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Phenotypic stability of new cotton lines (*Gossypium hirsutum* L.)

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Abstract

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The genotype × environment interaction and stability of 24 advanced cotton lines and the standard cultivar Chirpan-539 were studied during 2019-2021. The years of study appeared to be different ecological environments. To evaluate the stability, different stability methods were used: the stability variances (s^2_i, S^2_i) of Shukla (1972), the ecovalence (W^2_i) of Wricke (1962) and the parameter YS_i of Kang (1993). The regression coefficient (b_i) and the deviation from regression (S^2d_i) (Eberhart & Russel, 1966) were calculated only for seed cotton yield. A cluster analysis was applied to group the genotypes by phenotypic stability for the studied traits. It was found that the tested cotton genotypes significantly interacted with the environmental (years) conditions in terms of seed cotton yield, boll weigt, fiber length and lint persentage, which required their stability to be studied. Given the estimates of the parameter YS_i and the overall performance based on the variantces s^2_i and S^2_i, and the ecovalence W^2_i, the most valuable lines for the selection programs with cotton were: for seed cotton yield – 678 and 654, combining yield and stability expressed by regression and variance methods, 705 and 724, with high YS_i scores due to high yields, 692, responsive to favorable environments; for boll weight – 701, 581 and 678; for lint percentage – 661, 663 and 718 and for fiber length – 724, 721 and 583, showed high average level and high stability for the relevant traits. Complex breeding value, high average level and stability, for two traits simultaneously was found in lines: 678 – for seed cotton yield and boll weight; 701 – for boll weight and lint percentage; 581 – for boll weight and fiber length. Cluster analysis very well groups genotypes by phenotypic stability and contributes to their more efficient use in breeding programs. The lines distinguished as most valuable based on the analysis of research results, formed independent smaller groups.

Keywords: cotton; new lines; *G. hirsutum* L.; genotype-environment interaction; phenotypic stability; economic traits

Introduction

The phenotypic manifestation of traits is determined by the genotype, the environmental conditions and the genotype-environment interaction. The main effect of genotype (G), the main effect of environment (E) and the main effect of genotype × environment determine the genotype performance (Sadabadi et al., 2018). Meteorological conditions of years are crucial for cotton grown in our country. Bulgaria is the northern border of the spread of cotton culture.

Cotton is grown under non-irrigated conditions with insufficient temperature sum and rainfall during vegetation. There is no a defenite regularity in precipitation during the cotton growing season over years. Climatic conditions differ frequently from year to year. One of the main goals of cotton breeding is to develope stable varieties with consistent performance in terms of yield and fiber quality against the background of various agro-meteorological conditions across years.

Many methods and approaches have been developed to assess the phenotypic stability of varieties, well described in a number of reviews (Lin et al., 1986; Becker & Leon, 1988). Most widely used models are the regression methods of Finlay & Wilkinson (1963), Eberhart & Russell (1966), the variance method of Shukla (1972) and the YS_i parameter of Kang (1993) for simultaneous assessment of yield and stability. Many researchers used these methods to evaluate the adaptability and stability of various cotton genotypes, such as commercial cultivars, new varieties, promising lines, hybrids and their parents, across environments to select superior and adaptable ones (Khalifa et al., 2010; Dewdar, 2013; Balakrishna et al., 2016; GüvercÍn et al., 2017; Patil et al., 2017; Chinchane et al., 2018; Sadabadi et al., 2018; Iqbal et al, 2018; Shashibhushan & Patel, 2020; Deho et al., 2021; Kumbhalkar et al., 2021). Vavdiya et al. (2021) used the regression parameters (b_i, S^2d_i) to evaluate stability of 50 "line × tester" (10 × 5) crosses, at three different sowing dates.

Recently, to evaluate stability, many researchers used PC analysis (Principle Component Analysis, includes analysis of the variance of main components), AMMI method (additive main effect and multiplicative interaction), combined AMMI analysis (includes additive basic effects and multiplicative interaction) and GGE biplot analysis (genotype main effect and genotype × environment interaction effect). The AMMI method and the GGE biplot model were often used to analyze experimental data from different ecological experiments and compare the results (Farias et al., 2016; Pretorius et al., 2015***;*** Moiana et al., 2014; Maleia et al., 2017; Orawu et al., 2017; Riaz et al., 2019; Shahzad et al. 2019; Simasiku et. al., 2020). Biplot analysis was used to examine the genotype (G) and genotype × environment interaction (G×E) (Farias et al., 2016; Fathi Sadabadi et al., 2018) and to test environments and mega environments (Xu et al., 2013; Igbal, 2018; Mare et al., 2020). Maleia et al. (2019) using the AMMI method evaluated the stability and adaptability of native and introduced varieties. According to the findings of Riaz et al. (2013) AMMI model is highly effective for analysis of multi-environment trials.

Due to the great importance of variety stability for sustainable agriculture it is necessary to constantly evaluate the newly created lines. Sustainable production requires development of stable cultivars that can produce optimum yields in different agro climatic conditions (Abro et al., 2020). According to the same authors identification of stable and more adaptable strains is an important aspect of cultivar development and support the idea that in cotton, stability studies are necessary prior to the release of new varieties.

The stability assessment of advance cotton genotypes across different environments is of great importance for cotton production and cotton breeding (Deho et al., 2021). Some of these lines will be realized as new varieties, others will be used as parental components for hybridization. The crossing of parents possessing high stability may result in highly stable genotypes (Bertan & Costa de Oliveira, 2007). Shashibhushan & Patel (2020) concluded that parents showing considerable stability for yield produced hybrids having greater productivity and stability. These results were in accordance with some earlier studies (Balakrishna et al., 2016; Patil et al., 2018; Chinchane et al., 2018). Stability is one of the most desirable properties of a genotype to be released as a variety/hybrid for commercial cultivation or use as a parent in crop improvement programmes (Kumbhalkar et al., 2021).

The aim of this research was to study the genotype × environment interaction and to evaluate the phenotypic stability for most important economic traits of advanced cotton lines, which will help to make a decision about their efficient use in selection.

Materials and Methods

The experimental material included 24 new advanced cotton lines, obtained through intra- and inter-specific hybridization, and the standard cultivar Chirpan-539. Lines 639, 641 and 633 were created by crossing of the allotetraploid *Gossypium thurberi* Tod. × *G. raimondii* Ulbr. with different *G. hirsutum* L. varieties and backcrossing of the triple hybrid (*G. thurberi* Tod. × *G. raimondii* Ulbr.) × *G. hirsutum* L. with *G. hirsutum* L. Lines 678 and 724 were created by hybridization of the *G. hirsutum* L. species with the wild diploid species *G. thurberi* Tod. and saturating backcrosses with the *G. hirsutum* L. The others were obtained through intraspecific hybridization within the *G. hirsitim* L. species.

The study was carried out in the experimental field of the Field Crops Institute in town of Chirpan during the period 2019–2021. The years of study appeared to be different ecological environments. In Bulgaria meteorological factors during the vegetation period of cotton in different years are very diverse and sometimes to contrasting. Competitive variety trials were conducted in three consecutive years in four replications and a harvest plot of 20 m^2, with row to row spacing of 60 cm and plant to plant spacing of 10 cm. The studed traits were: seed cotton yield (kg/ha); boll weight (g); fibre length (cm) and lint percentage (%). Fibre length was determined by the „butterfly" method on 40 individual plants (10 of replication) and lint percentage – on average sample for each replication. Statistical analysis of the genotype × environment interaction was performed, and different stability parameters were used to assess the phenotypic stability of genotypes in different environments (years): the mean values (x) of studied traits; the regression coefficient (b_i) and the deviation from the linear regression (S^2_{di}) (Eberhart & Russel, 1966); the stability variances (s^2_i, S^2_i) for linear and nonlinear interactions (Shukla, 1972); the ecovalence (W^2_i)

(Wricke, 1962) and the YS_i parameter of Kang (1993) for simultaneous assessment of yield and stability. The program STABLE (Kang & Magari, 1995) was used to estimate the genotype × environment interaction and stability parameters (s^2_i, S^2_i, W_i and YS_i).

A cluster analysis was applied to group the genotypes by phenotypic stability, based on the relevant stability measures, for the studied traits.

The years of study were characterized as follows: in terms of temperature sum, 2019 and 2020 were warm (P = 16.1–20.0%), 2021 was average (P = 40.6%); in terms of rainfall, 2019 (P = 23.3%) was moderately wet, 2020 and 2021 г. (P = 71.9–87.1%) were dry.

P% is the coverage factor (coefficient of security) for the temperature sum in May-September and for the rainfall in May-August. The studied years were compared with average long-term values of base period of last 30 years (1991–2021). This period was considered as a climatic norm (Alexandrov et al., 2010).

Results and Discussion

The analysis of phenotypic variance of studied 4 traits of 25 cotton genotypes (24 lines and the standard cultivar) tested in 3 environments (years) showed that the genotypic variation was insignificant for seed cotton yield and boll weight and significant for lint percentage and fiber length (Table 1).

Dechev & Valkova (2007) reported significant genotype variation only for lint percentage, although after analysis of variance for each year separately, they observed significant differences between lines for other studied traits. According to Valchinkov (2000) genotypes can differ in their stability even in insignificant differences. The variation by years was significant for all traits and shows the great importance of year conditions in determining the phenotypic expression of these traits. Similar results were also obtained in cotton with other genetic material (Stoilova & Dechev, 2001–2002; 2002; Stoilova, 2004; Dechev & Valkova, 2007). The expression of genotype-environment interaction is of great importance for the effectiveness of selection and breeding strategy. The genotype-environment interaction was significant for all studied traits, due to the unequal response of genotypes to the changes in environmental conditions. Stoilova (2010) reported significant interaction of these traits with the environment. Stoilova & Dechev (2000–2001) reported significant genotype × environment interaction for seed cotton yield. In another research (Stoilova & Dechev, 2002) the genotype × environment interaction was significant for seed cotton yield and lint percentage and insignificant for boll weigh and fiber length. Stoilova (2004) found significant genotype × environment interaction for seed cotton yield, boll weight and lint percentage and insignificant only for fiber length., Dechev & Valkova (2007) reported a significant genotype-environment interaction for seed cotton yield and boll weight, and insignificant for lint percentage and fiber length. In other studies by the same authors, the genotype-environment interaction was significant for seed cotton yield, modal and staple fiber length, and for other traits (Valkova & Dechev, 2005; 2006; 2012).

The previous studies have shown that the genotypes tested, in all cases, interacted with the environment in terms of seed cotton yield, while for the boll weight, lint percentage and fiber length in some cases they had a similar reaction to the different conditions of environments, which is explained by the genotype of studied varieties and lines and with traits specifics. High stability for the fiber length in different environments was found for the lines obtained from the interspecific *Gosypium hirsutum* L. × G. *barbadense* L. hybridization (Stoilova & Dechev, 2001–2002; Stoilova, 2004). A precise assessment of stability of genotypes with significant genotype-environment interaction is required for a correct selection decision.

The variances for the presence of nonlinear interactions (heterogeneity) for all traits were insignificant. In a study by Stoilova (2010) the heterogeneous variance was significant only for the fiber length, while for the other traits it was insignificant. The insignificant variances of heterogeneity

Table 1. Analysis of phenotypic variance of studied traits

Sources of variation	DF	Mean Squares			
		Seed cotton yield, kg/ha	Boll weight	Lint percentage	Fiber length
Genotypes – G	24	95832ns	0.234 ns	11.818**	3.829*
Environments – E	2	596352**	7.134**	45.703**	103.430**
Interaction – G×E	48	62998.67**	0.168**	4.488**	1.828**
Heterogeneity	24	416.82ns	5.189^{-04}ns	-4.052^{-03}ns	-4.028^{-03}ns
Residual	24	125580.5**	0.336**	8.981**	3.661**
Pooled error	216	96.5	0.050	0.580	0.610

Significance of variances at P < 0.05(*) and P < 0.01(**), respectively.

show linear type of interactions, which is prerequisite for the reliability of the regression methods for stability analysis. Significant heterogeneity was found for the seed cotton yield (Stoilova, 2004) and lint percentage (Stoilova & Dechev, 2002). According to Shukla (1972) the presence of nonlinear interactions (heterogeneity) reduces the certainty of regression coefficients and the behavior of genotypes with respect to their stability can be better estimated by variance methods rather than by regression coefficients.

The mean values and results of stability analysis of studied traits are presented in Tables 2–5.

Seed cotton yield. Averaged over the three years, the seed cotton yields obtained from the tested lines varied from 1298 kg/ha to 1628 kg/ha. Lines 678, 705 and 724 had the highest yields – 1612–1628 kg/ha, exceeding the standard cultivar Chirpan-539 by 10.8–11.9%. Line 705 was the most productive. Of the other lines, some slightly exceeded the standard cultivar, while some others were equal or inferior to it. According to the regression model proposed by Eberhart & Russell (1966), a variety is stable in different environments if it shows unit regression coefficient ($b_i = 1$) and zero mean square deviation from the regression ($S^2d_i = 0$).

According to Lin et al. (1986) a given genotype may considered to be stable if it shows small variation in different environments, if its response to changing environmental conditions corresponds to the mean response rate of all genotypes in the experiment and if the residual mean square from regression model is small. When determining stability with the regression coefficient b_i, the assessment depends on the accepted concept of stability (Becker & Leon, 1988). According to the biological concept, the most stable genotypes are considered the genotypes with regression coefficient $b_i = 0$ or close to zero.

According to the agronomic concept, genotypes with

Table 2. Average data (*kg/ha*) for the seed cotton yield over years and stability parameters by Eberhart and Russel (1966) (b_i, S^2d_i), Shukla (1972) (σ^2_i, S^2_i), Wricke (1962) (W^2_i) and Kang (1993) (YS_i)

Seed cotton yield, kg/ha							
Genotypes	Mean values	b_i	S^2d_i	σ^2_i	S^2_i	W^2_i	YSi
Chirpan-539	1455	1.83	12593	42625**	84621**	83470	-2
489	1298	0.14	28416	78484**	156017**	149451	-10
572	1432	2.12	1751	34178**	68104**	67928	-4
579	1504	1.25	18418	38761**	77249**	76361	8+
581	1468	0.91	18112	37042**	73904**	73198	-1
583	1417	0.58	16178	37178**	73999**	73447	-5
639	1479	2.23	9877	58598**	116218**	112861	1
641	1362	0.11	128592	298865**	595310**	554951	-8
633	1553	0.59	929	3539**	7076*	11552	14+
654	1545	0.88	1091	-92ns	-166ns	4871	20+
661	1517	0.00	2717	29106**	57707**	58595	9+
662	1560	0.27	39297	96346**	192685**	182317	15+
664	1365	0.81	16463	3411**	68014**	67809	-7
678	1617	1.23	1	-1235 ns	-2469ns	2768	27+
679	1573	1.05	32622	67988**	135684**	130138	16+
692	1587	2.95	7838	114662**	227435**	216018	17+
701	1522	1.73	1929	15646**	31007**	33828	10+
705	1628	0.59	6010	14463**	28945**	31653	20+
709	1400	1.05	10059	19353**	38654**	40649	-6
718	1483	0.29	2226	14973**	29893**	32590	2
721	1445	1.06	22428	46355**	92567**	90332	-3
722	1356	1.65	101886	230323**	460350**	428835	-9
724	1612	-0.07	15804	61002**	121964**	117288	18+
729	1525	0.43	26220	62262**	124520**	119603	11+
733	1547	1.20	65567	140474**	280222**	263512	13+

b_i = 1.0 are considered most stable. In terms of seed cotton yield, the agronomic concept of b_i was of greater importance because genotypes that had mean values above mean for the trial were evaluated as more valuable. In this case, it can be assumed that the lines 679, 709 and 721 were high stabile (b_i = 1.05–1.06). However, these three lines had high values for the regression deviation (S^2d_i), showing sensitivity to environmental changes. According to Deho et al. (2021) at high S^2d_i values, can be expected genotypes to achieve high yields in favorable environments.

Genotypes that significantly have regression coefficient greater than unit have special compatibility for environments with high performance (Finlay & Wilkinson, 1963).

Lines 572, 639 and 692 with a regression coefficient b_i = 2.12–2.95 can be considered specifically adapted to favorable environments.

Stability parameters – variances s^2_i and S^2_i for linear and nonlinear interactions, respectively (Shukla, 1972) and ecovalence W^2_i (Wricke, 1962), unidirectional assess stability of genotypes. Genotypes with lower values are considered more stable because they interact weaker with environmental conditions. At significantly high values of one of the two parameters (s^2_i, S^2_i) genotypes are considered unstable. Based on these three stability parameters, lines 654 and 678 were most stable for the seed cotton yield. Lines 641 and 692 were most unstable, because of high values of the three parameters.

Parameter YS_i (Kang, 1993) for simultaneous assessment of yield and stability is based on the statistical significance of differences (genetic effects) and the variance of interaction with the environment. This parameter rated lines 678, 654, 705 and 724 as most valuable.

From the analysis of results it follows that line 678 had best performance for seed cotton yield and stability, followed by line 654. These two lines were high-yilding and stable based on regression and variance stability methods, and with high scores of YS_i. Lines 705 and 724, showed the highest yields and high ratings of YS_i parameter, were very unstable in terms of variance methods. In the case of varieties with high yield and low stability, it is difficult to predict yield in the conditions of changing environments (Dimova et al., 2006). Stability analysis is an important tool in predicting the response of various genotypes over changing environments (Kumbhalkar et al., 2021). Lines 572, 639 and 692 responsive to favorable environments, were also very unstable by variance methods, but higher yields in favorable environments can be expected. The large differences in yield by year to year explain the low stability of lines, confirming that the specific conditions of years were crucial for the seed cotton yield in our conditions.

To establish the similarity in the reaction of studied lines to the environmental conditions (the years), a cluster analysis was applied (Figure 1). Grouping was performed on the established regression and variance stability parameters in Table 1. Cluster analysis separated the studied lines into two main clusters. The first main cluster included 10 lines showed high productivity, (from 1525 kg/ha to 1628 kg/ha), on average for the cluster 1575 kg/ha compared to 1455 kg/ha for the standard cultivar, and high scores on the YS_i parameter. The lines of this cluster were divided into two larger groups, which were further divided into smaller groups. The second main cluster included 12 lines and the standard cultivar showed lower productivity (from 1365 kg/ha to 1522 kg/ha) – 1444 kg/ha on average for the cluster and low scores on the YS_i parameter. Lines 705, 678 and 724 performed best in productivity have fallen into one main cluster, but in different groups, because of different stability. Lines 679, 709 and 721, with a regression coefficient close to one (stable according to the agronomic concept), as well as lines 692, 572 and 639, responsive to favorable environments (b_i > 1), were in different main clusters, due to different yields and different YS_i estimates. Lines 678, 654, 705 and 724, showed the highest YS_i scores, have fallen into one main cluster, in different groups. The first two lines 678 and 654 were stable based on all stability measures. The other two were unstable on variance methods, but had high estimates of the YS_i parameter due to high yields. Lines 678, 654, 705 and 633 formed a smaller group of great interest for breeding programs. Line 633 was unstable according to variance methods. Lines 722 and 641 were located independently, because of low yields and the lowest stability. Lines 678, 654, 705 and 724, showed the highest YS_i scores, have fallen into one main cluster, in different groups. The first two lines 678 and 654 were stable based on all stability measures. The other two were unstable on variance methods, but had high estimates of the YS_i parameter due to high yields. Lines 678, 654, 705 and 633 formed a smaller group of great interest for breeding programs. Line 633 was unstable according to variance methods. Lines 722 and 641 were located independently, because of low yields and the lowest stability.

The research results correspond to those reported by Dewdar (2013) that thigh yield genotypes can differ in yield stability, and suggest that yield stability and high mean yield are not mutually exclusive. The clustering of lines based on their stability for seed cotton yield corresponds to the information obtained from the data analysis in Table 1, on the basis of which the genotypes referred to one group or different groups. There was also a division of genotypes within the groups. The YS_i parameter, for simultaneous assessment

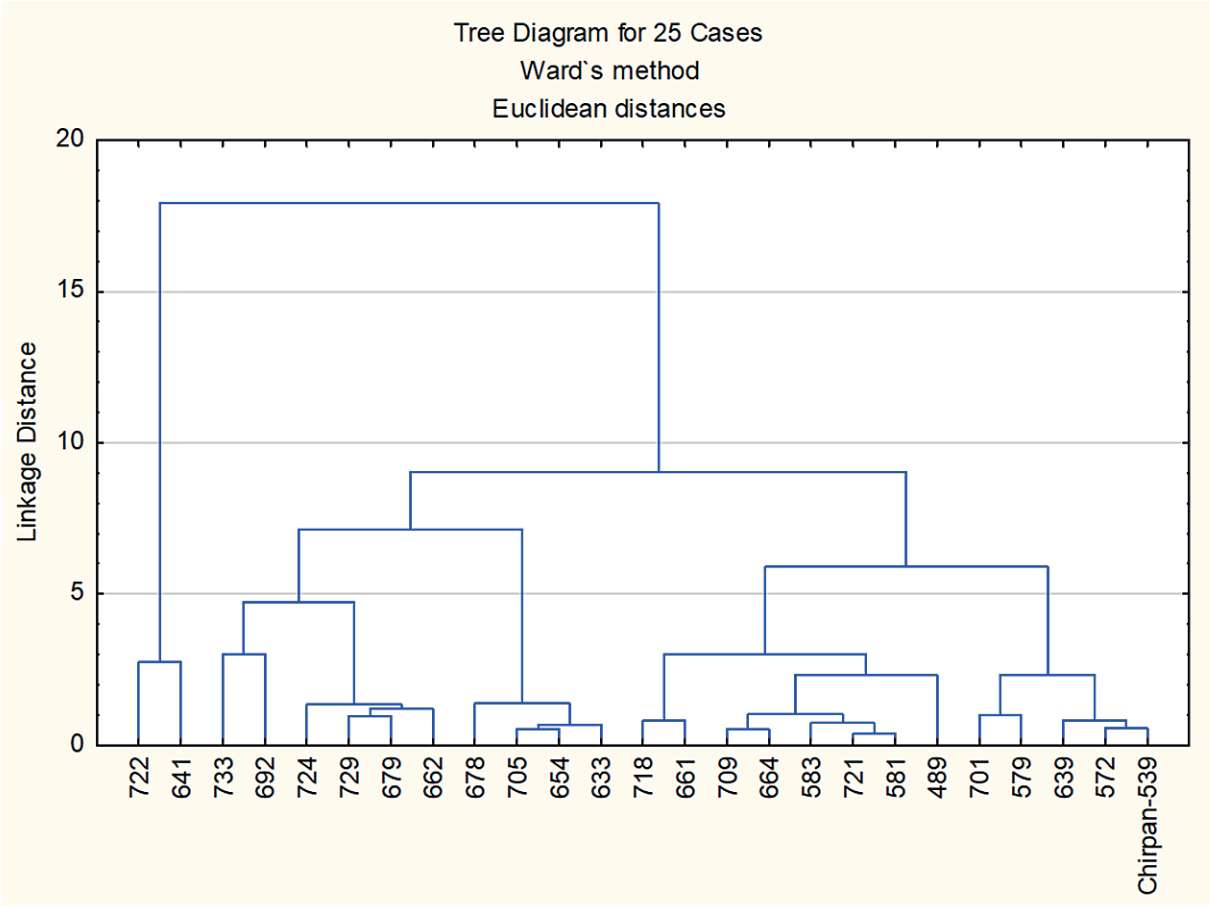

Fig. 1. Dendrogram based on six stability measures for seed cotton yield of 25 genotypes

of yield and stability, was of the greatest importance for line clustering. Only two lines were stable in terms of variance parameters *(s^2_i, S^2_i* and *W^2_i)* and estimates of the *YS_i* parameter was more dependent on the genetic effects of yield. The dendrogram confirms the established in Table 1 complex breeding value as regards yield and stability of lines 678 and 654, which formed a smaller group with line 705, with the highest yield, and line 633.

Boll weight. The boll weight varied from 4.8 g to 5.3 g. Compared to the standard cultivar, some lines had insignificant higher boll weight (by 0.1–0.3 g), others less boll weight. Line 701 had the highest boll weight.

Based on the variances s^2_i and S^2_i of Shukla (1972) and ecovalence W^2_i of Wricke (1962) high stability was found in 12 lines and the standard variety, with different boll weight. Some of these lines had an insignificant higher boll weight than the standard variety. Lines 583, 641, 661 and 705 were most unstable.

The YS_i parameter has defined as most valuable line 701 with the highest boll weight (5.3 g) and the highest YS_i rating, followed by 581, 678, 722, with boll weight 5.2 g, 679 and 489, with boll weight 5.0 g. Line 722 showed significant values of the variances s^2_i (at $P < 0.05$) and S^2_i (at $P < 0.01$) and consequently was unstable on both indicators.

The analysis of results shows that in terms of boll weight, line 701 with the highest boll weight and the highest value of YS_i parameter was most valuable for this trait. Lines 581, 678, 679 and 489 combining high average level (boll weight of 5.0–5.2 g) and high stability based on all stability measures were also very valuable for the selection programs.

Cluster analysis for the boll weight, based on stability measures, divided the lines into two main clusters, each with two subgroups (Figure 2). The differentiation of genotypes within the subgroups was also strong. The first main cluster included lines unstable based on variance methods.

Table 3. Average data for the boll weight over years and stability parameters by Shukla (1972) (σ^2_i, S^2_i), Wricke (1962) (W^2_i) and Kang (1993) (YS_i)

Boll weight, g					
Genotypes	Mean values	σ^2_i	S^2_i	W_i	YS_i
Chirpan-539	4.9	0.036 ns	0.071ns	0.079	10+
489	5.0	0.003ns	0.005ns	0.018	18+
572	4.8	0.014ns	0.028ns	0.039	-1
579	4.9	0.117ns	0.235*	0.229	2
581	5.2	0.006ns	0.012ns	0.025	25+
583	4.9	0.385**	0.768**	0.722	-1
639	4.9	0.115ns	0.229*	0.225	5
641	5.0	0.281**	0.562**	0.530	3
633	5.0	0.011ns	0.021ns	0.033	12+
654	5.0	0.047ns	0.094ns	0.100	15+
661	5.0	0.470**	0.938**	0.878	5
662	4.9	-0.006ns	-0.012ns	0.002	4
664	4.9	0.006ns	0.012ns	0.025	7
678	5.2	0.068ns	0.136ns	0.139	24+
679	5.0	0.006ns	0.012ns	0.025	18+
692	5.0	0.197*	0.394**	0.377	14+
701	5.3	0.003ns	0.005ns	0.018	28+
705	5.2	0.397**	0.795**	0.745	17+
709	4.8	0.183*	0.367**	0.351	-4
718	4.9	0.277**	0.554**	0.524	-6
721	5.0	1.070**	2.138**	1.982	5
722	5.2	0.167*	0.334**	0.321	19+
724	4.9	0.073ns	0.146ns	0.148	5
729	5.1	0.263**	0.526**	0.498	13+
733	4.9	0.016ns	0.033ns	0.044	7

The lines with higher boll weight (5.0–5.2 g) and high YS_i scores belonged to the first larger group, and the lines with less boll weight and lower YS_i scores, belonged to the second larger group. The second main cluster included all lines stable according to variance methods. Lines with less boll weight and low YS_i values belonged to the first larger group, and lines with higher boll weight (5.0-5.3 g) and high YS_i scores, belonged to the second larger group. Thus, the lines with the same boll weight, but with different stability according to the variance methods referred to different main clusters.

Lines 705, 722, 678, 701, 581, 679 and 489 showed boll weight over 5.0 g and high YS_i scores were in different main clusters due to different stability according to variance methods. The first two ones referred to the first subgroup of the first main cluster, and the other 5 lines referred to the second subgroup of the second main cluster. Lines 678, 701 and 581, with a boll weight (5.2–5.3 g) and the highest scores of the YS_i parameter, stable under all stability measures, formed a separate smaller group, lines 679 and 489, with less boll weight and lower YS_i scores were in another smaller group.

Lines 705, 661, 641 and 583, which proved to be very unstable, were in one main cluster, in different subgroups. The last three lines formed a smaller group, while line 705 was located in another subgroup, due to high average level and high score of the YS_i parameter.

Lint percentage. The lint percentage by years varied from 37.4% to 41.1%. The standard cultivar Chirpan-539 had lint percentage of 39.5%. Line 661 had a significant higher lint percentage than the standard cultivar, the other lines were equal to it, or had a lower lint percentage.

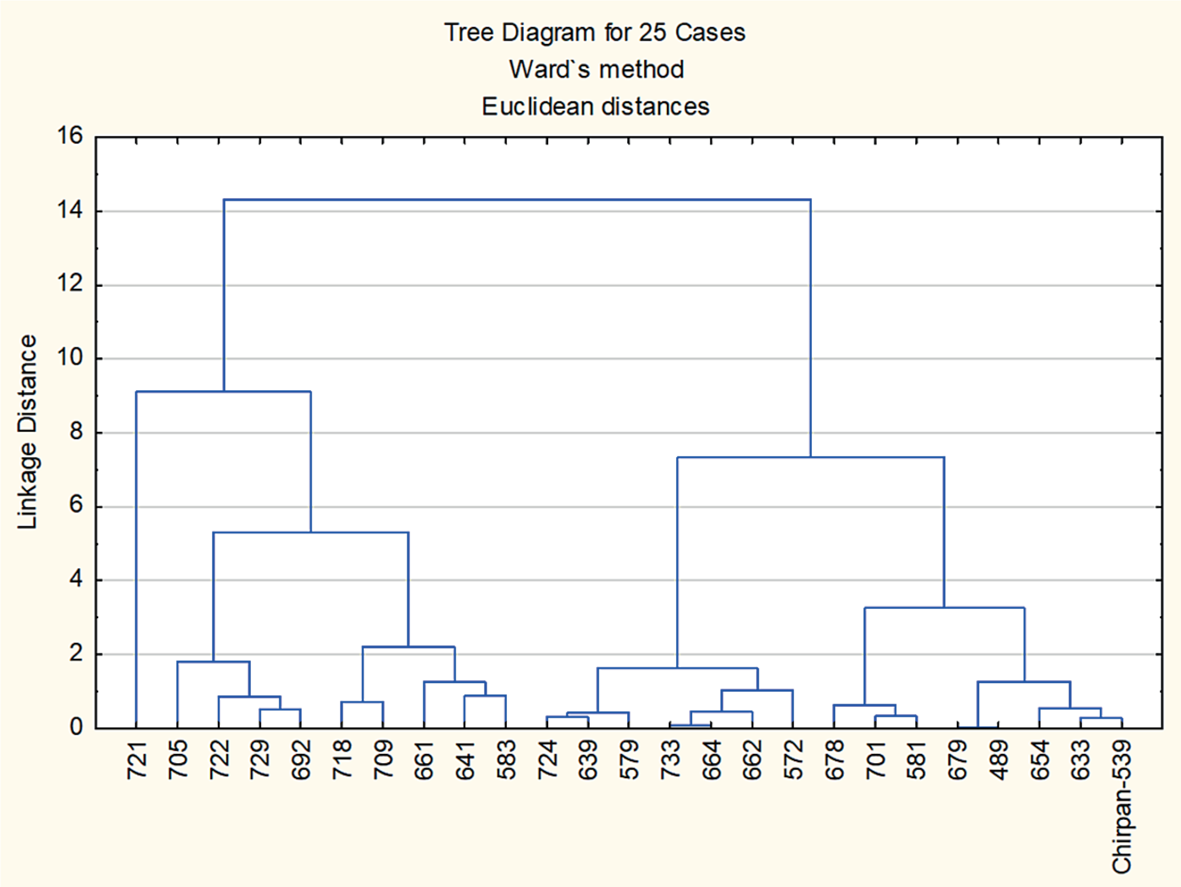

Fig. 2. Dendrogram based on four stability measures for boll weight of 25 cotton genotypes

The variances s^2_i u S^2_i of Shukla (1972) and the ecovalence W^2i of Wricke (1962) have defined as stable 7 lines with different lint percentage.

Kang's YS_i parameter identified lines 661, 633 and 718 as most valuable in terms of lint percentage. These three lines were characterized by high lint percentage (40.0–41.1%) and high YS_i values. Line 661 with the highest lint percentage and the highest YS_i rating was most valuable. Lines 583, 654 and 662, also with high lint percentage (40.0–40.9%) were unstable in terms of variance parameters, while lines 572, 679, 701 and 721, with lower lint percentage (38.5–39.4) had high stability based on variance parameters.

In research of Stoilova (2004), according to the YS_i index, the standard cultivar Chirpan-539 had also high rating. In this study, for this cultivar the variances s^2_i and S^2_i were significant at $P < 0.05$ and $P < 0.01$, respectively and defined it as low stabile.

In view of cotton breeding programs, line 661 has emerged as most valuable in terms of lint percentage, followed by lines 633 and 718. These three lines combined a high average level and stability based on all stability measures, and had the highest scores on the YS_i parameter. Lines 572 and 701 appeared to be also valuable, showed lower lint percentage but high stability. Lines 583, 654 and 662, showed high lint percentage (40.0–40.9%) were very unstable in variability, i.e. in their response to divers environments.

Clustering on this trait confirmed the estimates for the selection value of lines found based on the analysis of results in Table 4. The lines were divided into two main clusters, each with two larger groups. The first main cluster included lines that were unstable according to variance methods and low YS_i scores. The second main cluster included lines recorded different yields and different stability. The lines that proveded to be stable based on the variance methods were found in the two larger groups, due to different lint percentage and different estimates on the YS_i parameter, and formed smaller groups. Lines of the second larger group formed two small-

Table 4. Average data for the lint percentage over years and stability parameters by Shukla (1972) (σ^2_i, S^2_i), Wricke (1962) (W^2_i) and Kang (1993) (YS_i)

Lint percentage, %					
Genotypes	Mean values	σ^2_i	S^2_i	W_i	YS_i
Chirpan-539	39.5	1.930*	3.859**	3.910	13+
489	39.1	5.949**	11.897**	11.305	3
572	39.1	-0.088ns	-0.175ns	0.198	11+
579	39.7	2.666*	5.333**	5.266	15+
581	39.2	2.978**	5.955**	5.838	5
583	40.0	1.775*	3.549*	3.625	18+
639	39.0	5.881**	11.762**	11.180	2
641	38.9	5.749**	11.498**	10.937	0
633	40.4	0.322ns	0.644ns	0.951	25+
654	40.9	3.870**	7.740**	7.480	19+
661	41.1	0.433ns	0.867ns	1.157	28+
662	40.8	9.100**	18.200**	17.103	18+
664	39.7	13.540**	27.080**	25.273	10+
678	38.2	3.903**	7.807**	7.542	-6
679	38.5	0.011ns	0.023ns	0.380	4
692	39.8	2.067*	4.134**	4.163	17+
701	39.4	0.608ns	1.216ns	1.478	16+
705	39.0	12.766**	25.532**	23.849	1
709	37.8	1.389ns	2.778*	2.915	0
718	40.0	0.109ns	0.218ns	0.559	23+
721	38.8	-6.859^{-02}ns	-0.137ns	0.233	7
722	38.0	13.148**	26.296**	24.552	-7
724	37.4	9.131**	18.263**	17.161	-10
729	38.7	9.099**	18.199**	17.102	-3
733	37.8	5.988**	11.976**	11.378	-9

er groups due to different stability. Lines 661, 718 and 633 stable based on all stability measures and with the highest YS_i scores, formed one smaller group. The lines from the other smaller group were unstable according to the variance methods, but had relatively high YS_i scores, because of high lint percentage. Lines of these two smaller groups could be included in crosses in order to achieve faster selection progress with respect to the mean level of trait and its stability.

Crosses could also be performed between genotypes of the two larger groups in order to improve the mean level of trait or its stability in lines showed lower stable or high unstable lint percentage, as well as to obtained new valuable genotypes.

Fibre length. The fiber length of studied lines varied from 24.7 mm to 26.6 mm. The standard cultivar Chirpan-539 had fiber length of 24.9 mm. Longer fiber (26.0–26.6 mm) than that of the standard cultivar was found in 10 lines, by 1.1–1.7 mm superior. Lines 724 and 729 had the longest fiber.

The stability of lines for this trait determined by the two stability variances s^2_i and S^2_i and the ecovalence W^2_i showed that high stability was found for 12 lines with different fiber length. The YS_i parameter has identified as the most valuable lines 724, 721 and 583, with a fiber length of 26.4–26.6 mm, 1.5–1.7 mm above the standard cultivar and high stability based on the three stability parameters, followed by lines 572, 709, 581, 662, exceeding the standard cultivar in fiber length by 1.1–1.4 mm. Lines 729 and 722 with high YS_i scores due to the longer fiber length were unstable. Lines 579, 633, 678 and 692, as well as the standard cultivar, were stable based on the three stability measures, but had short fiber and low values of the YS_i parameter. These lines are less valuable for selection, as well as 9 other lines with short fiber and low stability according to the variance stability parameters.

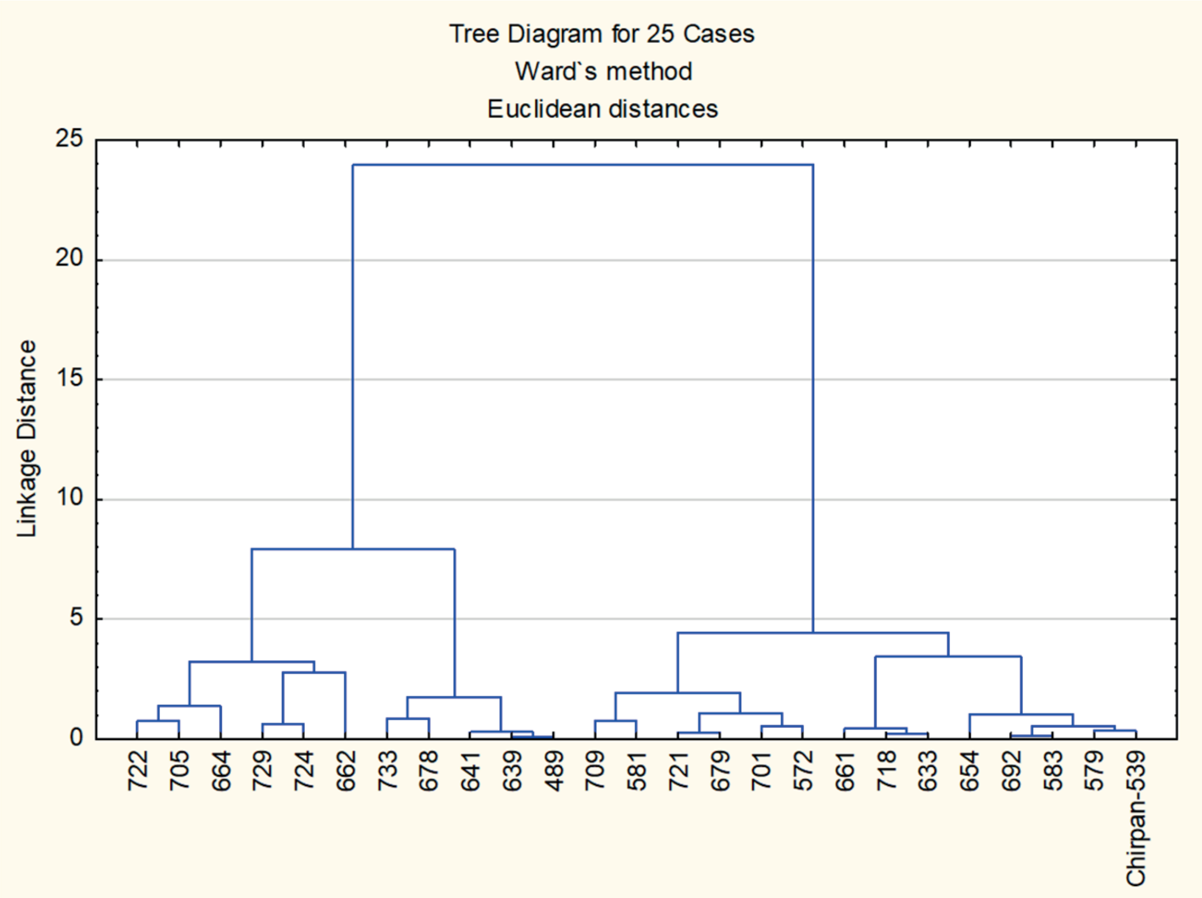

Fig. 3. Dendrogram based on four stability measures for lint percentage of 25 cotton genotypes

Lines 724, 721 and 583, combining a longer fiber and stability on all stability parameters, and the highest YS_i scores, appeared to be most valuable for the cotton breeding programs.

As for the fiber length, at a lower level of separation, four larger groups were formed, which belonged to one main cluster. The first and third groups included lines that were unstable according to variance methods and with low YS_i scores because of low mean values. Lines 729 and 641, also lines 722 and 639, with higher YS_i scores because of higher mean values, separated into two smaller groups. The other two larger groups, the second and the fourth, included the lines stable according to the variance methods.

The lines in the second larger group, stable on all stability measures, appeared to be more valuable. Lines 724, 721, 583 and 572, with the highest complex breeding value, formed an independent smaller group. The analysis of the dendrogram also reveals that some lines recorded the same fibre length or the same stability felt into different main groups because of they differed respectively in stability or in fibre length.

Summarized results of the analyses showed that the genotypes significantly interacted with the environmental conditions for all studied traits. The genotype × environment interaction was the strongest expressed for the seed cotton yield. Breeding useful stability was observed for all studied traits, some genotypes showed stability simultaneously for two traits.

Given estimates of the YS_i parameter and the overall performance on the variances s^2_i and S^2_i, and the ecovalence W^2_i, the most valuable for the cotton breeding programs appeared to be lines: for the seed cotton yield – 678 and 654, combining yield and stability expressed by regression and variance methods, 705 and 724 with high YS_i scores due to high yields, and 692 responsive to favorable environments; for boll weight – 701, 581 and 678; for lint percentage – 661,

Table 5. Average data for the fiber length over years and stability parameters by Shukla (1972) (σ^2_i, S^2_i), Wricke (1962) (W^2_i) and Kang (1993) (YS_i)

Fiber length, mm					
Genotypes	Mean values	σ^2_i	S^2_i	W_i	YS_i
Chirpan-539	24.9	-0.057ns	-0.113ns	0.042	1
489	25.8	1.875*	3.749*	3.597	8
572	26.3	0.721ns	1.441ns	1.473	20+
579	25.7	0.296ns	0.592ns	0.692	10+
581	26.0	0.299ns	0.599ns	0.698	17+
583	26.4	0.387ns	0.774ns	0.858	23+
639	26.1	3.714**	7.427**	6.979	10+
641	26.3	1.955*	3.910*	3.744	16+
633	25.5	0.389ns	0.777ns	0.861	6
654	25.4	3.778**	7.549**	7.098	-3
661	24.8	6.011**	12.015**	11.207	-8
662	26.0	0.336ns	0.672ns	0.764	16+
664	25.6	4.492**	8.985**	8.412	0
678	25.5	0.717ns	1.433ns	1.466	7
679	25.9	4.936**	9.862**	9.229	7
692	24.7	0.049ns	0.099ns	0.237	-2
701	25.7	1.420ns	2.837*	2.759	10+
705	25.6	2.911**	5.816**	5.503	0
709	26.1	0.282ns	0.564ns	0.666	19+
718	25.0	1.849*	3.698*	3.548	-2
721	26.4	0.774ns	1.547ns	1.571	24+
722	26.5	4.604**	9.207**	8.618	17+
724	26.6	0.108ns	0.217ns	0.346	26+
729	26.6	2.342*	4.680**	4.455	23+
733	25.3	1.594ns	3.187*	3.079	4

663 and 718 and for fiber length – 724, 721 and 583, showed high mean values and high stability for the relevant traits. Complex breeding value, high average level and stability, for two traits was found in lines: 678 – for seed cotton yield and boll weight; 701 – for boll weight and lint percentage; 581 for boll weight and fiber length.

The use of different stability methods for assessment and analysis of stability of studied genotypes allowed to significantly improve their analysis, classification and evaluation.

Genotypes with a high overall score of the YS_i parameter differed in stability. Among these rated high based on the YS_i there were also those with low stability expressed by variance methods.

Cluster analysis shows a significant diversity of genotypes in terms of their stability for the studied traits. The lines distinguished as the most valuable for the studed traits based on the analysis of the results in Table 1–4 formed independent smaller groups.

Determining the groups of phenotypic stability can greatly facilitate their use in breeding programs. Cluster analysis provides a visual comparison of genotypes based on a set of stability measures on the basis of which better decisions can be made for breeding programs. This analysis groups very well the genotypes based on their stability expressed by complex of stability measures and provides visual comparison among them. It gives very useful information to identify effective crosses for the combinatorial selection. The results support the conclusion of Dechev & Bozhanova (2009) that the cluster analysis was valuable and useful for the selection in terms of the correct grouping of source material for the combinational selection.

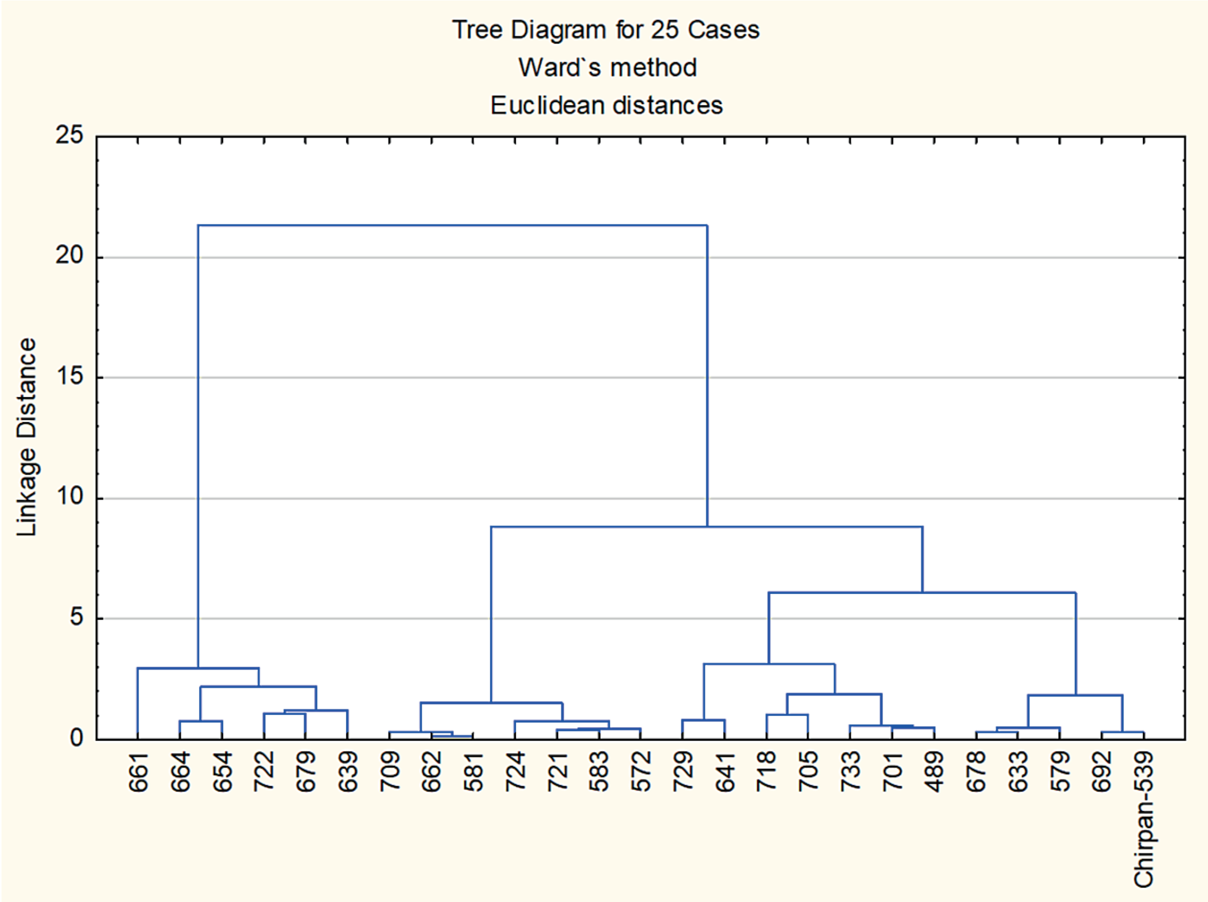

Fig. 4. Dendrogram based on four stability measures for fibre length of 25 cotton genotypes

Conclusions

The studied cotton lines significantly interacted with the environmental conditions (the years) about the seed cotton yield, boll weight, fiber length and lint percentage, which required their stability to be studid.

Lines 678 and 654 combining high yield and high stability expressed by regression and variance methods, 705 and 724 with high YS_i scores due to high yields and 692 possessing specific adaptation to favorable environments, appeared to be most valuable for cotton breeding programs.

Lines 701, 581 and 678 had best performance for boll weight, 661, 663 and 718 emerged as the most valuable in terms of lint percentage, 724, 721 and 583 had a complex breeding value for fiber length. For the relevant traits, these lines had high average level and high stability based on all stability methods.

Complex breeding value, high average level and high stability, for two traits simultaneously was found in lines: 678 – for seed cotton yield and boll weight; 701 – for boll weight and lint percentage; 581 for boll weight and fiber length.

Cluster analysis groups very well genotypes by phenotypic stability and contributes to their more efficient use in breeding programs. Lines distinguished as the most valuable based on the analysis of research results formed independent smaller groups.

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