - A	15	732.3	83.3	48.82	64.4^{+++}
Years - B	1	4.2	0.5	4.17	5.5^{+}
Interaction A×B	15	59.1	6.7	3.94	5.2^{+++}
Error	93	70.5	8.0	0.76	

The year variation was also significant, but had weak effect on the total variation, which can be explain with the fact, that 2008 and 2009 were not differed strongly in meteorological conditions, both years 2008 and 2009 were with close values in terms of temperature and rainfall supply during the cotton vegetation period. The year effect was of greater importance for the fiber length – 24.8 %. Weakly to very weakly significance was seen for the year effect on the fiber lint percentage. The genotype × environment interaction was significant for all traits that means by all these traits the genotypes interacted with the environmental conditions.

The total yield, average for two years, varied from 1075 to 2233 *kg/ha* in Darmi (Table 5). Average for two years Darmi insignificantly surpassed the standard for earliness and productivity - Chirpan-539 by 6.2 %, Helius surpassed it by 3.2 %, Natalia – by 1.5 %, while Beli izvor was equal with it. The other Bulgarian varieties were inferior to it by 1.5 - 9.4 %, but the differences were insignificant with the exclusion of Veno showed the lowest seed cotton yield. The Macedonian variety 5140 average for two years realized 95.2 % compared to the standard variety. In 2008 the variety 5140 exceeded the standard by 3.1 % while in 2009 stood behind it by 13.3 %. All Turkish varieties in seed cotton yield average for two years were inferior to the standard by 29.7 % to 48.9 %. Among them the variety Barut-2005 showed the highest seed cotton yield, followed by Nazili-84/5. The Turkish varieties showed relative stability of yields in both years which could be explained with the similar years conditions.

Table 5. Agronomic and technological properties of studied varieties in 2008-2009 (average for two years)

Variety	Seed cotton yield *kg/ha*	In percent to Chirpan-539	Early September yield *kg/ha*	In percent to seed cotton yield	Boll weight *g*	Fiber length *mm*	Lint percentage *%*
Chirpan-539	2103	100.0	1875	89.1	5.2	25.6	41.2
Beli Iskar	2122	100.9	1979	93.3	5.3	25.7	39.7^{000}
Veno	1905	90.6^{0}	1781	93.5	5.3	25.3^{00}	40.1
Trakia	2071	98.5	1978	95.5	5.1	25.2^{00}	39.5^{000}
Helius	2171	103.2	2078	95.7	5.2	25.3^{00}	39.7^{000}
Avangard-264	2053	97.6	1991	97.0	5.1	27.6^{+++}	37.0^{000}
Perla	2010	95.6	1917	95.4	5.2	26.9^{+++}	38.3^{000}
Natalia	2134	101.5	2029	95.1	5.2	27.3^{+++}	38.9^{000}
Darmi	2233	106.2	2140	95.8	5.2	27.7^{+++}	39.0^{000}
Colorit	2055	97.7	1961	95.4	5.5^{+}	26.7^{++}	38.5^{000}
Vega	2075	97.8	1973	95.1	5.3	27.3^{+++}	38.5^{000}
5140	2002	95.2	1887	94.3	5.5^{+}	25.9	38.4^{000}
Barut-2000	1479	70.3^{000}	958^{000}	64.8	5.7^{+++}	28.2^{+++}	43.3^{+++}
Nazili-84/5	1313	62.4^{000}	734^{000}	55.9	5.4	27.0^{+++}	44.7^{+++}
Nazili-663	1104	52.5^{000}	639^{000}	57.9	6.3^{+++}	27.7^{+++}	45.1^{+++}
Nazili-954	1075	51.1^{000}	499^{000}	46.4	5.6^{++}	27.9^{+++}	43.2^{+++}
GD 5 %	19.8	9.4	18.3		0.3	0.5	0.9
GD 1%	26.2	12.5	24.2		0.4	0.7	1.1
GD 0.1 %	33.9	16.1	31.3		0.5	0.9	1.5

The yields obtained from the first picking, average for two years, varied from 499 *kg/ha* to 2140 *kg/ha*. The variety Darmi realized the highest yield at the firs picking, followed by Helius. The Macedonian

variety was equal with the standard – Chirpan-539, but it was inferior to the other Bulgarian varieties. The Turkish varieties were very late in maturity and realized low yields at the first picking. The Bulgarian cotton varieties were very early and had the highest index of earliness – 89.1-97.0 *%* (yield obtained from the 1st picking referred to total seed cotton yield in *%*). The Macedonian variety 5140 by this trait (94.3 *%* index of earliness) was inferior to some Bulgarian cotton varieties. The Turkish varieties were very late in maturity and they had low indices of earliness – 46.4-64.8 *%*.

In respect of ball weight the best indices (average for two years) were observed for the Turkish varieties Nazili-663, Nazili-954, Barut-2000 and for the Bulgarian variety Colorit. The variety Nazili-663 had the biggest ball weight – 6.3 *g* by 1.1 *g* bigger than that of the standard.

The fiber length of the studied varieties varied from 25.2 *mm* to 28.2 *mm* measured by "*butterfly*"method. The longest fiber was found for the Turkish variety Barut-2005 and the shortest - for the Bulgarian varieties Trakia and Helius. The fiber length for the Bulgarian varieties was from 25.2 *mm* to 27.7 *mm*. The varieties Beli Iskar, Veno, Trakia, Helius and the standard cultivar Chirpan-539 had short fiber (25.2-25.7 *mm*) and high lint percentage (39.7-41.2 *%*). The other varieties and the standard cultivar Avangard-264 were with longer fiber (26.7-27.7 *mm*) and lower lint percentage (37.0-39.0 *%*). Among them the longest fiber was found for Avangard-264 and Darmi – 27.6 - 27.7 *mm*, respectively.

The fiber lint percentage average for two years was in limits 37.0-45.1 *%*. The Turkish varieties distinguished by high lint percentage – 43.2-45.1 *%*. For the Bulgarian cotton varieties it was 37.0-41.2 *%*. The varieties Beli Iskar, Veno, Trakia, Helius and the standard cultivar Chirpan-539 had comparatively high lint percentage – 39.5-41.2 *%*, while the others had lower lint percentage – 37.0-39.0 *%*. In the last ones in 2009 the lint percentage was higher than in 2008, but the negative correlation between fiber length and lint percentage retained its character. The Macedonian variety had also lower lint percentage (38.4 *%*) which was equal for the two years.

The varieties and standard cultivars were clustered by five traits (early September and total seed cotton yields, ball weight, fiber length and lint percentage) on the averaged data in Table 5. The dendrogram presented on Fig. 3 showed that the varieties divided into two basic clusters. The first cluster included all Bulgarian varieties and Macedonian variety 4150 while the other cluster included all Turkish varieties.

In one cluster with Cirpan-539 (standard for earliness and productivity) were the varieties Beli Iskar, Trakia, Helius, Veno, Colorit and 5140. The last two varieties formed separate group. The varieties Trakia and Helius, obtained by experimental mutagenesis, were genetically very similar. High similarity was found for Colorit and Macedonian variety 4150. These two varieties are of different origin, but average for the two experimental years, they had close agronomic indices and significantly bigger balls than the other Bulgarian varieties.

The other cluster included Avangard-264 (standard for fiber quality), Darmi, Perla, Natalia and Vega. The variety Colorit refers to this group, but average for the two years of the experiment showed small fiber length (measured by *"butterfly"* method) in comparison with normal years with enough rainfall supply, and felt into the other group. In these varieties with longer fiber the quickly passing of the flowering-maturity period in 2009 reflected strongly negatively on their fiber length. The shortening of fiber length for the variety Colorit with longer vegetation period than the other varieties was the strongest. Genetic similarity based on the average data was found for Natalia and Vega.

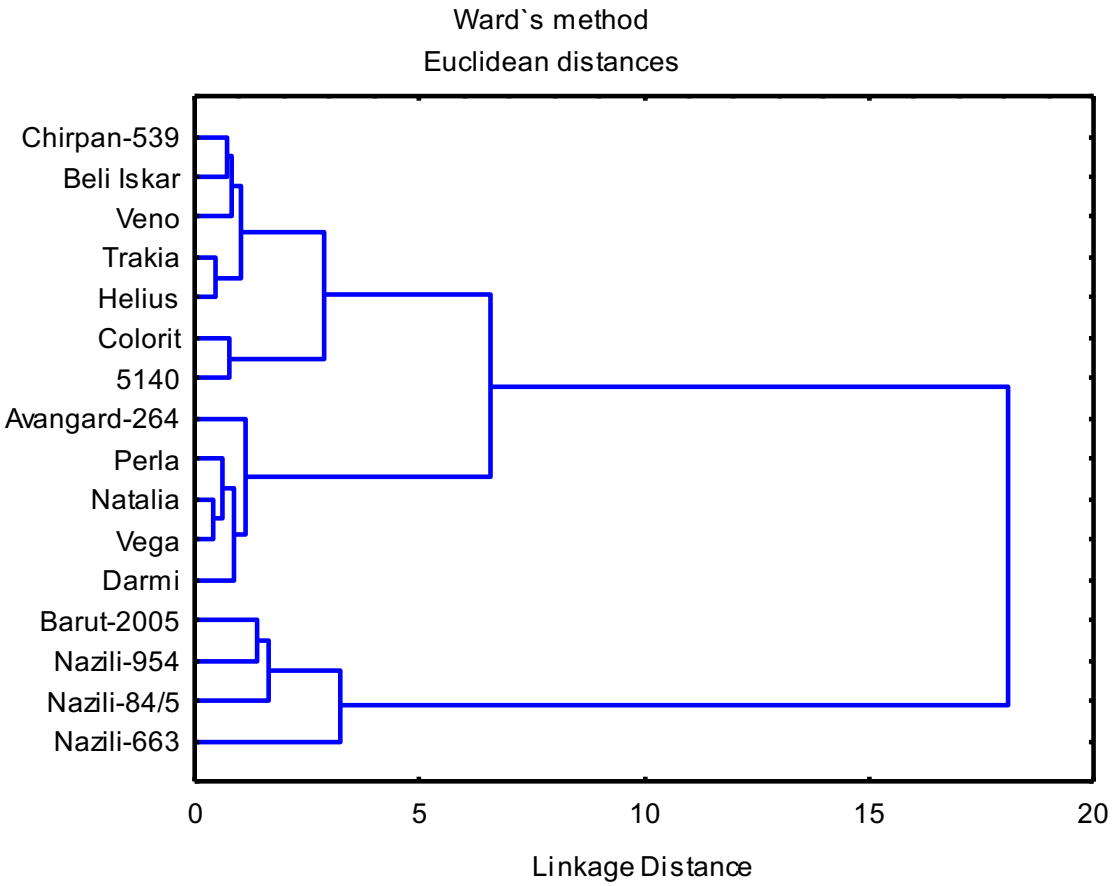

Figure 3. Dendrogram of cluster analysis of 16 cotton varieties by 5 traits based on averaged data in 2008-2009

Concerning the grouping of varieties and their similarity, the clustering in 2008 was more demonstrative compared to that in 2009. The conditions in 2008 were also unfavorable for the fiber length, but the differences in fiber length and lint percentage between the varieties were better expressed.

The Bulgarian varieties (and standard cultivars) were obtained from two differently purposeful breeding programs: creation of early cultivars of high genetic potential for yield over 4500-5000 *kg/ha* and breeding of cultivars with improved fiber quality. Intraspecific hybridization within the *G. hirsutum L.* species and experimental mutagenesis were used in breeding of early and high productive varieties. For the breeding of cultivars of improved fiber quality interspecific hybridization of the species *G. hirsutum L.* × *G. barbadense L.* was applied.

The cluster analysis showed that the genotypes resulting from two differently purposeful breeding programs genetically differed and clearly separated into two groups. It is evident that the varieties within groups were relatively close, indicating a narrow genetic variation. At present the breeding for yield and for fiber quality continue to be the priority directions in the cotton breeding.

The results from the technological fiber analysis of the Bulgarian varieties and standards, measured with *HVI* (High Volume Instrument) by *BTEX* in Bourgas (Bulgaria) are given in Table 6. The micronair valus varied from 3.5 to 4.2 *mic.* The varieties Helius, Avangard-264, Perla, Vega, Kolorit

and Natalia had micronair values from 3.5 to 3.9 *mic* and their fiber could be characterized as fine according to classification of cottons by fineness (from 3.0 to 3.9 *mic*). The other varieties and the standard cultivar Chirpan-539 had micronair values 4.0-4.2 *mic* and their fiber was middle fine (from 4.0 to 4.9 *mic*). The fiber strength was 26.4-29.0 *g/tex* (>25) which means that the varieties and standards had very strong fiber. The strongest fiber was found for Veno (29 *g/tex*), Colorit (28.2 *g/tex*) and Trakia (28.1 *g/tex*).

Table 6. Fiber properties of the studied varieties tested with HVI (High Volume Instrument) by BTEX Bourgas, Bulgaria

Varieties	Micronaire, *mic*		Strength, *g/tex*		Length, *mm*		Uniformity, *%*		Elongation, *%*	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Chirpan-539	4.1	0.07	27.8	0.81	26.75	0.84	81.3	1.17	9.2	1.23
Beli Iskar	4.1	0.05	26.4	1.20	27.11	0.71	82.8	0.87	8.9	0.64
Veno	4.0	0.05	29.0	1.61	26.72	0.91	82.1	0.99	8.9	0.63
Trakia	4.2	0.06	28.1	1.41	26.27	0.73	81.2	1.18	8.6	0.77
Helius	3.9	0.05	27.9	0.80	26.74	0.78	82.5	1.12	8.9	0.72
Avangard-264	3.5	0.04	26.9	0.44	27.28	0.71	82.8	1.02	8.7	0.42
Perla	3.7	0.07	27.8	0.94	28.31	0.49	83.0	0.95	9.6	1.18
Natalia	3.8	0.05	27.9	1.15	28.44	0.35	83.7	1.86	9.1	0.85
Darmi	4.3	0.05	27.2	1.31	28.44	1.04	82.7	1.24	8.1	0.86
Colorit	3.9	0.03	28.2	1.31	28.00	0.68	82.6	1.36	8.6	0.70
Vega	3.5	0.05	26.7	0.73	2 7.31	0.60	82.6	0.73	8.1	0.72

In fiber length (26.27-28.44 *mm*) the varieties and standards belonged to middle long fiber cotton. The longest fiber was found for Darmi and Natalia (28.44 *mm*). The uniformity of fiber 81.2-83.7 *%* showed high uniformity in fiber length. Chirpan and Natalia distinguished by very good elongation of fiber – 9.1-9.2 *%* (9-10) wiliest the others had fairly good fiber elongation – 8.1-8.9 % (8-9).

The varieties and standards, on the data for fiber micronaire, strength, length, uniformity and elongation, divided into two basic clusters (Fig.4). The genotypes from the two clusters differed mainly in fiber length and fineness. The clustering of the genotypes based on these fiber properties was similarly to that on figures 1-3 for the most useful agronomic traits. The varieties Darmi (for its fiber fineness) and Beli Iskar (for its fiber length) changed their main clusters but each of them formed separate group. Genetic differences between varieties were observed in both basic clusters. The most closely related were Chirpan-539 and Trakia, Veno and Helius, Avangard and Vega, Perla and Natalia, which can be explained with their pedigree, the breeding methods and preliminary selection by traits.

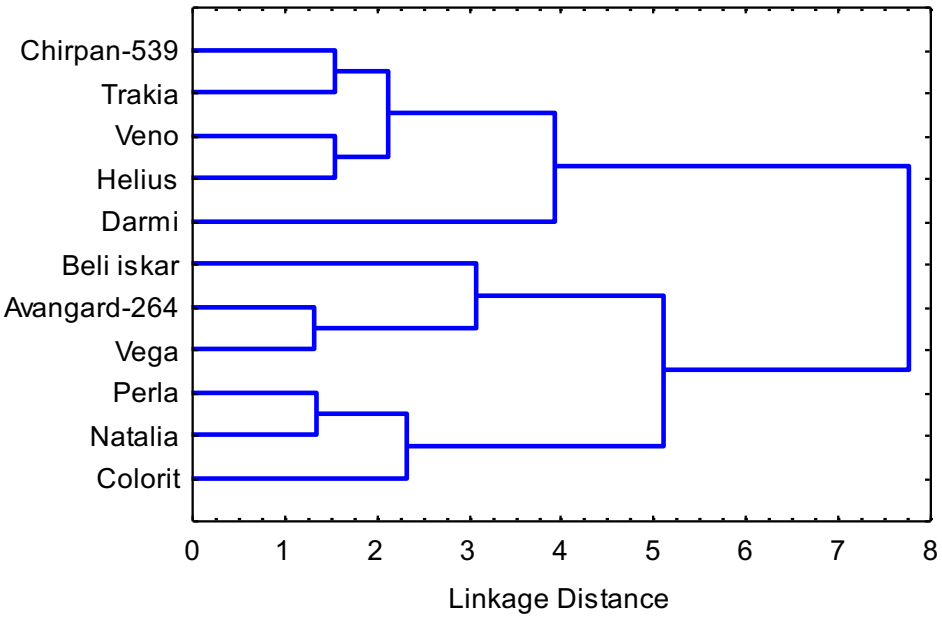

Fig. 4. Dendrogram representing genetic distances between 11 cotton varieties, by 5 fiber technological properties, resulted from two differently purposeful breeding programs

4. CONCLUSIONS

By the Bulgarian cotton breeding large variety diversity has been created which is a good precondition for the development of cotton production in our country. The Bulgarian cotton varieties resulted from two differently purposeful cotton breeding programs differed mainly in length, fineness and lint percentage of fiber.

The cluster analysis based on the varieties agronomic and fiber technological properties confirmed the genetic differences between the Bulgarian varieties.

The Bulgarian varieties in fiber length (26.27-28.44 *mm*) belong to middle long fiber cotton and in micronaire values (3.5-4.9 *mic*) they refer to middle fine and fine cottons. The varieties Avangard-264, Perla, Vega, Colorit and Natalia distinguished by longer and finer fiber, whilst the varieties Chirpan-539, Veno, Beli Iskar, Trakia and Helius had short fiber and high lint percentage.

All varieties possessed strong fiber (26.4-29.0 *g/tex*) with very good uniformity (81.2-83.7 *%*). They had good and fairly good fiber elongation (8.1-9.2 *%*).

In a complex evaluation of technological properties the variety Natalia seems to be the best. It surpassed Avangard-264 (standard for fiber quality) in strength, length and elongation.

In a complex evaluation of agronomic and fiber technological properties the varieties Darmi and Helius were the best and surpassed Chirpan-539 (the standard for earliness and productivity) in seed cotton yield by 6.2 *%* and 3.2 *%*, respectively and had higher index of earliness than it. They were obtained by two differently purposeful breeding programs. The variety Helius combined its higher productivity with comparatively high lint percentage, the variety Darmi – with longer fiber.

Phenotype manifestation of the traits depended on the varieties genotype to the greatest degree. The year effect was weak. The genotypes had different reaction to the different year conditions by the studied traits.

The Macedonian variety 5140 in our climatic conditions significantly was inferior to the standard Chirpan-539 in seed cotton yield by 4.8 % and in lint percentage by 2.6 %.

The Turkish varieties were late in maturing. They matured 12 to 30 days later than the Bulgarian ones. Because of their lower yields and latens in maturity, they are not suitable to be introduced as commercial varieties. However, they distinguished by bigger bolls, longer fiber and higher lint percentage, and set up higher the first fruit-branch then the Bulgarian ones, and in this respect they proved to be very valuable for the Bulgarian cotton breeding.

The cluster analysis provides useful additional information about the similarity and genetic distance of genotypes. The Bulgarian varieties were genetically distant from the Turkish ones.

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