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STABILITY ANALYSIS OF THE NEW COTTON LINES

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Abstract

The genotype × environment interaction and the stability of eight cotton lines and the standard variety were studied during 2014-2017. The years of the study appeared to be as different ecological environments. The stability variances (σ^2_i and S^2_i) of Shukla (1972) and YS_i index of Kang (1993) were calculated. It was found that the cotton genotypes tested interacted significantly with the environmental (year) conditions in terms of seed cotton yields, boll weigt, fiber length and lint persentage. For an effective selection of these traits, the genotypes had to be tested in different years at diverse environmental conditions and a calculation of the phenotypic stability parameters was necessary for a more precise selection. Based on Sukla's variance stability parameters the breeding usefull stability was observed for all studed traits. Some lines were stable for more than one traits. Line 553 was found to be stable for the seed cotton yield, boll weight and lint percentage, lines 489 and 457 – for the boll weight and fiber length. These lines appeared to be very suitable for inclusion in crosses. According to Kang's YS_i index the complex breeding value (the average level of trait and stability) was found in: line 553 for the seed coton yield, boll weight, fiber length and lint percentage; line 489 for the boll weight, fiber length and lint percentage; line 535 for the seed coton yield and boll weight; line 449 for the boll weight and fiber length; line 457 for the fiber length. These lines are very suitable for the cotton breeding programs to create genotypes with a high expression and high stability of the traits.

Key words: cotton, *G. hirsutum* L., genotype-environment interaction, phenotypic stability, economic traits.

INTRODUCTION

Sustainable agriculture is based on highly productive and stable varieties. The phenotypic stability of varieties is their main ecological characteristics, related to the genotype × environment interaction, i.e. the different reaction of varieties to the changing environmental conditions. In different test environments the varieties change ranks as a result of their interaction with the environment. Some varieties had an 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 (De Carvalho et al., 2015; Farias et al., 2016; Moiana et al., 2014; Pretorius et al., 2015; Riaz et al., 2013; Zeng et al., 2014).

The ecological stability of genotypes is the subject of intensive research in the genetic and breeding studies with different crops. Many statistical methods and approaches for its estimation have been developed. The most widely used models are the regression methods of Finlay & Wilkinson (1963), Eberhart & Russell (1966), the variance method of Shuckla (1972) and the YS_i parameter of Kang (1993) for the simultaneous assessment of yield and stability.

Many researchers used these methods to evaluate the stability and adaptability of different cotton genotypes (commercial cultivars, new varieties, promising lines, hybrids and their parents) across environments to select the superior and adaptable ones (Balakrishna et al., 2016; Chinchane et al., 2018; Deho et al., 2021; Dewdar, 2013; Fathi et al., 2018; Güvercİn et al., 2017; Iqbal et al., 2018; Khalifa et al., 2010; Patil et al., 2017; Shashibhushan & Patel, 2020). Vavdiya et al. (2021) used the regression parameters (b_i) (S^2_{di}) to evaluate the stability of 50 “line × tester” (10 × 5) crosses, at three different sowing dates.

Recently, as method of evaluating the stability, many researchers used the PCI analysis (the Principle Component Analysis, includes an analysis of the variance main components), the AMMI method (Additive Main effects and Multiplicative Interactions) and the GGE biplot analysis (Genotype main effect and Genotype × Environment interaction). The AMMI method and the GGE bi-plot model were often used to analyze experimental data from different ecological experiments and compare the results (Farias et al., 2016; Maleia et al., 2017; Moiana et al., 2014; Orawu et al., 2017; Pretorius et al., 2015**;** Riaz et al., 2019). The biplot analysis was used to examine the genotype (G) and the genotype × environment interaction (GE) (Farias et al., 2016; Fathi Sadabadi et al., 2018; Yan and Kang, 2003) and to test environments and mega-environments (Xu et al., 2014). 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. 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) the AMMI model is highly effective for the analysis of multi-environment trials.

Cotton in Bulgaria is grown under non-irrigated conditions with insufficient temperature and rainfall during the vegetation. There is no definite rhythm of precipitation during the cotton growing season over the years. The climatic conditions differ frequently from year to year. One of the main goals of the cotton breeding is to develop stable varieties with a consistent performance in terms of productivity and fiber quality against the background of various agro-meteorological conditions for the cotton cultivation in Bulgaria over the years. Because of this, in the selection of cotton, it is necessary to constantly evaluate the newly created lines.

To determine the breeding value of the advance lines, included in the competitive variety testing, it is important to determine their phenotypic stability. Some of these lines will be realized as varieties for implementation in practice, others will be used as parental components for hybridization. The crossing of parents with high stability may result in highly stable genotypes.

The aim of this research was to study the genotype × environment interaction and to evaluate the phenotypic stability of the new promising cotton lines, with a view to their more efficient use in selection.

MATERIALS AND METHODS

The experimental material included eight new promising cotton lines, obtained through the use of intra and interspecific hybridization, and the standard variety Chirpan-539. Lines 426, 449, 457, 550 and 553 were created by remote hybridization of the *G. hirsutum* L. with the wild diploid species *G. thurberi* Tod., *G. davidsonii* Kell. and *G. raimondii* Ulbr., and saturating backcrosses with the *G. hirsutum* L. species. Lines 346, 489 and 535 were obtained through intraspecific diallel and line × tester crosses. One of the parents of these three lines included in its genotype *G. barbadense* L. germplazm. The standard variety was of intraspecific origin *G. hirsitim*.

The study was carried out in the experimental field of the Field Crops Institute in the town of Chirpan during the period 2014-2017. The years appeared as different ecological environments. In Bulgaria the agro-meteorological factors during the vegetation period of cotton in different years are very diverse and sometimes contrasting. The competitive variety trials were carried out in four 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 following characters were analyzed: seed cotton yield/ha; boll weight; fibre length and lint percentage. The fibre length was determined by the "butterfly" method on 40 individual plants (10 of replication) and lint percentage - on average sample for each replication. The program STABLE (Kang & Magari, 1995) was used to estimate genotype×environment interaction and stability parameters σ^2_i and S^2_i of Shukla (1972) as well as Kang's YS_i parameter (1993).

The period of the study included years with different temperature sum and rainfall and they were characterised as follow: in terms of temperature sum 2015, 2016 and 2017 were warm (P=14.3-17.2%), 2014 was average to medium cool (P=66.7%); in terms of rainfall 2015 and 2017 were moderately wet (P=28.6-33.3%), 2014 was wet (P=12.9-14.8%) and 2016 was dry (P=93.1%).

The coefficient of security (P%) was determined on the basis of the arrangement of years in descending order, respectively by the temperature sum for May-September and the rainfall sum for May-August ($P\% = n/(m+1)\times100$, where n was the consecutive number of the year of testing; m – the total number of years included in the descending order /row of years - climatic norm.

The period 1989-2018 (last 30 years) was considered as a climatic norm (Alexandrov et al., 2010).

RESULTS AND DISCUSSION

The two-factor dispersion analysis **(Table 1)** showed that the genotypic effect was insignificant for the seed cotton yield and boll weihgt and was highly significant for the fiber length and lint percentage.

Insignificant differences for the seed cotton yield and some of its components were reported by Stoilova & Dechev (2002) in cotton lines of a hybrid origin and by Valkova & Dechev (2003) in the mutant cotton lines.

The genotypic differences (genotypic effects) were insignificant due to the large effects of the environment and the genotype-environment interaction on the total variation and the small differences between the genotypes, although there were significant differences in the individual years (Dechev & Valkova, 2007).

The genotypes had a different norm of reaction when one environment was replaced by another - favorable with unfavorable (Lidanski & Naydenova, 1993).

Lidanski & Stoilova (2000) considered the reaction norm of the long-fiber cotton lines in a qualitative aspect, applying a methodology developed by Lidanski & Naydenova (1993), and concluded that the genotypes had a specific norm of reaction to different environments. Some of the genotypes were more responsive to favorable environments, others reacted more strongly to unfavorable environments and some others showed a high adaptability or had a reaction adequate to the environmental conditions.

In our study, the established unproven genotypic differences for the seed cotton yield were due to the greater effect of the environment and the genotype × environment interaction on the total variation.

Besides the different norm of reaction, small differences between the genotypes, especially for the boll weight, were also important for the insignificant differences. In the individual years of the study there were significant differences for both the seed cotton yield and the boll weight. The genotypic effects were significant for the other two traits – the fiber length and the lint percentage, which means, the lines included in the study showed a genotypic diversity due to genetic causes.

In the total variation of all traits studied, the variation of years had the highest relative share (51.57-71.96%) (data not given here). High and significant mean squares due to years indicated considerable diferences among environments (years) and their predominant effect on all studed traits. The genotype × environment interaction mean squares were highly significant for seed cotton yield, fiber length and lint percentage, indicating different response of the gentypes to different year conditions. The genotype × environment interaction mean square for the boll weight was weakly significant. In case of significant genotype × environment interaction, the selection of genotypes must be conducted in different ecological environments. Several years of research are needed to increase the efficiency of selection (Dechev, 2004). Calculation of the parameters of phenotypic stability of genotypes is a prerequisite for a more precise selection.

None of the studied characters showed significant heterogeneity, which means that the stability of lines can be assessed both by regression and variance methods. It is considered that in non-linear interactions (significant heterogeneity) the behavior of genotypes with respect to their stability can be better assessed by the variance rather than by regression coefficients (Shukla, 1972).

Table 1. Analysis of the phenotypic variance of the studied characters

Sources of variation	DF	Mean Squares			
		Seed cotton yield, kg/ha	Boll weight	Lint percentage	Fiber length
Genotypes - G	8	12043.75ns	0.309ns	14.975**	3.572**
Environments - E	3	263951.70**	5.594**	137.036**	67.219**
Interaction - G×E	24	7122.71**	0.152*	4.074**	0.948**
Heterogeneity	8	9785.63ns	0.168ns	4.746ns	1.308ns
Residual	16	5791.25**	0.144ns	3.739**	0.768**
Pooled error	96	1328.60	0.092	0.58	0.24
Significance of variances at P=0.05(*) and P=0.01(**), respectively					

The mean values and the results of the phenotypic stability analysis of the characters under study are presented in **Table 2.**

Seed cotton yield. The seed cotton yield varied from 1531 *kg/ha* to 1794 *kg/ha.* By this character, most of the lines differed slightly from each other and also from the standard variety. Valchinkov (2000) in experiments with maize reported that the genotypes differed in their stability when the differences in the yield were insignificant. Lines 535, 457, 550 and 553 showed a higher productivity and in the seed cotton yield exceeded the standard variety Chirpan-539 by 9.0 to 11%.

The stability variances (σ^2_i u S^2_i) of Shukla (1972), which take into account linear and non-linear interactions, respectively, one-wayly assess the stability of genotypes. The genotypes having lower values of both parameters are considered to be more stable because they interacted less with the environmental conditions. The negative values of σ^2_i and S^2_i are considered to be 0. At a significant high value of either of the two parameters - σ^2_i or S^2_i the genotypes are considered to be unstable. Based on this, according to the results in Table 2, lines 426, 553 - which were of the more productive genotypes, and 346 emerged as stable in terms of their performance. Lines 535 and 550 – of the most productive, 449 and 489 were the most unstable genotypes. The standard variety Chirpan-539 and line 457 showed a slightly better stability.

Table 2. Average data (2014-2017) for the studied characters and stability parameters σ^2_i and S^2_i of Shukla (1972) and Kang's YS_i index (1993) for nine cotton genotypes (eight lines and the standard variety)

Genotypes	Mean values	σ^2_i	S^2_i	YS_i
Seed cotton yield, kg/ha				
Chirpan-539	1615	8309.52**	4089.84*	-8
346	1656	1715.37ns	1558.58ns	0*
426	1731	-698.36ns	-763.06ns	5*
449	1735	20863.64**	5924.45*	-2
457	1771	5427.40**	7400.37**	1*
489	1531	9286.76**	11251.71**	-10
535	1794	10177.88**	9234.17**	3*
550	1771	9180.69**	13457.05**	0*
553	1761	-156.68ns	-31.84ns	7*
Boll wight, g				
Chirpan-539	5.2	0.113ns	0.181ns	5*
346	4.9	0.391**	0.596**	-7
426	5.1	0.233ns	0.138ns	1
449	5.2	0.261*	0.247ns	4*
457	4.9	0.063ns	0.017ns	-3
489	5.3	0.234ns	0.011ns	9*
535	5.3	0.038ns	0.063ns	10*
550	5.0	0.147ns	0.151ns	0
553	5.1	0.098ns	-0.005ns	4*
Lint percentage, %				
Chirpan-539	41.0	4.248**	3.554**	-5
346	41.8^{**}	3.929**	1.157ns	1*
426	40.9	3.329**	5.314**	-4
449	39.9^{000}	1.247ns	1.922*	-3
457	39.5^{000}	1.038ns	1.803*	-4
489	42.3^{***}	7.301**	11.288**	4*
535	40.6	4.569**	1.811*	-7
550	42.2^{***}	10.764**	6.526**	3*
553	41.0	0.234ns	0.270ns	7*
Fiber length, mm				
Chirpan-539	25.9	0.727*	0.995*	-4
346	26.2^{***}	0.049ns	-0.002ns	2*
426	25.7	1.461**	2.280**	-10
449	27.1^{***}	1.619**	1.330**	4*
457	26.4^{**}	0.499ns	0.202ns	4*
489	26.9^{***}	0.488ns	0.248ns	8*
535	26.6^{***}	2.735**	0.864*	-1
550	26.3^{*}	0.198ns	0.384ns	1
553	26.8^{***}	0.754*	0.607ns	5*

Very useful information about the breeding value of genotypes was obtained by the YS_i index of Kang (1993) for a simultaneous assessment of the yield and stability, based on the reliability of differences (genetic effects) and the variance of interaction with the environment. According to this index, as it is shown in Table 2, line 553 was assessed as the most valuable in terms of seed cotton yield, followed by lines 426 and 535.

From the analysis of the results it can be noted that the highest breeding value was found for line 553 combining high productivity and highly stability. Line 535 exibited the highest seed cotton yield and a positive score on the YS_i index of Kang (1993), but was very unstable on the two stability variances (σ^2_i and S^2_i) of Shukla (1972). This line could be included in crosses with line 553, also with lines 426 and 346, which had high stability based on the variance parametres of Shukla and positive estimates on the YS_i index.

Boll weight. The studied lines had close values for the boll weight (4.9-5.3 g). Lines 489 and 535 had the largest bolls, while lines 346 and 457 had the smallest. This character showed high stability. Based on the stability variances σ^2_i and S^2_i six lines and the standard variety were found as stable. Lines 457, 553 and 535 had lower values of both variances and were more stable than the others. Line 346 was the most unstable and line 449 was also defined as unstable.

On the basis of the YS_i index lines 535 and 489 were define as the most valuable in terms of this character, folowed by the standard variety and lines 449 and 553.

The analysis of the results showed that lines 535 and 489 appeared to be the most valuable for the boll weight. Both lines were stable according to the variances of Shukla and combined the highest boll weight and stability according to Kang’s YS_i index. The standard variety and line 553 showed also high stability on the basis of the variance parameters and had positive values of the YS_i criterion.

Fiber lint percentage. The fiber lint percentage varied from 39.5% to 42.3% **(Table 2).** Lines 449 and 457 had the lowest lint percentage. The highest fibre lint percentage was found in lines 489 and 550. The variances σ^2_i u S^2_i defined these two lines as very unstable. Lines 426 and 535 were also unstable. Line 553 only was found to be highly stable. Some differences were observed in the assessment of some lines stability on the basis of the two variance parameters. The S^2_i defined lines 449 and 457 as unstable, while the variance σ^2_i assessed them as stable. The variance σ^2_i defined lines 346 as unstable, the variance S^2_i defined it as stable. These three lines were unstable, as one of the two stability parameters had high and significant values. The standard variety was very unstable on both stability variances.

According to the YS_i index, line 553 was found as the most valuable, followed by lines 489 and 550. The last two lines had the highest fiber lint percentage as a result the YS_i criterion assessed them highly.

The results of the analysis showed that line 553 was found as the most valuable according to the variances of Shukla (1972) and according to Kang's YS_i criterion (1993). Lines 489 and 550 had the highest fiber lint percentage as a result of which the YS_i criterion assessed them highly, but were very unstable on the the two variances of Shukla.

Fibre length. The fiber length varied from 25.7 *mm* to 27.1 *mm*. Of the genotypes studied, the longest fibre was found for line 449 and the shortest – for line 426, followed by the standard variety. For this fiber property the stability variances σ^2_i и S^2_i showed high stability for four lines 346, 457, 489 and 550. Lines 449 and 426, also the standard variety, were very unstable. The YS_i index determined as the most valuable line 489, followed by lines 553, 457 and 449.

The summarized results for the traits studied showed that according to the variance parameters of Shukla line 553 was stable in terms of seed cotton yield, boll weight and lint percentage; line 489 - for the boll weight and fiber length; line 457 – for the fiber length and lint percentage.

Of the two methods used, particularly valuable from the point of view of selection is the method of Kang (1993), which evaluates genotypes simultaneously on average level and stability. Based on this method the complex breeding value (the average level of trait and stability) was found in the lines: 553 – for the seed cotton yield, boll weight, fiber length and fiber lint percentage; 489 - for the boll weight, fiber length and lint percentage; 535 – for the seed cotton yield and boll weight; 457 - for the fiber length; 449 – for the boll weight and fiber length; 426 - for the seed cotton yield; the standard variety – for the boll weight; 550 – for the fiber lint percentage.

All these lines are very valuable for combinatorial selection to create new cotton genotypes with a high expression of traits and high stability in different environments (over years). Line 553 is the most valuable for future selection, for inclusion in crosses, in order to improve the productivity and stability of the new genotypes.

Line 553 best combined seed cotton yield and stability, lint percentage and stability, line 535 - boll weight and stability, line 489 - fiber length and stability. The inclusion of these lines in one breeding program is a prerequisite for even greater expectations for the cotton breeding.

According to Shukla's variance parameters and Kang's YS_i index, line 553 showed a good performence in terms of seed cotton yield, boll weight and fiber lint percentage; line 489 – for the boll weight and fiber length; 426 - for the seed cotton yield; 457 – for the fiber length; 535 – for the boll weight. These lines can be used in the cotton breeding for creation of superior genotypes with a high expression of traits and high stability.

CONCLUSION

The studed cotton lines and the standard variety reliably interacted with the environmental (year) conditions in terms of seed cotton yield, boll weight, fiber length and lint percentage, which required their study of stability. The breeding useful stability was observed for all traits studied. Some lines were stable for more than one character. According to Shukla’s variance parameters line 553 was found as stable for the seed cotton yield, boll weight and lint percentage, lines 489 and 457 – for the boll weight and fiber length. These lines appeared very suitable for inclusion in crosses. The complex breeding value (the average level of trait and stability) was found in lines: 553 for the seed coton yield, boll weight, fiber length and lint percentage; 489 for the boll weight, fiber length and lint percentage; 535 for the seed coton yield and boll weight; 449 for the boll weight and fiber length; 457 for the fiber length. These lines are very suitable for the cotton breeding programs to create genotypes with a high expression and high stability of the traits. Line 553 combined the best yield and stability, lint percentage and stability, line 489 - fiber length and stability, line 535 - boll weight and stability, which makes them even more valuable for the selection of cotton.

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