Phenotypic stability for economic traits of Bulgarian and foreign cotton varieties

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Abstract

The interaction genotype × environment and stability for most important economic traits of 31 Bulgarian and foreign cotton varieties were studied in 2016 – 2019. The years of research were used as different ecological environments. To evaluate the stability, different stability methods were used: the stability variances (σ^2_i, S^2_i) of Shukla (1972), the ecovalence (W^2_i) of Wricke (1962), the parameter YS_i of Kang (1993) and the regression parameters (b_i, S^2d_i) of Eberhart & Russel (1966) (for the seed cotton yield only). There was significant genotype × year interaction for all traits under study. Stability was found for all traits, some genotypes showed stability for two traits. According to the regression parameters (b_i and S^2_{di}), regarding seed cotton yield, the varieties Helius, Trakia, possessing high productivity, Dorina and Chirpan-539 (standard variety) showed a relatively stable performance in different year conditions. The Helius variety, combining high yield and stability according to the regression and variance parameters, outlined as the most valuable for the cotton production. Viki and Denitsa varieties, high yielding, showed specific adaptation to favorable environments and they also were very valuable for implementation in the production. The Greek variety 791-169 combined high average level for the boll weight (5.5 g) and high stability. The Viki, Avangard-264, Eva and Vega varieties (boll weight 5.4-5.5 g) also showed stable performance on all stability parameters. The Viki variety emerged as the most valuable in terms of ginning out turn, combining high mean value (36.1%) and stability. The Boyana and Nelina varieties showed also stable performance (ginning out turn 35.3-35.7%). The varieties Natalia, Dorina, Perla-267 and Colorit in fiber length were compared with the foreign ones and had stable performance by all stability methods. Given the estimates of the parameter YS_i and the overall performance according to the variances σ^2_i, S^2_i and ecovalence W_i^2, the varieties Eva, Natalia, Millennium, Perla-267 and Colorit combined best 1st fruiting branch height and stability, which makes them very valuable for the cotton breeding programs.

Key words: cotton; *G. hirsutum* L.; varieties; genotype × environment interaction; stability; economic traits

INTRODUCTION

Sustainable agriculture is based on highly productive and stable varieties. Stability of the varieties is an important ecological characteristic, which requires in-depth knowledge about the "genotype × environment" interaction and about the ecological organization of the quantitative traits when changing environments.

Cotton production in our country is developing in conditions of limited temperature resources and unstable rainfall, and therefore the economic productivity of cotton is closely dependent on agrometeorological conditions during its growing season. In our country, cotton is grown under dry, non-irrigated conditions, with a strong deficit of precipitation during the summer months.

The cotton varieties grown in our country, in order to realize their productive potential to a greater extent and provide yields under non-irrigated conditions, must have high adaptability and ecological plasticity, to show tolerance to high stress temperatures in July and August, and especially to drought that occurs during these months, and coincides with the periods of flowering and boll formation.

The agrometeorological conditions of the years during the vegetation period of cotton are characterized by strong variation and there is no definite regularity in their rhythm, which significantly complicates the universalization (typicality) of the selection process as a whole. These circumstances determine multi-vector and adaptive selection. One way to increase yields is to create and implement cotton varieties with high and stable yields and better adaption to diverse climatic conditions of the years.

The phenotypic stability of genotypes is a part of the problem related to the genotype × environment interaction, i.e. with the different reaction of the varieties when changing envirpnmental conditions. In different test environments, varieties changed places as a result of their interaction with the environment. Different genotypes responded differently to environmental variations. Some varieties had excellent performance in some environments and very poor in others, indicating a change in their average performance in many environments and a significant genotype × environment interaction (Riaz et al., 2013; Moiana et al., 2014; Zeng et al., 2014; De Carvalho et al., 2015; Pretorius et al., 2015; Farias et al., 2016).

According to Mahtabi et al. (2014), Riaz et al. (2019), in order to improve the stability of genotypes through selection, it is essential to determine the various factors which are responsible for genotype stability or genotype × environment interaction.

Ecological stability is the subject of intensive research in genetic and breeding studies with different crops.

For evaluation of genotypic stability and interaction with environment, number of methods, measures and different concepts have been developed (Lin et al., 1986; Westcott, 1986; Becker & Leon, 1988). The most widely used methods are the regression methods of Finlay & Wilkinson (1963), Eberhart & Russell (1966), the dispersion method of Shuckla (1972), the Kang's method (1993) for simultaneous assessment of yield and stability.

Many researchers have been used these methods to assess the stability and adaptation of different cotton genotypes (comercial cultivars, new varieties, promising lines, hybrids and their parents) across environments to select the superior and adaptable ones (Khalifa et al., 2010; Dewdar, 2013; Balakrishna et al., 2016; Patil et al., 2017; Chinchane et al., 2018; Fathi et al., 2018; Iqbal et al, 2018).

Güvercİn et al. (2017) tested the adaptability and stability of 12 cotton varieties (*Gossypium hirsutum* L.) in 8 environments (4 regions and 2 years) using different stability parameters, such as environmental index, genotype mean value, variation coefficient, ecovalence, variance of stability, regression coefficient, deviations from the regression mean square, variance (dispersion), standard deviation, etc., and found that the genotypes BA 308 and Dicle 2000 were the most productive with high average yield and suitable for all environments.

Fathi et al. (2018) according to the regression slope close to 1, considered genotype 8 as the most stable among all 40 studied genotypes since it had smaller share in the genotype × environment interaction according to Wricke's ecovalence (1962) and Shukla (1972) stability variance.

Shashibhushan & Patel (2020) investigated the stability of conventional crosses and crosses based on CMS and GMS using the stability parameters mean value, regression coefficient (b_i) and regression deviation (S^2_{di}), and found that conventional crosses showed high average yields per/plant and approximately unit regression coefficient and slight regression deviation compared to crosses based on CMS and GMS. Crosses based on CMS and GMS also showed stable yields in places. Similar results have been reported by Tuteja et al. (1999).

Pinki et al. (2018) tested 3 cotton varieties in 6 environments (3 sowing periods and 2 years) and after analyzing the stability of yield and its components according to the model of Eberhart & Russell (1966) concluded that early sowing was the most favorable, followed by normal sowing and late sowing.

Vavdiya et al. (2021) used the regression parameters (b_i) (S^2_{di}) to assess the stability of 50 "line × tester" (10 x 5) crosses, at three different sowing dates.

Deho et al. (2021) evaluated the stability of three srtains and two commercial check varieties in 4 different locations and found that genotypes produced high average yield had regression coefficient bi>1 (1.22-1.68) and concluded that these genotypes were specifically adapted to favorable environments, while the check variety with b_i=0.98 close to

1 showed wide adaptation to all environments, and one strain showed regression coefficient (b_i=0.714) somewhat close to unity 1.0 could be considered wide adaptable to some extent.

Recently, to assess stability, many researchers have applied PCI analysis (includes analysis of the variance main components), AMMI method (Gauch & Zobel, 1988), combined AMMI analysis (includes additive basic effects and multiplicative interaction), GGG biplot analysis (Yan et al., 2000). These analyzes are based on biplot grafs and represent a matrix of data, and allow visualization the information (Fathi et al., 2018).

The grouping of genotypes by analysis of the variance components makes it possible to find the most stable ones, which are of special importance for the selection.

Biplot analysis was widely used to examin the genotype (G) and genotype × environment interaction (GE) (Yan & Kang, 2003; Fathi et al., 2018), and to test environments and megaenvironments (Xu et al., 2013).

Shahzad et al. (2019) tested 41 genotypes (11 inbred lines and 30 intraspecific cotton hybrids) in 6 different environments using the AMMI method to analyze and compare the results. They found that most hybrid genotypes showed better and more stable performance than inbred lines for yield and fiber quality traits, and were more adaptable to different environments. Maleia et al. (2019) evaluated the stability and adaptability of native and introduced varieties using the AMMI method.

According to the findings of Riaz et al. (2013) AMMI model is highly effective for the analysis of multi-environment trials.

The AMMI method and the GGE bi-plot model were often used to analyze experimental data from different ecological experiments and compare the results, in order to better assess the main effects of genotypes in different environments under different conditions, to study the genotype × environment interaction and the stability and adoptability of genotypes (Farias et al., 2013; Orawu et al., 2017; Riaz et al., 2019).

Research have been conducted in Bulgaria to study the phenotypic stability of new cotton varieties and promising lines (Vakova & Dechev, 2005; Stoilova & Genov, 2000; Stoilova, 2001; 2004; 2010; Dimitrova et al., 2004; Dimitrova & Stoilova, 2005; Stoilova & Dechev, 2001-2002; 2002)

In determining the selection value of new cotton varieties and advanced lines submitted to competitive variety testing, it is of great importance to study their phenotypic stability.

The aim of this study was to determine the phenotypic stability for most important economic traits of 20 Bulgarian and 11 foreign cotton varieties and to identify most stable, with a view to their implementation in the cotton production or their use in the future breeding programs.

MATERIAL AND METHODS

The study included the varieties: Bulgarian - Chirpan-539, Beli Iskar, IPTP Veno, Boyana, Viki, Plovdiv, Kris (obtained from intraspecific hybridization); Trakia, Helius, Philippopolis, Sirius (obtained by experimental mutagenesis); Avangard-264 (from interspecific hybridization); Perla-267; Vega, Colorit, Rumi, Darmi, Nelina, Natalia and Dorina (obtained from the crosses of lines *G. hirsutum* L. × *G. barbadense* L. with varieties *G. hirsutum* L.; foreign – Deltapine 30, Stoneville 112 – American, Millennium, Eva, 791-169 – Greek, C-9070 – Uzbek, Nazily-84 – Turkish, Tabladila-16 – Spanish, T-08 – Romanian and Siokra-1-4 – Australian.

Four competition cotton variety trials were carried out in the experimental field of Field Crops Institute in Chirpan, in the period 2016 - 2019, on leached vertisoil type, by the block method, in four replications and a plot of 20 m^2, by applying the conventional technology for cotton cultivation in our country under non-irrigated conditions. The characters studied were total seed cotton yield (kg/ha), boll weight (g), ginning out tern (%), fiber length and 1st fruiting branch height setting – very important for mechanized harvesting. 10 plants from each replication were observed.

The four consecutive years, during which the experiment was conducted, were used as different ecological environments. 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 ($\bar{x}$) of studied characters; the regression coefficient (b_i) for estimating the environments and the deviation from the linear regression (S^2_{di}) according to the model of Eberhart and Russel (1966); Shuckla's

(1972) stability variances (σ^2_i, S^2_i) for linear and nonlinear interactions; Wricke's ecovalence (W^2_i) (1962) and Kang's (YS_i) index (1993), for simultaneous assessment of genotypes by mean level and stability. ANOVA were carried out for each year and over years. The program STABLE (Kang & Magari, 1995) was used to estimate the genotype × environment interaction and for culculating the stability parameters (σ^2_i, S^2_i,W_i and YS_i).

The years of the study were characterized as follows: in terms of temperature security all years of the study were warm (P=14.3-19.4%); in terms of rainfall, 2017 and 2019 were moderately wet (P=22.6-33.3%), 2018 was wet (P=20.9%) and 2016 was dry (P=93.1%).

P - security coefficient determined on the basis of the order of the years in descending order, respectively by the temperature sum for May-September and the rainfall sum for May-August (P%=n/m*1×100, where n was the order number of the year of testing; m – the total number of years included in the descending order of years - climatic norm. The period 1989-2018 (last 30 years) was considered as the climatic norm (Alexandrov et al., 2010).

RESULTS AND DISCUSSION

The analysis of the phenotypic variance of the studied 5 traits of 31 cotton genotypes tested in 4 environments / years (2016 - 2019) (Table 1) shows that the factor (genotypic) influence was insignificant for the boll weight, and the 1st fruiting branch height setting, and significant for the total seed cotton yield, lint percentage and fiber length. For the last three traits, the varieties included in the study have shown genotypic diversity.

The variation by years was significant for all traits and shows the great importance of the year conditions for determining the magnitude of these traits. The genotype × environment interaction was significant for all studied traits, due to the unequal response of the genotypes to the change in the environmental conditions. Stoilova (2010) also reported significant interaction of these traits with the environment (the years).

Stoilova & Dechev (2000-2001) reported significant interaction of the total seed cotton yield with the environment. According to Stoilova (2001) the genotype × environment interaction was significant for the total seed cotton yield and ginning out turn and insignificant for the boll weight, fiber length and 1st fruiting branch height setting. In another research (Stoilova, 2004) the genotype × environment interaction was highly significant for the total seed cotton yield, boll weight and lint percentage and insignificant only for the fiber length.

Previous studies have shown that the genotypes tested, in all cases, interacted with the environment in terms of total seed cotton yield, ginning out turn, while for the boll weight and fiber length in some cases had a similar reaction to the different conditions of the environments, which is explained by the genotype of the studied varieties and lines.

High stability for the fiber length in different environments was found for the lines obtained from

Table 1. Analysis of phenotypic variance of studied 5 characters of 31 cotton genotypes tested in 4 environments / years (in 2016-2019)

Sources of variation	Degree of freedom	Mean Squares				
		Seed cotton yield	Boll weight	Fiber length	Lint percentage	Height of 1st fruiting branch
Genotypes - G	30	32826**	0.418 ns	1.343 **	7.114 **	1.383ns
Environments - E	3	299346.7**	12.375**	12.83**	30.354**	121.344**
Interaction (GxE)	90	14383.78**	0.352**	0.473**	1.253**	1.058**
Heterogenity	30	191.76ns	0.001ns	0.0004ns	0.002ns	0.003ns
Residual	60	21479.79**	0.528**	0.709**	1.878**	1.586**
Pooled error	360	3596	0.088	0.118	0.313	0.264

Significance of variances at P=0.05(*) and P=0.01(**), respectively the interspecific *Gosypium hirsutum* L. × G. *barbadense* L. hybridization (Stoilova, 2001, 2004; Stoilova & Dechev, 2001-2002).

The variances for the presence of nonlinear interactions (heterogeneity) for all traits were insignificant. The results are in accordance with these reported by Stoilova (2001) that heterogeneous variances for all traits were unproven. Stoilova & Dechev (2001-2002) reported significant heterogeneous variance for the total seed cotton yield. In a study by Stoilova (2010) the heterogeneous variance was significant only for the fiber length, while the heterogeneous variances for the other five traits were insignificant.

The insignificant variances of heterogeneity showed linear type of interactions, which was prerequisite for the reliability of the regression methods for stability analysis. Significant heterogeneity has been found for the total seed cotton yield (Stoilova, 2004) and ginning out turn (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

Table 2. Average data for the seed cotton yield (kg/ha) over years and stability parameters by Eberhart and Russel (1966) (b_i, S^2_{di}), 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^2_{di}	σ^2_i	S^2_i	W^2_i	YS_i
Helius	1652	1.23	2374.6	6801.6ns	10117ns	20480.3	**33***
Trakia	**1695**	0.94	6085.7	16851.9**	25217.1**	48685.9	26*
Boyana	149.1	1.54	724.4	4656.8ns	6933.0ns	14461.0	25*
Viki	1648	1.62	1935.9	9013.3ns	13342.0*	26687.3	**32***
Philipopolis	143.5	0.62	2756.3	4874.5ns	7315.1ns	15072.1	21*
Plovdiv	1493	1.46	3276.1	11005.9*	16507*	3227.9.6	22*
Denitsa	1621	1.68	2236.7	10600.2*	15818.3*	31141.1	**27***
Kris	1412	0.45	4444.0	15299.3**	22949.7**	44328.7	11
Sirius	1356	1.82	269.5	7279.5ns	10770.6ns	218215	12*
Avangard-264	1373	1.63	4569.7	16609.9**	24633.2**	48006.9	8
Darmi	1352	0.01	8022.0	32631.1**	48827.0**	92969.6	3
Rumi	1270	1.54	5976.8	19605.6**	29324.2**	56414.1	-4
Nelina	1322	1.45	681.7	3549.1ns	5276.8ns	11352.4	8
Natalia	1123	1.43	547.8	2992.6ns	4474.7ns	9790.5	-2
Dorina	1283	1.24	526.2	1624.3ns	2439.7ns	5950.4	5
Vega	1371	-0.01	2954.2	18485.5**	27482.0**	53270.7	7
Perla-267	1269	0.43	7534.8	24321.0**	36361.9**	6946.7.6	-5
Colorit	1141	**2.11**	430.9	13600.3**	20187.8**	39560.5	-9
Beli Iskar	1457	0.66	3315.5	10159.6*	15242.4*	29904.4	19*
Veno	1471	0.25	2868.1	13400.1*	20053.5**	38998.8	20*
Stoneville 112	1233	1.29	10025.7	28917.0**	43313.2**	82546.0	-7
Deltapine	1236	0.30	9892.6	32766.1**	48686.7**	93347.5	-6
Millennium	1335	0.75	22740	6663.1ns	9972.5ns	20091.7	10
791-169	1324	1.78	7634.6	27556.3**	41315.2**	78727.3	1
Eva	**1562**	-0.37	1620.5	23459.0**	35058.8**	67228.5	21*
T-08	1453	0.70	4334.9	12732.0*	19100.8**	37123.7	18*
C-9070	1425	1.30	6064.3	17729.0**	26589.1**	51147.5	12*
Nazili-84	1357	0.77	3062.7	8812.8ns	13121.6*	26124.7	13*
Tabladila-16	1520	-0.07	1627.7	15915.5**	23540.5**	46058.2	20*
Siokra-1-4	1290	1.30	6086.0	17787**	26670.5**	51310.3	-1
Chirpan-539 St	1365	1.09	3729.7	10199.3*	15231.0*	30015.7	10

better estimated by variance methods rather than by regression coefficients.

The mean values and results of stability analysis of traits studied are presented in Table 2.

Seed cotton yield. Average for four years, the seed cotton yield from the Bulgarian varieties varied from 1123 kg/ha to 1695 kg/ha. The varieties Helius, Trakia, Viki and Denitsa produced the highest yields of 1621-1695 kg/ha, exceeding the standard variety Chirpan-539 by 18.7-24.2%. The Trakia variety was the most productive variety. Of the other Bulgarian varieties, some of them slightly exceeded the standard variety, while others were equalized or inferior to it. Natalia and Colorit varieties were emerging as the lowest productive. The foreign varieties have realized average yields from 1233 kg/ha to 1562 kg/ha, which was 90.3-114.4% of the mean yield of the standard variety. The varieties Eva and Tabladila-16 appeared to be the most productive varieties among the foreign ones and exceeded the standard variety by 14.4% and 11.3%, respectively. The Romanian variety T-08 and the Uzbek variety C-9070 also slightly exceeded the standard variety.

The genotype × environment interaction had the strongest influence for the seed cotton yield (40.7% compared to 30.4% for the genotypes and 28.3% for the environments / years) (data not specified), which was very indicative of the genotypes different response to the different environmental conditions.

Eberhart & Russell (1966) suggested the varieties stability i.e. varieties response to the environmental changes to be measured with the coefficient of linear regression and the deviation from the regression. According to their model, a given variety is stable over different environments if it shows unit regression coefficient (b_i=1) and with mean squares deviation from regression equal to zero (S^2_{di}=0).

According to Lin et al. (1986) a particular 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 on the environmental index 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 the genotypes with regression coefficient b_i=0 or close to 0. On this basis, Darmi, Vega (b_i=0.01) and Tabladilla-16 (b_i=-0.07) varieties were rated the most stable.

According to the agronomic concept, genotypes with b_i=1.0 are considered most stable. In our case, the varieties Helius (b_i=1.23), Trakia (bi=0.94) and the standard variety Chirpan-539 (b_i=1.09) could be considered highly stable. These three varieties showed relatively low values of the regression deviation (S^2_{di}) and could be considered as stable and well adapted to all environments (favorable and unfavorable). In terms of seed cotton yield, the agronomic concept of b_i was of greater importance because genotypes that had mean values above the overall mean of the trials were evaluated as more valuable.

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

The varieties Boyana, Viki, Denitsa, Sirius, Avangard-264, Colorit, Rumi and 791-169 with regression coefficient b_i>1.0 (1.54-2.11) can be considered especially adapted to favorable environments. Avangard-264, Rumi and 791-169 had high values of the S^2_{di} deviation showing fluctuation to environmental changes. According to Deho et al. (2021) due to high values of S^2_{di}, genotypes are expected to give good yield under favorable environmental conditions.

Dorina, Nelina and Natalia varieties, with regression coefficients close to unit or slightly above unit (b_i=1.24-1.45) and with low values of S^2_{di}, can be considered relatively stable on both parameters or weakly responsive to favorable environments, but these varieties showed low yields (1123-1491 kg/ha) and could not be the ideal varieties. Perla-267, Darmi and Deltapine 30 varieties were very unstable according to the regression parameters b_i and S^2_{di}.

Stability parameters - variances (σ^2_i and S^2_i) of Shuckla (1972), which render an account linear and nonlinear interactions, respectively, and ecovalence (W^2_i) of Wricke (1962), unidirectionally assess stability of genotypes. Genotypes that show lower values are considered more stable because they interact weaker with environmental conditions.

Negative values of the variances σ^2_i and S^2_i are considered zero. At significantly high values of one of the two parameters (σ^2_i, S^2_i) genotypes are considered unstable. Based on the three stability parameters, the varieties Helius - high-yielding, Philippopolis, Boyana, Sirius, Nelina, Natalia, Dorina and Millennium were the most stable for the seed cotton yield. Darmi, Perla-267, Stoneville 112, Deltapine 30 and 791-169 varieties were the most unstable.

Very useful information about the selection value of genotypes is provided by the YS_i index of Kang (1993) that enables simultaneous estimation of yield and stability based on the statistical significance of differences (the genetic effects) and variance of interaction with the environment. According to this parameter, Helius and Viki varieties were rated as the most valuable, followed by Denitsa, Trakia, Boyana, Plovdiv, Philipopolis, Eva, IPTP Veno, Tabladila-16, Beli Iskar and T-08.

From the analysis of results it follows that Helius variety had best performance regarding yield and stability. This variety was stable on all stability parameters and had the highest rating of YS_i. Boyana, Sirius, Nelina, Natalia and Dorina varieties were stable on the regression parameters (b_i and S^2_{di}), variances σ^2_i and S^2_i and ecovalence W^2_i, but had low productivity for the studied period, Natalia and Dorina varieties in seed cotton yield were inferior to the standard variety Chirpan-539.

The varieties Philippopolis and Millennium, stable based on both variances σ^2_i and S^2_i, and ecovalence W^2_i, had low productivity close to the standard variety. Many of tested varieties had better performance than the standard variety Chirpan-539 surpassing it in productivity and stability. The Trakia variety showed the highest productivity for the studied period, was very unstable based on the variances σ^2_i and S^2_i. The Viki and Denitsa varieties showed responsiveness to favorable environments (years) (b_i=1.62; 1.68) and according to the YS_i index were rated as one of the most valuable after the Helius variety.

Stoilova (2001) found that on the basis of these stability parameters, the candidate variety № 412 (Vega variety) and standard varieties Chirpan-539 and Avangard-264 were highly stable. Newer, more productive and more stable varieties were involved in the present study. The research results corresponded to those reported by Dewdar (2013) that high-yield genotypes could differ in yield stability and suggested that yield stability and high mean yield were not mutually exclusive.

Colorit variety (b_i=2.11) was the most responsive to the environmental conditions, but it prodused very low yield over the studied period and showed significantly high values of the variances σ^2_i and S^2_i, which means that it was very unstable, but higher yields could be expected in favorable environments.

Eva and Tabladila-16 varieties showed the highest yield among the foreign varieties, respectively by 14.4% and 11.3% above the standard variety, with regression coefficient close to zero (b_i = -0.37; -0.07), were stable according to the biological concept, but were very unstable based on the variances σ^2_i and S^2_i. Both varieties were rated highest based on the YS_i index. The variety Millennium, which in seed cotton yield was close to the standard variety, was the most stable on all parameters.

Based on the generalized analysis, it can be concluded that Helius variety, showed best performense, was most valuable for cotton production, This variety combined simultaneously high yild and high stability based on regression and variance parameters. It can be considered as most stable and can be recommended for wider adaptability. Viky variety, high yilding and with specific adaptation to favorable environments, was also very valuable for wider adaptability. Foreign varieties, under our conditions, gave unstable and uncertain yields. Among these varieties, Eva and Tabladila-16 recorded the highest yields for the period and 791-169 exhibited specific adaptation to favorable environments, were of greater interest for the selection programs with cotton.

Boll weight. As for the boll weight, on average for the period, the studied varieties did not show genotypic differences (Tabl. 3). According to Valchinkov (2000), genotypes can differ in their stability even in insignificant differences. The years had the strongest influence (45.6%) on the formation of this character followed by the genotype-environment interaction (38.9%).

Shahzad et al. (2019) suggested that most of the phenotypic variation of yield traits was explained by environment (E) rather than genotype (G) or genotype × environment interaction (GEI), while the variability in fiber quality traits was mostly attributable to the effects of G and GEI. Similar results have been reported by Meredith et al. (2012), Campbell et al. (2012), Zeng et al. (2014).

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
Helius	5.3	0.503**	0.752**	1.445	12*
Trakia	5.2	1.138**	1.706**	3.228	-4
Boyana	5.3	0.305*	0.456**	0.890	8
Viki	**5.5**	**0.032ns**	**0.048ns**	**0.124**	28*
Philipopolis	5.2	0.169ns	0.252ns	0.508	5
Plovdiv	5.3	0.128ns	0.192ns	0.394	12*
Denitsa	5.2	0.235*	0.352*	0.694	3
Kris	5.0	0.438**	0.657**	1.264	-10
Sirius	5.2	1.137**	1.705**	3.225	-3
Avangard-264	5.4	0.142ns	0.213ns	0.433	26*
Darmi	5.1	0.282*	0.423**	0.828	-3
Rumi	5.2	0.523**	0.783**	1.501	-1
Nelina	5.0	**0.038ns**	**0.056ns**	**0.140**	0
Natalia	5.3	0.394**	0.589**	1.141	12*
Dorina	5.1	0.253*	0.379*	0.745	-3
Vega	5.4	0.082ns	0.123ns	0.265	23*
Perla-267	5.3	0.387**	0.580**	1.120	2
Colorit	5.4	0.187ns	0.281*	0.560	25*
Beli Iskar	5.3	**0.012ns**	**0.017ns**	**0.069**	12*
Veno	5.3	0.353**	0.530**	1.027	12*
Stoneville 112	**5.7**	0.330*	0.495**	0.962	**30***
Deltapine	5.5	0.534**	0.801**	1.532	22*
Millennium	**5.2**	0.909**	1.359**	2.584	1
791-169	5.5	**0.012ns**	**0.018ns**	**0.067**	**31***
Eva	5.4	0.176ns	0.263ns	0.527	27*
T-08	5.3	0.294*	0.442**	0.862	6
C-9070	5.4	0.286*	0.430**	0.838	19*
Nazili-84	5.6	0.398**	0.597**	1.152	24*
Tabladila-16	5.3	0.707**	1.060**	2.019	11
Siokra-1-4	5.3	0.392**	0.589**	1.135	7
Chirpan-539 St	5.3	0.147**	0.219**	0.446	16*

The boll weight varied from 5.0 g to 5.7 g. The American variety Stoneville 112 had the largest bolls, by 0.4 g greater than that of the standard. Compared to the standard, some varieties had larger boll weight, others by 0.1 - 0.3 g smaller.

Bulgarian varieties had boll weight of 5.0 g to 5.5 g, foreign ones - from 5.2 g to 5.7 g. The American variety Stoneville 112 and the Turkish Nazili-84 had the largest bolls - 5.6 - 5.7 g and in this respect they were superior to the Bulgarian varieties.

The varieties Viki, Philipopolis, Plovdiv, Avangard-264, Nelina, Vega, Beli Iskar, 791-169 and Eva showed high stability based on the variances (σ^2_i and S^2_i) of Shuckla (1972) and ecovalence (W^2_i) of Wricke (1962). Some of these varieties had larger, while others had smaller boll weight than the standard variety. Trakia, Sirius, Millennium and Tabladilla varieties were most unstable.

The YS_i index has defined as most valuable the varieties 791-169 and Stoneville 112, followed by Viki, Eva, Colorit, Nazili-84, Vega and others. Stoneville 112 variety, with the highest boll weight (5.7 g) and high YS_i rating, showed significant values of the variances σ^2_i (at P=5%) and S^2_i (at P=0.1%), which outlined it as unstable based on both indexes. Variety Nazili-84 with a boll weight of 5.6 g was also unstable on both variances (σ^2_i and S^2_i).

The analysis of the results shows that in terms of the boll weight, a relatively stable performance was found for the Greek variety 791-169, combining high average level (boll weight 5.5 g) and high stability. Viki, Eva and Vega varieties possessing boll weight 5.4-5.5 g and high stability based on all stability parameters, were also of interest for the selection programs.

Ginning out turn. The ginning out turn by varieties varied from 33.8% (for the variety Perla-267) to 36.9% (for the variety Millennium) (Table 4). The Bulgarian varieties regarding this trait (33.8-36.3%) were comparable to the foreign ones (34.4 - 36.9%). The standard variety Chirpan-539 had ginning out turn 36.3%. Trakia variety was equal to it. Viki and Colorit varieties had relatively high ginning out turn. Some varieties were inferior to the standard variety. Among the Bulgarian varieties, Perla-267, Vega and Rumi had lowest ginning out turn (33.8-

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)

	Ginning out turn, %				
Genotypes	Mean values	σ^2_i	S^2_i	W_i	YS_i
Helius	35.7	0.978*	1.466**	2.865	21*
Trakia	36.3	3.097**	4.644**	8.812	24*
Boyana	35.7	**0.060ns**	**0.090ns**	**0.290**	**24***
Viki	36.1	0.200ns	0.301ns	0.684	**30***
Philipopolis	35.9	3.003**	4.505**	8.550	20*
Plovdiv	35.5	1.154**	1.732**	3.362	13*
Denitsa	35.7	0.827*	1.240*	2.442	21*
Kris	35.1	0.287ns	0.431ns	0.927	10
Sirius	35.8	4.178**	6.267**	11.846	19*
Avangard-264	35.5	3.203**	4.804**	9.110	12
Darmi	35.2	1.715**	2.572**	4.934	4
Rumi	34.9	1.141*	1.712**	3.324	1
Nelina	35.6	**-0.004ns**	**-0.006ns**	**0.110**	**21***
Natalia	35.0	0.524ns	0.787ns	1.593	6
Dorina	35.1	0.971*	1.457**	2.847	7
Vega	34.4	-0.007ns	-0.011ns	0.10	-1
Perla-267	**33.8**	0.367ns	0.551ns	1.152	-2
Colorit	36.1	1.887**	2.830**	5.415	23*
Beli Iskar	35.2	0.934*	1.401*	2.744	9
Veno	35.1	0.187ns	0.281ns	0.647	9
Stoneville 112	34.7	0.906*	1.359*	2.665	-1
Deltapine	34.6	0.164ns	0.246ns	0.581	2
Millennium	**36.9**	1.961**	2.941**	5.624	**26***
791-169	35.3	0.201ns	0.302ns	0.687	14*
Eva	34.4	0.751ns	1.127*	2.230	-1
T-08	35.7	3.929**	5.894**	11.149	14*
C-9070	35.5	3.111**	4.667**	8.853	9
Nazili-84	35.5	1.104*	1.655**	3.219	15*
Tabladila-16	35.0	1.024*	1.536**	2.995	3
Siokra-1-4	34.4	**0.050ns**	**0.075ns**	**0.261**	-1
Chirpan-539 St	36.3	0.908*	1.362*	2.670	28*

34.9%), from the foreign ones these were Stoneville 112, Deltapine 30 and Eva (34.4 – 34.7%).

The genotype had the strongest influence on the formation of this trait (51.5% of the total variation), while the years and genotype × environment interaction were with less influence (21.8% and 27.0%, respectively). These results were in accordance with those reported by Stoilova (2004), that the genetic variation was most significant (67.1%) for the ginning out turn, while the variation by years was much weaker. This character was relatively stable and was less affected by environmental conditions.

The variances (σ^2_i u S^2_i) of Shuckla (1972) and the ecovalence (W^2_i) of Wricke (1962) have defined as stable 10 varieties - Boyana, Viki, Kris, Nelina, Natalia, Perla-267, IPTP Veno (Bulgarian), Deltapine, 791-169 and Siokra (foreign), with different ginning out turn. The varieties Boyana, Nelina, with ginning out turn 35.7% and 35.6 %, and Siokra, with lower value - 34.4%, had the lowest values of these stability parameters and consequently the highest stability. The varieties Trakia, Philippopolis, Sirius, Avangard-264, T-08 and C-9070 had the lowest stability.

Table 5. 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)

Fiber length, mm					
Genotypes	Mean values	σ^2_i	S^2_i	W_i	YS_i
Helius	25.9	0.961**	1.442**	2.744	-5
Trakia	25.7	0.511**	0.767**	1.480	-10
Boyana	26.2	0.984**	1.477**	2.810	3
Viki	26.2	0.741**	1.112**	2.126	6
Philipopolis	25.9	**0.066ns**	**0.096ns**	**0.232**	**2**
Plovdiv	25.8	0.131ns	0.196ns	0.412	0
Denitsa	26.0	0.323*	0.484*	0.952	1
Kris	26.0	0.901**	1.352**	2.575	-4
Sirius	25.8	0.116ns	0.174ns	0.371	-1
Avangard-264	26.1	0.203ns	0.305ns	0.617	9
Darmi	26.3	0.161ns	0.241ns	0.498	18*
Rumi	26.5	0.198ns	0.297ns	0.602	23*
Nelina	26.1	0.152ns	0.228ns	0.473	7
Natalia	26.8	0.172ns	0.258ns	0.529	**34***
Dorina	26.6	0.143ns	0.214ns	0.446	**30***
Vega	26.5	0.518**	0.776**	1.499	17*
Perla-267	26.5	**0.075ns**	**0.112ns**	**0.255**	**27***
Colorit	26.6	0.203ns	0.305ns	0.617	**28***
Beli Iskar	26.3	0.796**	1.194**	2.281	11
Veno	26.2	0.219ns	0.330ns	0.663	10
Stoneville 112	26.7	0.465**	0.698**	1.352	24*
Deltapine	26.5	0.470**	0.706**	1.367	18*
Millennium	26.4	0.377*	0.567*	1.104	18*
791-169	26.4	0.842**	1.263**	2.410	12*
Eva	26.7	0.932**	1.399**	2.662	**25***
T-08	26.2	0.473**	0.710**	1.375	3
C-9070	26.6	1.254**	1.881**	3.566	20*
Nazili-84	26.4	0.530**	0.794**	1.532	13*
Tabladila-16	26.2	0.691**	1.037**	1.987	3
Siokra-1-4	26.3	0.632**	0.948**	1.820	7
Chirpan-539 St	26.0	0.408*	0.612**	1.191	2

Kang's (YS^i) index identified the varieties Viki, Millennium and Chirpan-539, showed ginning out turn 36.1 - 36.9%, as the most valuable, followed by Boyana, Nelina and 791-169, with lint percentge 35.3 - 35.7%. In research of Stoilova (2004), according to the YS_i index, the standard varity Chirpan-539 had also high rating. In the current study, the standard variety Chirpan-539 and the Trakia variety, with the highest mean of the Bulgarian varieties (36.3%), had significant variances σ^2_i and S^2_i, respectively at P=5% for Chirpan-539 and P=1% for Trakia. Millennium variety, with the highest mean value from the foreign varieties - 36.9%, also showed significant variances σ^2_i and S^2_i at P = 1%, which defined it as a variety with low stability.

In view of the cotton breeding programs, the Viki variety has emerged as the most valuable in terms of ginning out turn, combining high average level (36.1%) and stability. This variety, in terms of ginning out turn, was highly stable based on all stability parameters, and had the highest score of the YS_i index. Boyana and Nelina varieties, with lower mean values (35.3-35.7%), also had high stability on all stability parameters and relatively high scores on the YS_i.

Fiber length. The fiber length of studied varieties varied within narrow limits, from 25.7 mm to 26.8 mm for the Bulgarian varieties and from 26.2 mm to 26.7 mm for the foreign ones (Table 5). The standard variety Chirpan-539 had fiber length of 26.0 mm. Of the Bulgarian varieties, Rumi, Natalia, Dorina, Vega, Perla-267 and Colorit showed longer fiber exceeding the standard variety by 0.4-0.8 mm. Among the foreign varieties, longer fiber by 0.5-0.7 mm than that of the standard variety was found for the varieties Stoneville 112, Deltapine 30, Eva and C-9070.

The genotype, environmental conditions and genotype × environment interaction had relatively equal share - 34.0%, 31.7% and 35.1%, respectively in the overall variation of this character.

The varieties stability for this trait, determined by the two stability variances σ^2_i and S^2_i and the ecovalence W^2_i showed that the highest stability was found for the Philipopolis and Perla-267 varieties, with fiber length 25.9 mm and 26.5 mm. Nine other varieties - Plovdiv, Sirius, recorded fiber length 25.8 mm, Nelina, Avangard-264, IPTP-Veno, Darmi (26.1-26.3 mm), Rumi, Dorina, Colorit and Natalia (26.8 mm) also were stable according the three stability parameters.

The YS_i index has identified Natalia, Dorina, Colorit and Perla-267 varieties, the last three with fiber length 26.5 - 26.6 mm, as the most valuable followed by Eva, Stoneville 112, Rumi, C-9070, Deltapine 30, Millennium, Darmi and Vega. Colorit and Vega varieties confirmed their stable performance for this trait found by Stoilova (2001) both varieties had the high mean values and stability in terms of fiber length. The foreign varieties Stoneville 112, C-9070, Deltapine 30 and Millennium, with fiber length 26.4-26.7 mm, had significant values of σ^2_i and S^2_i (at P=1%) and high values of the W^2_i ecovalence. Natalia, Dorina, Perla-267 and Colorit varieties, comparable in fiber length (26.5-26.8 mm) with the foreign ones, possessing high stability on all stability parameters and with the highest YS_i scores, were the most valuable for the cotton breeding programs.

Height of first fruiting branch. The first fruiting branch height varied from 17.1 cm to 18.4 cm for the Bulgarian and from 17.5 cm to 18.3 cm for the foreign ones (Table 6). The lowest values of this character were accounted for the standard varietues and all others surpassed it. Rumi from the Bulgarian varieties and Eva from the foreign ones had the highest mean values.

The years conditions had the largest share in the general variation of this trait (72.7%), and the lowest share (8.2%) was of the genotype.

Stability variances σ^2_i and S^2_i and ecovalence W^2_i have defined as stable 8 varieties - Natalia, Perla-267, Colorit, IPTP Veno, Stoneville 112, Millennium, Eva and Siokra, with height of 1st fruiting branch 17.5-18,3 cm. Among them, Natalia, IPTP Veno, Eva and Siokra varieties stand out as the most stable, with the lowest values of stability parameters. The standard variety Chirpan-539, with height of 1st fruiting branch 17.1 cm, was also highly stable. Denitsa, Sirius, Avangard-264 and Nelina varieties were unstable.

The YS_i index determined as the most valuable Eva variety, followed by Rumi, Natalia, Millennium, Kris, Perla-267, Colorit and others. Natalia and Colorit varieties were rated as one of the most valuable based on this index by Stoilova (2010). Rumi and Kris, with high 1st fruiting branch (18.3-18.4 cm) had proven values (at P=5%) of the variances

Table 6. Average data for the height of the 1st fruiting branch over years and stability parameters by Shukla (1972) (σ^2_i, S^2_i), Wricke (1962) (W^2_i) and Kang (1993) (YS_i)

Height of the 1st fruiting branch, cm					
Genotypes	Mean values	σ^2_i	S^2_i	W_i	YS_i
Helius	18.2	1.424**	2.137**	4.100	19*
Trakia	17.8	1.331**	1.995**	3.836	3
Boyana	17.5	1.326**	1.989**	3.825	-8
Viki	17.6	0.745*	1.117*	2.193	-2
Philipopolis	18.0	1.237**	1.855**	3.574	11
Plovdiv	17.9	2.069**	3.104**	5.910	5
Denitsa	17.7	5.001**	7.507**	14.150	-2
Kris	18.3	0.995*	1.492**	2.896	**28***
Sirius	17.7	2.018**	3.026**	5.765	-2
Avangard-264	18.0	2.406**	3.608**	6.856	12*
Darmi	18.2	1.044**	1.565**	3.032	20*
Rumi	18.4	0.809*	1.213*	2.374	**29***
Nelina	17.7	2.242**	3.363**	6.395	-2
Natalia	18.2	**0.285ns**	**0.427ns**	**0.903**	**28***
Dorina	18.1	0.830*	1.244**	2.433	19*
Vega	17.7	0.589ns	0.883*	1.755	6
Perla-267	18.1	0.865ns	0.130ns	0.345	**25***
Colorit	18.1	0.446ns	0.668ns	1.354	**23***
Beli Iskar	17.6	0.691*	1.036*	2.041	-2
Veno	17.9	**0.262ns**	**0.393ns**	**0.838**	15*
Stoneville 112	17.5	0.441ns	0.661ns	1.339	1
Deltapine	18.0	0.538ns	0.807*	1.612	18*
Millennium	18.2	0.343ns	0.514ns	1.065	28*
791-169	17.8	0.537ns	0.805*	1.610	12*
Eva	18.3	**0.172ns**	**0.258ns**	**0.585**	**31***
T-08	17.7	0.850*	1.275**	2.488	1
C-9070	18.1	0.739*	1.108*	2.176	18*
Nazili-84	17.9	1.046**	1.567**	3.037	6
Tabladila-16	18.0	1.705**	2.557**	4.887	12*
Siokra-1-4	17.7	0.207ns	0.311ns	0.684	6
Chirpan-539 St	17.1	0.365ns	0.548ns	1.128	-2

σ^2_i and S^2_i indicating low stability. Eva, Natalia, Millennium, Perla-267 and Colorit varieties, with high mean values (18.1-18.3 cm), and high stability on all stability parametres, were the most valuable for the cotton selection.

Summarized results of the analysis showed that all genotypes significantly interacted with environmental conditions for all studied characteres. The genotype × environment interaction was the strongest expressed for the total seed cotton yield. Stability was observed for all studied traits, some genotypes showed stability for two traits. Given the estimates of the parameter YS_i and the overall performance of the variances σ^2_i and S^2_i, and the ecovalence W^2_i, the varieties showed relatively more stable performance were: for the seed cotton yield - Helius (high yielding and stable), Viki and Denitsa (possessing specific responsiveness to favorable environments); for the boll weight - 791-169 showed high mean value and high stability, Viki, Avangard-264, Eva and Vega also were with relatively stable performance; for the ginning out turn - Viki variety was the most stable, Boyana and Nelina also were stable; for the fiber length - Natalia, Dorina, Perla-267 and Colorit had best stability performance; for the 1st fruiting branch height – these were the varieties Eva, Natalia, Millennium, Perla-267 and Colorit.

CONCLUSIONS

The studied cotton varieties significantly interacted with the environmental conditions (the years) about the seed cotton yield, boll weight, fiber length and ginning out turn, and height of the 1st fruiting branch setting, which required study of their stability.

The Helius variety had the most stable performance for the seed cotton yield. This variety combened high yield and stability, expressed by the regression and variance methods. Vicky and Denitsa varieties produced high yield and possessed specific adaptation to favorable environments. These three varieties are recomended for implimentation in the cotton production.

As for the boll weight the Greek variety 791-169 had best performense showing high mean value (boll weight 5.5 g) and high stability. Avangard-264, Eva and Vega varieties (boll weight 5.4-5.5 g) also showed stable performance besed on all stability parameters.

The Viki variety emerged as most stable in terms of ginning out turn, combining high average level (36.1%) and stability. The Boyana and Nelina varieties with lint percentage 35.3-35.7% were also stable.

The varieties Natalia, Dorina, Perla-267 and Colorit had best stability performance for the fiber length and can be considered superior for their longer fiber and stability on all stability methods.

The Eva, Natalia, Millennium, Perla-267 and Colorit varieties combined high mean value of height of 1-st fruiting branch and stability, which makes them very valuable for cotton breeding programs.

Stability for two characters was found in the varieties: Boyana – for the seed cotton yield and ginning out turn; Viki - for the boll weight and and ginning out turn; Eva - for the boll weight and height of 1st fruiting branch; Natalia and Colorit - for the fiber length and height of 1st fruiting branch.

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