AGRICULTURAL UNIVERSITY PLOVDIV
DEPARTMENT OF CROP SCIENCE

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INTERACTION BETWEEN ENVIRONMENTAL CONDITIONS AND GRAIN YIELD IN COMMON WHEAT (*Triticum aestivum* L.) VARIETIES

ABSTRACT

Thesis for awarding the educational and scientific degree "DOCTOR" in the scientific specialty "Plant Growing"

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The study was conducted in the period 2009 - 2018 in the experimental fields of AGRONOM I HOLDING, Dobrich. http://agronom.bg/

The dissertation contains 185 typewritten pages, 46 tables, 23 figures. The list of cited literature includes a total of 215 literary sources, of which 25 in Cyrillic and 190 in Latin letters.

The dissertation was discussed at the Department council.

The defence of the dissertation will take place on 02. 10. 2020 from 11 hours of the meeting of the Specialized Scientific Jury at the II auditorium - Agricultural University, Plovdiv, with members:

Internal members:
Prof. Dr. Hristina Yancheva
Prof. Dr. Hristofor Kirchev
External members:
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1. INTRODUCTION

Any trait, quality or property affecting grain yield and / or quality is formed as a result of the interaction of genotype and environment. This direct influence of the natural environment, such as meteorological conditions of the season, soil and climatic features of the place of cultivation is the reason why the variety is considered as a "genotype" and a "phenotype". The whole selection process is inextricably linked to the evaluation of the variety (genotype), through observations on the phenotype. What is seen and selected in many cases is the result of growing conditions to a greater extent than the genetics of the individual. Therefore, it is extremely important to take into account the influence of the conditions on the manifestation of the traits in order to be able to assess which of the created varieties is more suitable for cultivation than the others. In the last 15 years, the study of theof genotype*environment interaction has become especially relevant, against the background of the already established lasting trends for climate change on the planet. The influence of the environment on the variety has been the focus of scientists in many crops, even as rose, cassava, sesame and peanuts, because it is important for their proper distribution. Research on cereals, which are the most widely grown in the world, is particularly numerous. Naturally, they have been the subject of research for a long time, because they are the staple food of mankind. Field crops are exposed to long-term and unpredictable effects from natural environmental factors, especially those with a longer growing season (barley, rapeseed, wheat). Genetic, physiological, biochemical, morphological, etc. aspects are already being studied for the influence of the environment in this context. Traits and quality properties, which are essentially a new approach for investigation, also. This is further evidence of the relevance and importance of this type of research.

Winter bread wheat is probably the most widely used crop for research on the effect of the environment on the phenotype. This is no coincidence, given that it is the world's food crop, which is why scientists are working hard to improve it. The long growing season of winter wheat (8-9 months) is the reason for organizing large-scale research on the subject, which affects a very wide range of its characteristics or properties, starting from productivity and grain quality, and reaching the genes and physiological processes in individual crop organs. They involve teams of different specialists who try to study the best possible nature's influence on wheat by applying an interdisciplinary approach to analysis.

In our country, research on the topic of genotype * environment has been conducted for about 30 years. Since then, periodic surveys have been carried out on the main field crops, mainly to establish the interaction between the factors and to evaluate the individual variety. To date, no important crop has undergone a comprehensive study of the effects of genotype x environment interactions on productivity and a comprehensive assessment of the variety through the wide range of methods and approaches available, despite the knowledge gained to date.

In the present study, the emphasis will be on the efficiency and objectivity of the evaluation of the interaction of the variety with the environment. Particular attention will be paid to the comparison between methods and approaches for assessing the behaviour of the variety in terms of its adaptability and plasticity. Recently, there has been interest in critically evaluating various statistical approaches to assess the interaction of the variety with the environment. Sometimes parametric methods are compared, which contradict each other. Therefore, a study was conducted to compare the information of the different approaches, methods or models for assessing the variation of yield against the background of multi environmental field trails (MET) and the manifestation of the individual variety of grain yield in them.

3. PURPOSE AND TASKS OF THE RESEARCH

The aim of the study is to research in the largest possible details the traits related to the influence of environmental conditions on the variation and the level of the grain yield trait in winter wheat.

In order to fulfil the set target, several tasks have been set. The main tasks are three. Each of them, in turn, contains specific sub-tasks that are related to the main aspects of the researched problem.

1. To study the influence of environmental conditions on grain yield

1.1. To determine the degree of effects of the conditions on the manifestation of the grain yield as main productivity trait

1.2. To establish the accuracy of the interaction of the genotype with the environmental conditions in productivity of wheat

1.3. To study the reaction of the genotype, its stability and plasticity in different conditions with respect to grain yield

2. To study the possibilities of different statistical methods and approaches for extracting correct information about the genotype*environment interaction in wheat grain production.

3. To analyze the suitability of different approaches for objective assessment of a particular variety in terms of a compromise combination between the manifestation of the grain yield trait and its plasticity and stability.

4. MATERIAL AND METHODS

General information about the experiments

This study covers mainly two periods of several years. A total of over 40 wheat varieties created in Bulgaria were studied during it. Nineteen of them were established in Agronom I Holding, three varieties (Laska, Svilena and Iveta) are distributed in production by the company under a 20-year license agreement with Dobrudha Agricultural Institute.

The data presented in the study are from field trials covering two periods of four (4) and two years, during which traits and parameters related to grain yield and quality were examined of a total of 24 varieties. In the first 4-year experiment, covering 5 locations of study for comparison, two standard varieties were used: Enola and Pryaspa. In the second 2-year field experiment, the varieties Pryaspa, LG Avenue and LG Anapurna were used in 3 test locations for standard varieties. It used the same 3 of the five original locations, but the number of varieties was increased to forty (40). Some of the studied varieties from the first experiment were repeated (12 varieties) and an additional 26 breeding lines, cultivars under test and newly recognized varieties were included in the experiment.
The test locations are selected to be representative of the individual grain-producing regions of the country.

The study included data from a single field experiment based on the three main factors characteristic of this type of study: genotype (G), year conditions (season E) and test location (L). All data collected for the various traits are based on the matrix presented here, after careful analysis of the data collected at a larger number of locations and several more test seasons. The tests that precede the analysis are mainly related to the elimination of locations giving similar data and conducting a test for normal distribution of data for each trait or parameter that is included in the study. Where the analysis was at the limit of reliability, the data were normalized using the 1 / n approach, which is classic for such studies. In many places in the presented figures the designation of the traits is in their English language version, due to the fact that most of the statistical programs do not work correctly in Cyrillic letters.

Characteristics of varieties studied

The varieties participating in the study are from the three main quality groups, according to which they are ranked in the study. In the quality group for standards the varieties Iveta (group A), Factor for group B and Alexa - for group B were used. The quality groups are presented according to the data of IASAS when recognizing each of the studied varieties. In the figures presented in the next section, the designation of the varieties is presented as figures from 1 to 24, for the grain yield trait

Methods and schemes of field experiments

The experiments were plotted in a Latin rectangle in three replications, against the background of 24 (first trail) and 40 (second trail) varieties studied, respectively. At each of the selected locations, the varieties were grown in plots of 10 m^2 at harvest. In each separate location the requirement for ensuring equal conditions for each variety participating in the scheme is strictly observed. This means sowing in one day, uniform feeding (fertilization) and care throughout the growing season and finally harvesting the plots. Each of the test locations has a unique combination of soil and climatic conditions. Because we accept each individual location as a complex of special and characteristic environmental conditions, we do not present a detailed characteristic of these places. For us, this is just a factor that we accept for statistical analysis as "fixed". This is the opinion of this factor in much of the classical research on the subject. On the other hand, we accept the conditions of the year (season) as a "random" factor, because weather conditions are unpredictable by the nature of the combination of temperature, humidity and light. With this factor we also do not characterize the conditions, because we assume that its impact is generally the same for each studied variety (genotype).

Therefore, in statistical theses, two factors are analyzed in a group through their effect on the manifestation of the studied trait. The comparison of each of the factors is based on the average manifestation of the trait in it. According to the change of the average values of the factors, each statistical hypothesis for comparison between the studied varieties under the trait is built.

Statistical methods and approaches and software

For the purposes of the development, a large number of statistical analyzes were used, which could mainly be divided into three groups, according to the information they provide:

1. Establishing the presence of the influence of conditions on the manifestation of traits and indicators or the so-called popular interaction of the genotype with the environment.
2. Analysis of the regularities of the interaction of the genotype with the environmental conditions.
3. Establishing the stability and plasticity of each tested variety. Particularly useful in this part of the analyses are programs, in which analyzes of numerous parameters for stability assessment are set, due to its specificity in the expression of each genotype in the changing environmental conditions.

5. RESULTS AND DISCUSSION

5.4. Suitability of popular methods for assessing the level and stability of grain yield

One of the most popular methods for determining stability under different conditions is joint regression analysis (**JRA**), proposed by Yates and Cochran (1938) and later modified by Finlay and Wilkinson (1963). Another old, but popular method, called General Adaptability (**GA**), was proposed by Eberhart and Russell (1966) and is the difference between grain yield and the value of the regression coefficient (**GY-bi**). Its use is very simple and perhaps that is why it has been abandoned almost completely mainly due to the presence of more complex evaluation parameters (Vulchinkov and Vulchinkova, 2007). Another index called the Stability Index (**SI**) (1988) is included in the analysis. It represents the sum of the grain yield values and the stability variant (σ^2_i) taken from the Shukla analysis

(1972). The next index is the coefficient of variation (**CVi**), according to the publication of Francis and Kannenberg, (1978), denoted in the results as **FK**. Three parameters are used to express part of the genotypic stability: mean, slope of the regression line (**bi**) and the sum of the square deviation (**S^2d_i**), which are part of the joint regression model called by (Flores et al., 1998) - (**J**oint **R**egression **A**nalysis = **JRA**). These approaches are analyzed in order to determine their suitability to divide the studied varieties into groups, depending on the combination between the level of yield and the degree of its change in MET. The values of the individual indices are not presented here, due to the fact that a large part of the approaches for ranking the varieties, regardless of how they are made, are described in the previous section. The values of each of the described parameters for each individual variety were used for ranking according to the "stability" index. Final ranking of the variety through the index "**GY-STAB**" was made on the basis of the sum of the rank assessments of grain yield (**GY**) and its stability (**STAB**), after which a ranking of the values was applied again.

Table 1 presents summary information on the rank ratings of the variety, according to the applied grading method. Without much analysis of the figures, it is clear that the information for each variety is very confusing, especially against the background of the others.

Table 1. Rank values of the varieties studied, according to the model used **(* - Standard varieties**)

№	Variety	Rank GY	Rank GA [1]	Rank SI [2]	Rank R [3]	Rank CV [4]
1	Tervel	22	24	15	18	23
2	A 15/89	1	1	1	21	1
3	Iveta	7	12	2	15	4
4	Apogej	20	23	18	20	20
5	Laska	8	20	4	9	10
6	Dageya	13	11	22	17	21
7	Samuil	9	22	14	22	14
8	Bilyana	4	3	5	14	3
9	Neven	17	7	12	16	17
10	Faktor	10	4	6	19	5
11	Presiyana	16	15	8	12	8
12	Ralitsa	2	2	3	24	2
13	Riana	3	8	23	23	6
14	Topolitsa	19	21	17	10	19
15	Ognyana	14	18	19	5	13
16	**Enola***	**15**	**14**	**11**	**4**	**12**
17	Alexa	23	13	20	3	22
18	Alisa	11	5	21	11	16
19	AP Velika	12	17	7	8	7
20	Bul Aneta	6	16	9	13	11
21	Vyara	5	6	10	1	9
22	Svilena	21	10	13	7	15
23	Hela	18	9	16	6	18
24	**Pryaspa***	**24**	**19**	**24**	**2**	**24**

1- GA = (GY-bi) - general adaptability, 2- SI = (GY + σ^2) stability index, according to Vulchinkov and Vulchinkova, (2007), 3- R - regression coefficient, 4 -CV- coefficient of variation, by Francis & Kannenberg, (1978),

For example, variety № 2 has a stability score of 1 to 21, which of them comes close to objective truth? Back for the variety Apogee (4), the values of the scores are similarly high and close (18-23). The analysis of these values against the background of the score for GY is absurd to think that an objective assessment can be made of any of the studied varieties. Even knowing the reaction of the standard varieties (Enola, Pryaspa) in this case is not useful due to the huge difference in their scores. The subsequent transformation of the data by applying ranking through the index "GY-STAB" is presented in Tables 2 and 3. The analysis of these figures could not give a clear idea of the effectiveness of each of the used methods of ranking. The ranking based on different indices for each variety naturally affects its rank differently, compared to the whole group. Furthermore, it is not clear what the trade-off between yield and variety stability is, through that rank. The results of the correlation analysis in Table 4 provide an answer. All the different types of correlations are applied in order to establish unambiguously the existence of a relationship between the indices. The correlations between GY and the index GY+STAB are high in each of the applied methods. The values of the correlation coefficient are relatively higher in the FK and SI methods, as in the latter they reach almost r = 0.890, which is reliable at the highest statistical level. In the method of Francis and Kannenberg (1978), the correlations are about r = 0.800, which is also a strong relationship. The correlations between the mentioned indices and the other two ranking approaches are high enough. What is the trade-off between yield and its stability in the applied approaches?

Table 2. Rank grain yield estimates and its adjusted values by the General Adaptability Index **(* GA**) and the Stability Index (**** SI**)

№	Variety	GA*			SI**		
		GY-	STAB	GY-STAB	GY-	STAB	GY-STAB
1	Tervel	22	18	18	14	5	5
2	A 15/89	1	21	8	1	7	2
3	Iveta*	4	15	9	2	2	1
4	Apogej	19	20	17	16	11	10
5	Laska	7	9	12	3	1	1
6	Dageya	21	17	15	21	13	14
7	Samuil	13	22	6	22	22	17
8	Bilyana	3	14	3	4	16	6
9	Neven	16	16	14	10	10	6
10	Faktor	6	19	13	5	4	3
11	Presiyana	10	12	11	7	6	4
12	Ralitsa	2	24	1	9	23	13
13	Riana	5	23	4	23	24	19
14	Topolitsa	20	10	16	15	8	8
15	Ognyana	14	5	7	18	17	15
16	Enola*	12	4	4	11	19	12
17	Alexa	23	3	17	19	9	11
18	Alisa	15	11	7	20	18	16
19	AP Velika	11	8	14	6	3	3
20	Bul Aneta	8	13	5	8	14	7
21	Vyara	9	1	2	12	20	13
22	Svilena	17	7	10	13	12	9
23	Hela	18	6	11	17	15	13
24	Pryaspa	24	2	9	24	21	18

Table 3. Rank grain yield estimates and corrected values using the "joint regression analysis" (* **JRA**) and the (** **FK**) Francis and Kannenberg (1978) statistical model

№	Variety	JRA*			FK**		
		GY-	STAB	GY-STAB	GY-	STAB	GY-STAB
1	Tervel	22	18	18	14	5	5
2	A 15/89	1	21	8	1	7	2
3	Iveta*	4	15	9	2	2	1
4	Apogej	19	20	17	16	11	10
5	Laska	7	9	12	3	1	1
6	Dageya	21	17	15	21	13	14
7	Samuil	13	22	6	22	22	17
8	Bilyana	3	14	3	4	16	6
9	Neven	16	16	14	10	10	6
10	Faktor	6	19	13	5	4	3
11	Presiyana	10	12	11	7	6	4
12	Ralitsa	2	24	1	9	23	13
13	Riana	5	23	4	23	24	19
14	Topolitsa	20	10	16	15	8	8
15	Ognyana	14	5	7	18	17	15
16	**Enola***	**12**	**4**	**4**	**11**	**19**	**12**
17	Alexa	23	3	17	19	9	11
18	Alisa	15	11	7	20	18	16
19	AP Velika	11	8	14	6	3	3
20	Bul Aneta	8	13	5	8	14	7
21	Vyara	9	1	2	12	20	13
22	Svilena	17	7	10	13	12	9
23	Hela	18	6	11	17	15	13
24	**Pryaspa***	**24**	**2**	**9**	**24**	**21**	**18**

Table 4. Correlations between grain yields is its stability in grouping varieties by estimating them by ***GA** methods - general adaptability (GY + bi); ** **FK**- statistical model of Francis and Kannenberg (1978), *** **R**-joint regression model; **** **S**-selection index (GY-σ^2);

Index	Correlation approach	r-coefficient	p-value	r-coefficient	p-value
		*GA (GY)		GA (stab)	
*GA (stab)	Pearson	**-0,403**	*0,0000*		
	Spearman	-0,403	*0,0506*		
	Kendall	-0,297	*0,0420*		
*GA (GY-Stab)	Pearson	**0,637**	*0,0000*	-0,023	*0,9300*
	Spearman	**0,633**	*0,0009*	-0,021	*0,9212*
	Kendall	**0,491**	*0,0009*	0,000	*1,0000*
		**FK (GY)		**FK (stab)	
**FK (Stab)	Pearson	0,305	*0,0000*		
	Spearman	0,305	*0,1470*		
	Kendall	0,232	*0,1124*		
**FK (GY-Stab)	Pearson	**0,802**	*0,0000*	**0,800**	*0,0000*
	Spearman	**0,792**	*0,0000*	**0,811**	*0,0000*
	Kendall	**0,616**	*0,0000*	**0,623**	*0,0000*
	Pearson	***R (GY)		***R (stab)	
***R (stab)	Pearson	-0,042	*0,0000*		
	Spearman	-0,042	*0,8465*		
	Kendall	-0,007	*0,9604*		
***R (GY-stab)	Pearson	**0,672**	*0,0000*	**0,705**	*0,0000*
	Spearman	**0,675**	*0,0003*	**0,696**	*0,0002*
	Kendall	**0,516**	*0,0005*	**0,486**	*0,0010*
		****S (GY)		***S (stab)	
****S (stab)	Pearson	**0,611**	*0,0000*		
	Spearman	**0,611**	*0,0015*		
	Kendall	**0,457**	*0,0018*		
****S (GY-stab)	Pearson	**0,889**	*0,0000*	**0,889**	*0,0000*
	Spearman	**0,890**	*0,0000*	**0,887**	*0,0000*
	Kendall	**0,747**	*0,0000*	**0,725**	*0,0000*

* **The values in bold type** are different from 0, with significance level α = 0.05,

This important question for us is answered by the values of the correlations between the indices “STAB” and “GY-STAB” in the same table 4. In general, their values by approaches are similar to those between GY and “GY-STAB”. An exception is the lack of correlation between the indices in GA ranking. We take this for granted because all three types of correlations show similar values. In contrast, in other approaches, the correlations are obvious. Their reliability is an indication that in the values of the index "GY-STAB" the weight of the indices building it is similar in value. This is extremely important because in this case there is no compromise between them in any direction. For information, in the model of Kang (1993), in which GY has a decisive role in the rank, while stability is in the background. In the study of other 4 approaches in the previous section it was stated that the method for indexing "GY-STAB" in these approaches is not relevant. In them, even the model of Kang (1993), through the parameter **Ysi** could be used as a reference for comparison of any statistical approach in this direction. In our case, this could be the General Adaptability (GA) approach, which shows similar results to the one mentioned above.

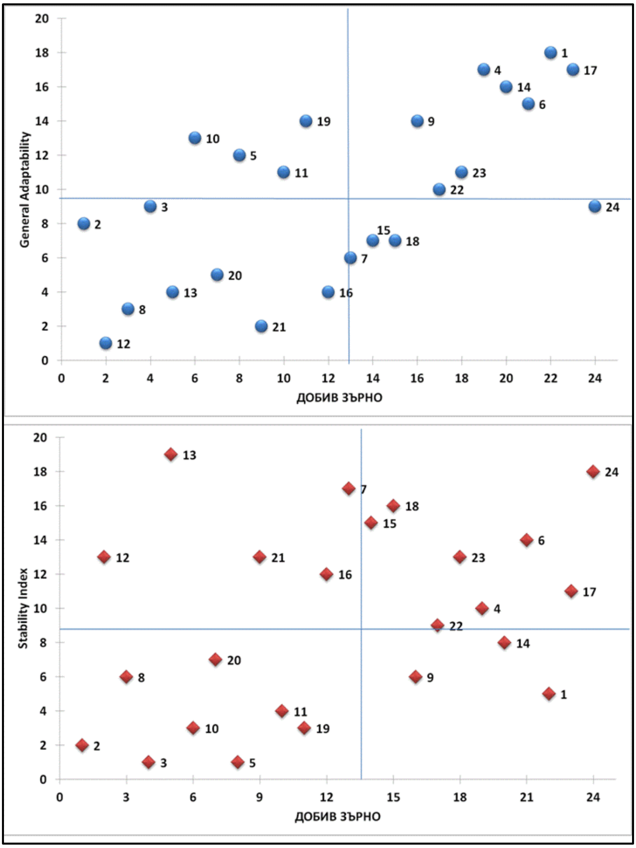

Figure 1. Visual representation (scatter plot) of the varieties points according to the yield-stability index and GY, according to the GA (*top*) and SI (*bottom*)

In order to check whether the obtained information can be used for grouping of the varieties, we constructed several figures (scatter plot) in which we placed the rank assessments of GY and the values of the index "GY-STAB" of each of the applied statistical methods (figures 1 and 2). Is it possible to arrange the most promising varieties in each of the ways? The latter should have the most appropriate compromise between GY and STABILITY.

Each table (figure) is conditionally divided into four zones: zone A - top right; zone B - top left; zone C - bottom right and zone D - bottom left. This is similar to the publications of Thiry et al., (2016), Tsenov et al., (2017), in which varieties are divided in a similar way to their response to contrasting environmental conditions. According to this arrangement, the varieties are grouped as follows: A- high GY, high STABILITY; B- medium GY, high STABILITY; C - high GY, low STABILITY and D - low GY and low STABILITY. Naturally, the four groups are important for us, especially the samples in zones A, B and C, depending on the conditions of the specific situation in the country. Naturally, the most desirable varieties are from group A.

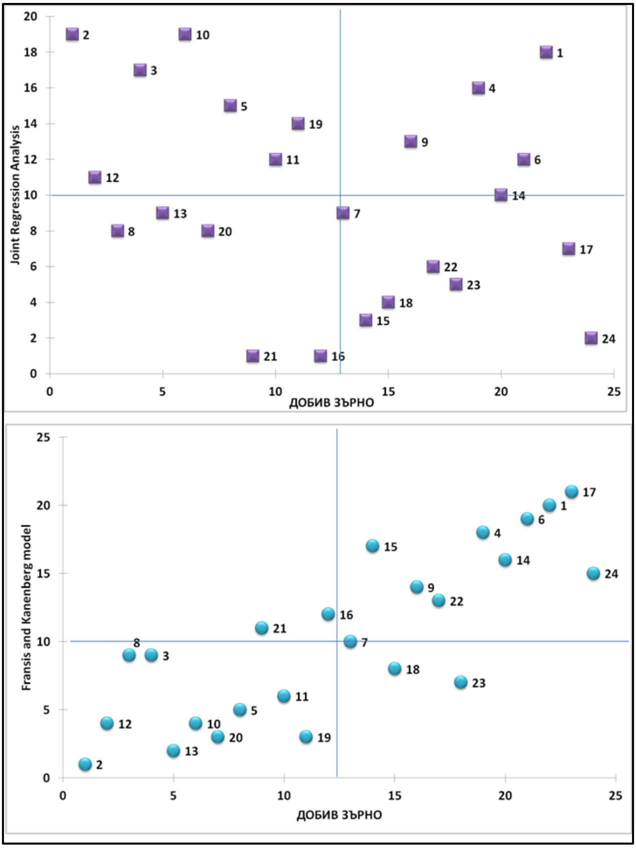

Figure 2. Scatter plot of the varieties points according to the yield-stab index and GY, according to the joint regression approaches JRA (*above*) and FK (*below*)

These are the designations in group A: 1, 4, 6, 9, 14, 22, 23 and 24. These same varieties were identified after examination by other methods in section 5.4. Varieties numbered 2, 8, 13, 20 should be avoided for cultivation due to the low and very variable grain yield at the locations. For the conditions of northern Bulgaria, where the conditions are more favourable for growing wheat, the varieties of group B are also suitable, because they have a high productive potential, despite the fact that it changes from season to season. For the conditions of southern Bulgaria, on the other hand, the varieties of group C are interesting, which have average yields, but are stable against the background of the stressful conditions in this part of the country.

The detailed comparison between the locations of the different varieties of the two figures shows several basic facts. ***First***: the varieties by each of the applied methods are distributed "evenly" throughout the table; ***second***: in general, the varieties located in the different zones are almost analogous; ***third***: the applied approach for sorting and variation of varieties is applicable and ***fourth***: the application of simple approaches such as regression coefficient (bi) or deviation from the regression line (σ2) or coefficient of variation (CV) in efficiency is close to the possibilities of large statistical programs designed specifically for these purposes.

5.5. Comparison of models for estimating level and stability of grain yield

Recently, the breeding evaluation of varieties is impossible without the quantitative evaluation of the genotype * environment interaction (Gubatov et al., 2016; Golkari et al., 2016; Karimzadeh et al., 2016). The reasons for this are that every trait in agricultural crops is strongly influenced by the environment. The term genotype * environment interaction is not new, but in the last 10 years it has gained special significance due to the existence of already working statistical methods and models for its evaluation (Gauch and Zobel. 1996, Yan and Hunt. 2001, Kang, 2002).

In cereals, research has led to the consensus of a number of researchers such as Lin et al., (1986), Snape et al., (2007) and Najafian et al., (2010) that without quantifying the "genotype * environment" interaction, it is impossible to make a real arrangement of varieties by grain yield in a wide range of conditions. The main premise and motive for such a statement is based on the term "stability", by which the variety is evaluated, not only as a level of yield, but also as a degree of variation in environmental conditions (Yan and Hunt. 2001, Annicciarico, 2002, Ayciccek and Yilderim, 2006).

In connection with the problem of adaptability, the term plasticity (durability, stability) was introduced (Annicchiarico, 2002). According to the dynamic concept of variability, a variety shows plasticity if its behaviour is similar to the group when the environmental conditions change.

Approaches to assessing the stability of the variety are divided into parametric, nonparametric and multivariate, as did one of the prominent theorists of the problem (Kang, 2002). Because the evaluation of any approach never gives complete information about the complex interaction genotype * environment of about 15 years, a number of visual methods for genotype assessment are widely used, which are classified as multivariate methods, because visual representation is the result of compromise between productivity and stability (Yan et al., 2000; Namorato et al., 2009; Ahmadi et al., 2012).

In this regard, the most effective for us are those of the approaches that have the strongest relationship between the level of the trait and the degree of its stability, respectively plasticity, or reliability. Nowadays, this is the *Biplot analysis*, because the information it provides is the most complex way (Ding et al., 2008), (Malla et al., 2010) and (Abakemal et al., 2016). This analysis is the basis of two models that have been widely used recently - AMMI and GGE (Ahmadi et al. 2012). According to recent research by (Roostaei et al., 2014), it turns out that it is through the GGE and AMMI models that the most acceptable compromise can be made between the level of trait and stability in a huge number of test locations (24). The studies of Alberts (2004) and Tazu (2011) make an in-depth analysis of the possibilities that each of these methods provides for the evaluation of a variety. However, little is still known about the suitability of individual models for compromising the assessment of productivity and stability of each variety in a given group (Roostaei et al., 2014).

Rank correlations were calculated using two statistical methods (JRA and NP) and two models (AMMI, GGE biplot), which are widely used to rank the studied genotypes according to the variation of their yield in different environmental conditions. In order to establish the effects of the genotype, the environmental conditions and the interaction between them, a combined analysis of the variants was applied, which also included the basic component analysis for the AMMI model. It was made using the statistical packages IBM SPSS 23 and GenStat 15. The ranking of the studied varieties by yield and yield stability was done using 4 different statistical approaches. In each of them, the ranking of the varieties is based on three criteria: **1:** grain yield (GY), **2:** stability (stab) and **3:** GY-stability (yield-stability). In each of the methods used, this is done differently, depending on how the stability of the program is interpreted. The criterion "yield-stability" is obtained after summing the values of the first two ranks, after which it is again subjected to ranking.

The arrangement and evaluation of the varieties according to the YS (i) statistic model was done using a special computer program (STABLE). The grain stability index (YSi) was calculated by the method of Kang (1993), which compromises between high-yielding and stable varieties. The variety with the highest grain yield receives a score (rank) of 24 and the one with the lowest - 1. The ranking of a variety was adjusted by the assessment of its stability as follows: - 8, - 4, and - 2 for measured significant stability at $P < 0.01$, 0.05 and 0.10, respectively 0 for insignificant stability of the variety The stability rating of - 8, - 4, and - 2, was chosen so as to change the rank of the genotype from that based only of extraction (Kang, 1988). In this way, an adjusted statistical grain yield is obtained, designated by the author as (Ysi). The grade stability rating was obtained according to the variation of the Shukla (σ^2) parameter, (Shukla 1972). The rank of the “yield-stability” criterion for each variety was obtained again after ranking based on the sum of the first two scores (yield) and (stability).

The scores according to the non-parametric model of Huehn (1990) are placed on each variety according to criteria similar to the first. Stables with a high score (24) are the varieties whose variant of the rank (S^2i) is the lowest in relation to the different test points or in relation to the sum of the absolute deviation from the maximum score of each variety (S^3i). The ranking of the varieties by yield stability is relative to the sum of the first two ranks, after the second is the average rank of the two stability criteria of this method.

The analysis by AMMI combines additional components in a single model for the main effects of varieties and environments, as well as components for the interaction effect. According to them, genotypes (or environment) with a large IPC score (either positive or negative) have a strong interaction, while genotypes (or environment) with an IPC1 score close to zero have low interactions, ie. low variation.

To describe stability, the AMMI statistical coefficient (D) is used, which is calculated according to the methodology of (Zhang et al., 1998). The genotype with the lowest value of the parameter D is considered the most stable (Zhang et al., 1998) and accordingly receives the highest (24) rank for the criterion "stability".

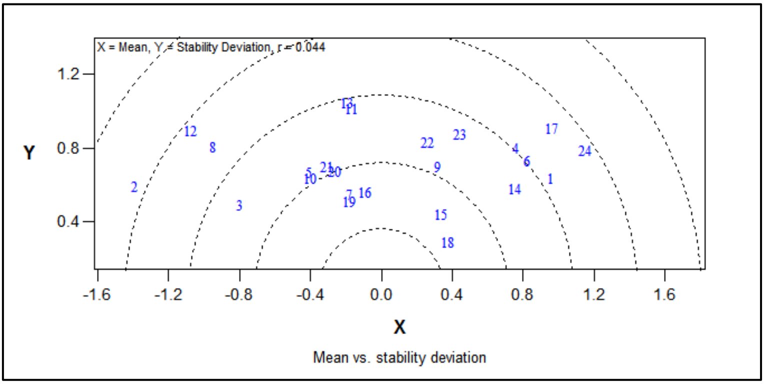

Figure 3. GGE Biplot classification of varieties based on their GY and its stability under MET conditions

The analysis of the GGE biplot model was obtained using the software of (Yan, 2001). Through it, each genotype in the group receives an assessment of the effect of genotype (G) and the genotype * environment (GE) interaction (Yan et al., 2000). For the evaluation of each variety, the main starting point is a small circle in the center of the biplot, which expresses the average "average" coordinate (**AEC**), which is the arithmetic mean of the evaluation PC1 and PC2 of the environment (E). There are concentric circles around the beginning of the coordinate system (0,0) (Fig. 3). The closer the point of a variety is to a concentric circle closer to the beginning, the weaker its variation under experimental conditions. For example: variety № 18 has the lowest variation, grade № 3 has a medium degree of variation, while variety № 2 varies the most from the whole group (Yan, 2001, Yan and Kang, 2003). In terms of stability, the ranking is based on the distance from the beginning (0,0) to the point of the variety, with the highest score having these varieties with the shortest distance to this place. The yield-stability parameter is the result of the sum of the first two points.

To determine whether a method can successfully divide varieties into groups according to their yield and stability (yield-stability), the three main types of correlations (Pearson, Spearman and Kendall) were calculated between the scores of the three parameters of each of the approaches used, using the statistical package Unistat 6.

According to the data from the study, some of which have already been published (Gubatov et al., 2017), the interaction of the variety with environmental conditions is very significant. This is clearly seen from the data in Table 5, which is a compilation between two analyzes mentioned in the material and methods section. According to them, almost all sources of variation are significant at a high level of reliability (*p-value*). Particularly strong is the interaction between the studied environmental factors, which reaches 1/3 of the total variation (31.94%). The strongest is the effect of the season (year), whose main effect is about 40%, and together with the test point cause almost all the variation of the interaction (88.72%). This is an extremely strong effect on the sign by environmental factors. The share of the genotype is very low (1.17%), but it participates in the interaction with the environment significantly strongly (about 12%).

The analysis of variants using the AMMI model found significantly higher shares of regression (22.20%) and deviations from it (77.80%). In practice, the variation in the experiment, expressed through the interactions, reaches 82.6% and about 10% residual variation. The presence of three components (PC1, PC2, PC3) in the interaction of the trait with the environment is indicative of its complex nature.

Indeed, the third component PC3 is not reliably high, but it is still an indication of the presence of a nonlinear interaction of grain yield with environmental conditions.

Table 5. Combined ANOVA and AMMI analysis of GE interaction variations over a four-year investigation period

Source of variation	SS %	df	MS	F-stat	*p-value*	η^{2**}
Main effect	*64.55*	*30*	*41,45*	*168,72*	*0,0000*	*0,911*
Year	43,12	3	276,904	1127,18	0,0090	*0,598*
Location	20,26	4	97,555	397,11	0,1380	*0,416*
Genotype	1,17	23	0,98	3,99	0,1110	*0,340*
Interaction	*31.94*	*173*	*3,56*	*14,47*	*0,0000*	
Year * Location	88.72	12	45,486	185,161	0,0000	*0,890*
Year * Genotype	6.95	69	0,619	2,521	0,0000	*0,387*
Location * Genotype	4.33	92	0,290	1,18	0,1560	*0,282*
Adjusted model	3.52	203	9,156	37,72	0,0000	*0,908*
Error	67,82	276	0,246			
Total	1926,49	479	4,022			
Regression	22.20	23	0.123	3.12	0.00000	
Deviation	77.80	276	0.435	2.55	0.00000	
IPCA1	58.8	25	0.99	3.86	0.00000	
IPCA2	12.6	23	0.57	2.23	0.00112	
IPCA3	11.2	21	0.23	0.90	0.59706	
Residuals	10.0	0	0.333	2.78	0.00012	

According to Gubatov et al., (2017) the nonlinear interaction is of the order of about 35% with a 50% share of PC1, which is really significant. Strong nonlinear interaction in grain yield is already reported as a regularity in most of the main cereals (Bose et al., 2014, Golkari et al., 2016, Karimzadeh et al., 2016, Dyulgerova & Dyulgerov, 2016, Ramazani et al. , 2016) and legumes (Asfaw et al., 2009, Sabaghpour et al., 2012) and reaches PC9, which is unique information. These facts speak eloquently of the complex nature of the variety's reaction to grain yield in a variety of growing conditions. In these circumstances, it is clear why a large part of the indices and parameters for assessing the genotype * environment interaction in different models give different information (Kaya and Turkoz, 2016, Storck, et al., 2016) in terms of correctness for assessing the variety relative to others in the study group. The different arrangement of the varieties according to the level of the trait and its stability in the different approaches is a reason to apply a score assessment, as in our study. The first ranking by rank (score) is according to the approach of Kang (1993), (Table 6). The way of forming the score and the difference in the yield score (GY) and the adjusted yield (YSi) can be clearly seen. The difference in the assessment of the genotype after correction of the score according to the parameter "yield - stability" becomes even greater (Table 6).

This arrangement, depending on the non-parametric approaches (YSi) and (NP), differs greatly if we focus on specific varieties. There are two main groups for comparison: a group of varieties that have a similar score (1, 8, 15, 23), a group that have contrasting scores in both approaches (2, 4, 10, 19).

The ranking of the varieties by yield and stability by AMMI analysis is presented in Table 8. According to the regularities of the analysis, the varieties around the beginning of the coordinate system have the highest yield (9, 10, 17). According to the GGE program, varieties 1, 4, 17, 24 have the highest score, ie different from those from the previous analysis. After adjusting the score for the stability of the varieties, the picture changes dramatically in some cases (Table 7).

Compared to the previous two models, the score of these varieties has a similar behaviour. It is clear that in each statistical approach the evaluation of the variety after subtraction of the "noise" caused by its interaction with the environmental conditions is different. For this reason, the two most modern methods have been widely used in recent years - AMMI and GGE (Asfaw et al., 2009, Sabaghnia et al., 2013).

Table 6. Ranking of 24 genotypes by estimating of yield-stability index (YS_i), according to the model of Kang (1993)

№	Genotype	Mean GY	Yield Rank	Adjustment to R.	Adjusted	Stability rating	YS (i)
1	Tervel	6,87	22	1	23	-8	15
2	A 15/89	6,15	1	-1	0	-4	-4
3	Iveta	6,38	4	1	5	-8	-3
4	Apogej	6,83	19	-1	18	-4	14
5	Laska	6,48	7	1	8	-8	0
6	Dageya	6,87	21	-1	20	-2	18
7	Samuil	6,58	13	-2	11	0	11
8	Bilyana	6,34	3	1	4	-2	2
9	Neven	6,73	16	-1	15	-4	11
10	Faktor	6,47	6	-1	5	-8	-3
11	Presyana	6,55	10	-1	9	-8	1
12	Ralitsa	6,22	2	-2	0	0	0
13	Riana	6,46	5	-1	4	0	4
14	Topolitsa	6,84	20	1	19	-4	15
15	Ognyana	6,72	14	2	25	-2	23
16	Enola	6,57	12	1	13	0	13
17	Alexa	6,90	23	1	22	-4	18
18	Alisa	6,73	15	1	16	-2	14
19	AP Velika	6,56	11	-1	10	-8	2
20	Bul Aneta	6,48	8	-1	7	-2	5
21	Vyara	6,52	9	1	10	0	10
22	Svilena	6,74	17	1	18	-4	14
23	Hela	6,79	18	1	19	-2	17
24	Pryaspa	6,98	24	2	26	0	26

Table 7. Rank estimates of grain yield and its correction by criterions by index for variance stability (YSi), Nonparametric analysis of GE interactions by ranks (NP)

Variety	Ranks by (YSi)			Ranks by (NP)		
	Yield	Stab	Yield-Stab	Yield	Stab	Yield-stab
1	22	23	15	22	22	20
2	1	0	-4	1	5	1
3	4	5	-3	4	21	9
4	19	18	14	19	18	18
5	7	8	0	8	6	5
6	21	20	18	21	19	19
7	13	11	11	13	11	10
8	3	4	2	3	20	9
9	16	15	11	16	14	14
10	6	5	-3	6	8	4
11	10	9	1	10	9	6
12	2	0	0	2	10	4
13	5	4	4	5	3	2
14	20	19	15	20	15	16
15	14	25	23	14	23	17
16	12	13	13	12	16	12
17	23	22	18	23	24	21
18	15	16	14	15	7	8
19	11	10	2	11	4	3
20	8	7	5	7	1	3
21	9	10	10	9	17	11
22	17	18	14	17	12	13
23	18	19	17	18	2	7
24	24	26	26	24	13	15

The main reason for this interest is the possibilities that both have for visual presentation of each variety, as a point against the background of the whole picture of the experiment. It is logical to ask the question: does this correspond to the objective truth about the relationship between the level of yield and its change in the conditions of the particular experiment?

The answer to this question is given by the correlations between the score evaluation of the parameters for evaluation of the yield and the stability of the variety (Table 9). The data show that the relationship between these two parameters is positive, but not strong enough. There are strong correlations between the estimates after the application of the nonparametric model and the two modern methods. The lack of a sufficiently strong correlation between the yield ranks and stability is considered normal in this case, because they show radically different characteristics of the variety. The fact that the nonparametric model shows high correlations is rather due to the way in which stability is assessed. On the other hand, the strong and reliable correlations between the yield estimate for AMMI and GGE (reaching almost one) are clear evidence of the similar assessment that the two models provide.

Table 8. Rank estimates of grain yield and its correction by criterions by by *AMMI-model and software program GGE Biplot (**GGE)

Variety	Ranks by AMMI*			Ranks by GGE**		
	Yield	Stab	Yield-Stab	Yield	Stab	Yield-stab
1	22	11	20	22	11	14
2	1	1	1	1	1	1
3	7	21	16	7	21	11
4	20	12	18	20	12	13
5	8	15	10	8	15	7
6	13	10	9	13	10	7
7	9	22	15	9	22	11
8	4	16	7	4	16	5
9	17	13	17	17	13	12
10	10	8	5	10	8	4
11	16	17	19	16	17	14
12	2	6	3	2	6	2
13	3	5	2	3	5	2
14	19	7	13	19	7	9
15	14	24	22	14	24	15
16	15	23	21	15	23	15
17	23	19	24	23	19	17
18	11	14	12	11	14	8
19	12	9	8	12	9	6
20	6	3	4	6	3	3
21	5	20	11	5	20	8
22	21	18	23	21	18	16
23	18	2	6	18	2	5
24	24	4	14	24	4	10

Our efforts are aimed at understanding whether the transformation to the score evaluation in "yield-stability" corresponds to the level of yield and its stability in different models. Each of the applied models for evaluation of the variety can be correctly used for this purpose. The evidence for this is indisputable (Table 10). All three types of correlations between the "yield-stability" criterion and the other two are high and reliable at the highest statistical level. In general, the "yield" criterion shows a slightly stronger relationship with "yield-stability" than the "stability" criterion, when comparing each method separately.

Table 9. Rank correlations between the criterions “Yield” and “Stability” by models of adjusted yield (Ys), Nonparametric analysis (N), AMMI (A) and GGE (G) by the ranked scores of grain yield, stability of yield

Variables	Ys(Yield)	Ys(STAB)	N(Yield)	N(STAB)	A(Yield)	A(STAB)	G(Yield)	G(STAB)
Ys(Yield)	**1**	0.8871**	0.2414	0.1085	0.1052	0.1043	0.1052	0.1043
Ys(STAB)	0.031*	**1**	0.9743	0.8150	0.2731	0.9903	0.2731	0.9903
N(Yield)	0.249	-0.007	**1**	0.0941	**< 0.0001**	0.9229	**< 0.0001**	0.9229
N(STAB)	0.336	0.050	0.350	**1**	0.0748	**0.0016**	0.0748	**0.0016**
A(Yield)	0.339	0.233	**0.852**	0.370	**1**	0.5905	**< 0.0001**	0.5905
A(STAB)	0.440	-0.003	0.021	**0.609**	0.116	**1**	0.5905	**< 0.0001**
G(Yield)	0.339	0.233	**0.877**	0.370	**0.998**	0.126	**1**	0.5905
G(STAB)	0.540	-0.003	0.021	**0.611**	0.116	**0,999**	0.133	1

** - Correlation coefficients - below diagonal; ** -significance (p-value) - above the diagonal*

When comparing the methods, the correlations are the strongest in the non-parametric approach of analysis (r = 0.802). Immediately after it, the modern two methods AMMI and GGE are arranged with completely similar interrelations between the studied parameters. Not to be overlooked is the already outdated approach of Kang (1988), which successfully separates the most successful varieties against the background of strong interaction with environmental conditions. Completely, as expected, the correlation values are the highest in Pearson's algorithm, followed by Spearman's, and the lowest in Kendall, regardless of the method used to form the three criteria. The types of correlations were analyzed in order to determine whether there are indeed objectively determined relationships between the studied quantities.

In conclusion, it can be said that the specific approach we applied provided us with information on the use of different statistical approaches to evaluate the specific variety against the background of the group (Malla et al., 2010, Roostaei et al., 2014). It became clear that each of the approaches used can group the varieties according to yield and its stability successfully. Biplot as an approach in this regard is the most appropriate and this is the main reason it is widely used for breeding and crop growing purposes (Ding et al., 2008; Bose et al., 2014).

Table 10. Rank correlations between the ranking of varieties by models of adjusted yield (Ys*), Nonparametric analysis (**NP), AMMI and GGE by the ranked scores of grain yield, stability of yield and corrected by its yield-stability

Method	Index, score	Type of correlation	Correlation	*2-tail p*	Correlation	*2-tail p*
			Yield		Stability	
*Ys_i	Yield-Stab	Pearson	**0,741**	0,0000	**0,621**	0,0000
		Spearman	**0,741**	0,0000	**0,604**	0,0018
		Kendall	**0,537**	0,0003	**0,464**	0,0016
			Yield		Stability	
**NP	Yield-Stab	Pearson	**0,802**	0,0000	**0,800**	0,0000
		Spearman	**0,792**	0,0000	**0,811**	0,0000
		Kendall	**0,616**	0,0000	**0,623**	0,0000
			Yield		Stability	
AMMI	Yield-Stab	Pearson	**0,738**	0,0000	**0,713**	0,0000
		Spearman	**0,731**	0,0000	**0,718**	0,0001
		Kendall	**0,562**	0,0001	**0,532**	0,0003
			Yield		Stability	
GGE	Yield-Stab	Pearson	**0,745**	0,0000	**0,728**	0,0000
		Spearman	**0,755**	0,0000	**0,733**	0,0001
		Kendall	**0,593**	0,0001	**0,544**	0,0003

*Values in **bold** are different from 0 with a significance level alpha=0,05;*

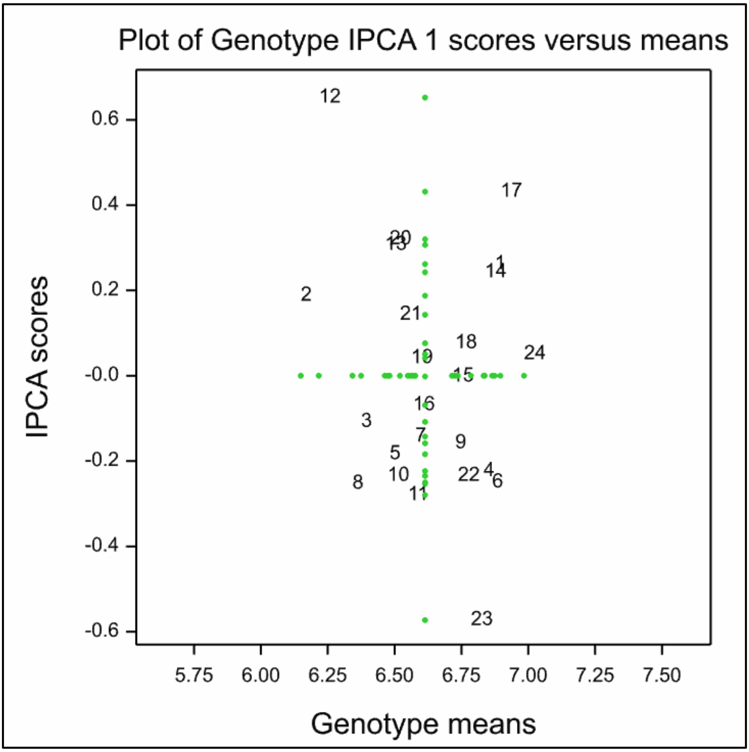

Figure 2. AMMI Biplot of IPCA scores vs. genotypic and environmental mean grain yields for the group of genotypes across the locations

After the ranking of each variety, we received specific information for the ranking of the varieties, according to the three criteria we studied. Then we decided to check whether the graphics module of the two most used software products GenStat 15 (AMMI) GGEbiplot 6.3, will group the varieties in a similar way, as most researchers believe (Sabaghnia et al., 2013, Bose et al., 2014)

AMMI analysis of the data from our experiment puts the points of each studied variety in the way shown in Figure 4. According to their location, the varieties marked 9 (Neven), 15 (Ognyana), 18 (Alica), 22 (Svilena), 4 (Apogee)), and 6 (Dagea) show the best combination between yield and overall stability. These are the varieties that have shown a slightly lower yield than the reference variety Pryaspa (24), but are significantly more stable than it. The location of 4 (Apogee) and 6 (Dagea) shows their excellent stability in adverse environmental conditions in southern Bulgaria (Yambol and Plovdiv).

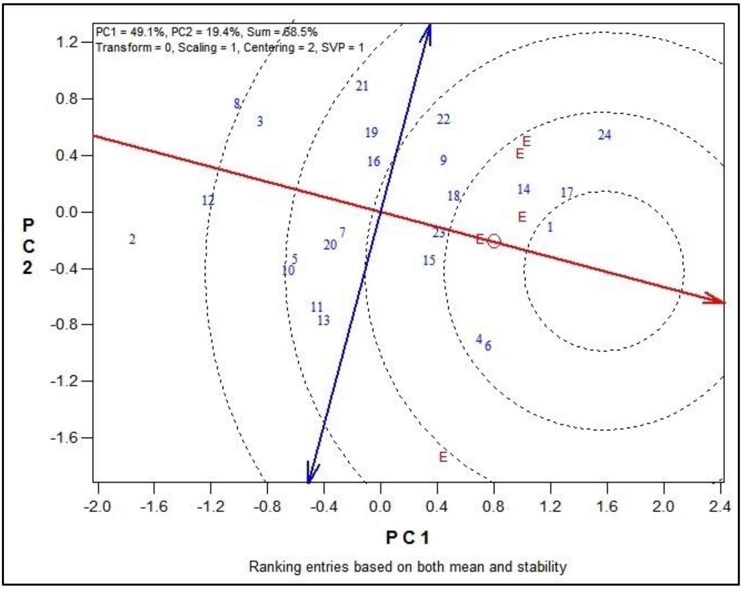

Figure 3. GGE Biplot ranking of cultivars based on their mean yield and stability across the four seasons

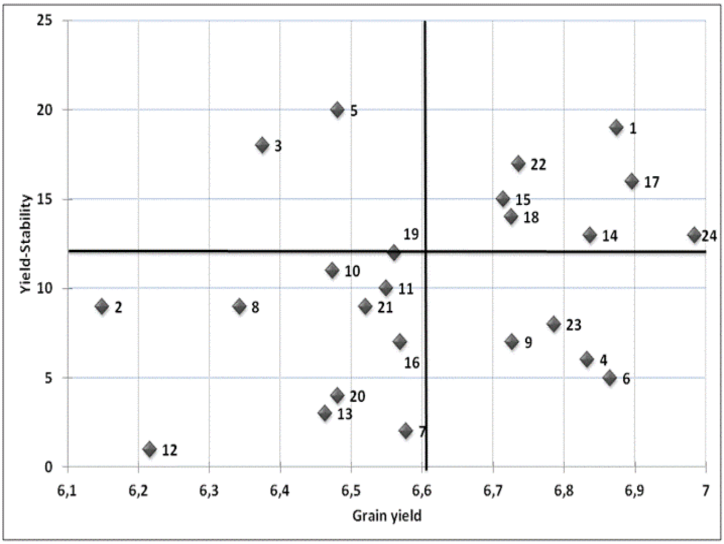

Figure 4. Scatter plot of yield-stability of cultivars by Ys_i ranking approach

According to the analysis of the GGE Biplot program, the location of the points in the already mentioned varieties is completely similar (Figure 5). There is a significant difference only in the variety Hella (23), which according to the graphical analysis has an excellent combination between yield and stability. In AMMI, this variety showed very high instability due to its strong variation (Fig. 6). Such differences caused by the analysis are common and have already been noted by many authors (Malla et al., 2010; Roostaei et al., 2014; Agyeman et al., 2015). In this case, it is important that much of the information provided by the different statistical models for varieties is similar (Table 29). Evidence of such a statement is the almost similar location of the studied varieties in terms of their yield-stability criteria, which the approach of Kang (1993) provides as information (Fig. 6).

Such an arrangement of the varieties, by their rankings, regardless of the method by which they are placed, is very appropriate because it provides visual information about the characteristics of each variety in terms of its yield and stability in the environment. Such visualization could be made for each individual approach or method. The results will be similar because the ranking approach is objective and recommended by a number of authors such as Huhn (1990), Kang (2002) and Kaya and Turkoz (2016). On the other hand, it is clear that the basic approach to creating a criterion "yield-stability" for grain yield adjustment is very correct and does not depend on the specific way of calculating it using indices or parameters in the individual methods.

5.6. Evaluation of wheat varieties through the stability of grain yield in ecological experiments, in order to zoning

The purpose of this part of the study is to verify and confirm in practice the effectiveness of different indices for distinguishing varieties according to their interaction with the conditions of the environment in which they are tested. The variety*conditions interaction is the reason for different in scale and direction variation, which in turn must be taken into account when varieties are sorted by grain yield or quality, or some other trait.

The collected database for yield and quality of the already mentioned features and indicators is subjected to stability analysis of each of them through the most used parametric and non-parametric methods for stability assessment, most of which were discussed in the previous sections. The evaluation of each individual variety was made using the latest statistical package “Stabilitysoft” (Pour-Aboughadareh et al., 2019), which calculates 18 separate statistical parameters (indices) for this. Each of them carries some information about the stability of the genotype, which is why almost all authors suggest using several of them for evaluation at the same time, which is quite logical. This makes it extremely difficult to arrange, which in principle should be based on one of them. It stems from the lack of choice between several indices in the adjustment of yield, through its stability, which is the main goal of the whole project. The suitability of each of them for evaluation must be made in each specific database, because their effectiveness changes as a result of factors of field experience: the number of varieties and the conditions of their cultivation as a climate, including the seasons. The main criterion used to assess suitability is the correlation between grain yield ranking and stability (KR= YSi) according to Kang's (1988) most popular approach, which appears in the software used and which has been discussed several times in previous sections. .

After calculating these indices, the ones that provide the most objective information about the ranking of the varieties in the group have been identified. The correlations between the indices and the ranking according to their values were calculated using the program XLStat 2014, and the analysis of variation was done with the statistical packages Statgraphics XVI, and IBM SPSS 23.

The analysis of grain yield data includes two main stages, which provide different levels of information on varieties:

1. The assessment of the specific manifestation of the varieties at the various test sites. The level and variation of grain yield in each of the regions are consistently indicated and analyzed in detail, in comparison with the average level of the group of varieties, as well as in relation to the used standard varieties.

2. The evaluation of the stability and plasticity of each variety in relation to the whole variation in the experiment (ABC). Ranking is the main tool by which each variety will be compared to the others, as well as to the standard varieties. This type of stacking aims to establish samples that combine high grain yield and above-average stability for the study group. For this reason, it is very appropriate to study a large number of varieties (over 30), as in our case.

The data show a reliable independent effect of each of the factors - location, season and variety, as well as the interaction between the variety and the location of study. The interaction of the season * genotype is unreliable. The change in grain yield is also a result of the *location * year interaction* (Table 11). Against the background of this analysis, it is clear that the variation in grain yield of each variety is an important element of its evaluation. Its manifestation depends on the direction and magnitude of the variation in relation to the average of the experience and in relation to the average of the standard varieties.

Table 11. Analysis of variances for grain yield

Source	df	MS	F	p-value
Main effect of the factors				
A:location	2	360.53	1488.03	0.0000
B:season	39	2.06815	8.54	0.0000
C:genotype	78	1.34285	5.54	0.0047
Interaction between the factors				
A*B	2	1.15687	4.77	0.0000
A*C	78	1.69799	7.01	0.0000
B*C	39	0.248266	1.02	0.4420

The Stabilitysoft software package used provides values of 18 indices to assess the stability of the feature. An elementary look at the numbers shows how significantly the order of each of the indices differs.

Which of them to take as the main one or which of them as a group? There is an abundance of research in different main areas for wheat breeding (quality, yield, stress tolerance, disseses tolerance), in which different parameters are effective for correcting the ranking by a given trait (Akcura et al., 2017; Bornhofen et al., 2017; Arshadi et al., 2018). If there is one whose values correspond to the grain yield, it would be very convenient for objective analysis. It is no coincidence that the ranks of two of the proposed statistical parameters are derived from the others. These are the parameter **SR** = sum of the ranks of all calculated parameters and **AR** = arithmetic mean of the ranks of all parameters. In order to determine which of the two mentioned indices (their rank) should be accepted for the adjustment of the ranking, the correlations between all ranks, including that of grain yield, were calculated (Table 12).

The relationship between the ranks of parameters SR and AR with the other ranks of the parameters are high and reliable, without exception. The connection between them is almost absolute (r = 0.96 ***), which means that it does not matter which of them will be used. At the same time, their correlation with grain yield is average but reliable (r = 0.58 *). This is a very "convenient" result in terms of stability in combination with productivity.

Table 12. Pearson correlations between the grain yield index ranks, the rank of the SR (SR) and the adjusted mean rank (AR)

Index	AR	p-value	R^2	SR	p-value	R^2
GY	0.58	0.0001	0.34	0.55	0.0002	0.30
$S^{(1)}$	0.77	< 0.0001	0.60	0.80	< 0.0001	0.64
$S^{(2)}$	**0.81**	**< 0.0001**	**0.66**	**0.83**	**< 0.0001**	**0.69**
$S^{(3)}$	**0.93**	**< 0.0001**	**0.87**	**0.94**	**< 0.0001**	**0.89**
$S^{(6)}$	**0.92**	**< 0.0001**	**0.85**	**0.93**	**< 0.0001**	**0.86**
$NP^{(1)}$	0.77	< 0.0001	0.60	0.78	< 0.0001	0.62
$NP^{(2)}$	0.79	< 0.0001	0.62	0.79	< 0.0001	0.63
$NP^{(3)}$	**0.90**	**< 0.0001**	**0.81**	**0.89**	**< 0.0001**	**0.80**
$NP^{(4)}$	**0.92**	**< 0.0001**	**0.85**	**0.91**	**< 0.0001**	**0.83**
W_i^2	0.79	< 0.0001	0.63	0.79	< 0.0001	0.62
σ^2_i	0.79	< 0.0001	0.63	0.78	< 0.0001	0.62
s^2d_i	0.76	< 0.0001	0.57	0.75	< 0.0001	0.56
CVi	0.48	0.0015	0.23	0.48	0.0014	0.23
KR	**0.86**	**< 0.0001**	**0.74**	**0.84**	**< 0.0001**	**0.70**
$\theta_{(i)}$	0.79	< 0.0001	0.63	0.77	< 0.0001	0.59
θ_i	-0.79	< 0.0001	0.62	-0.72	< 0.0001	0.52
SR	0.96	< 0.0001	0.92			
AR				0.96	< 0.0001	0.92

Given that the relationship between yield and any parameter is strong (r> 0.65), it is considered that it does not correctly assess the variation, which is generally negatively correlated with the level of the trait. In case the correlation is low (r <0.25) there is a danger to assess the stability more than the level of the trait that is the target. In this study, it is clear that the values of the AR parameter are an effective tool for correcting the rank of each variety in the group.

The information about the behavior of the varieties in a given region is interesting for the correct zoning of each variety. This is especially true for new varieties, the manifestation of which should be compared with those already zoned. The breeding efforts are constantly focused on creating plastic, adaptive and at the same time highly productive varieties. The relative grain yield of the eighteen varieties in descending order (relative to the average) is presented spatially in Figure 7 and vice versa, under the optimal conditions of the locations (A and B), and stress condition in location C.

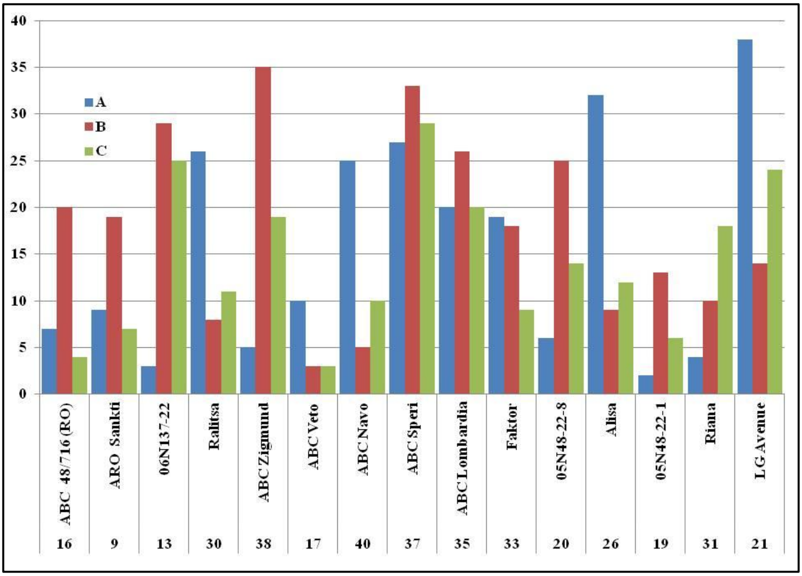

Figure 7. Arrangement of the varieties by their relative mean grain yield and by the AR6 index values at the test locations (ABC)

Four of the varieties (16, 36, 40 and 9) showed higher yields at all three locations. The rest ones – are productive in two of the three locations, compared to the checks. The high relative yields of these varieties at location C are impressive, with the exception of varieties No 26 and 28. This means that the high average yield from them is largely due to environment C, especially for varieties 35 and 37. On the other hand careful analysis of the standards shows that with a similar yield of them in the range of 8-8.16 t / ha, Pryaspa variety has an advantage in stressful conditions (C), in respect to the French LG Avenue.

Table 13. Pearson correlations between the ranks of the indexes (AR) and (AR6) in the different survey locations

Index	Location	AR	p-value	R^2
AR6	A	0.91	< 0.0001	0.83
	B	0.99	< 0.0001	0.99
	C	0.96	< 0.0001	0.92

The next step was to determine whether the values of the AR parameter could be used at the point level. The data show differences between the correlations with the yield at the level of the "location" factor (Table 13).

In two of the three locations such an arrangement is theoretically possible, according to the magnitude of the correlations (B = 0.50, C = 0.39). Unfortunately, the values of R^2 are too low (0.25 and 0.15, respectively) to be used as proof of assertion. For this reason, we made a compromise arrangement of varieties by grain yield rank to a value of 20, ie. the first half of the whole row (GY-R), (Table 14). Stability is noted against each of the varieties shown, and the more the number (+), the higher the yield rank is associated with a high stability rank (AR). In this way, varieties such as 9, 16, 17, 31 and 40 are detected, which are extremely valuable due to their high grain yield and significantly higher than the average stability for the group. Regarding the latter, they far exceed the standards of the Prespa variety (stability rank = 27) and LG Avenue (33). With some compromise in terms of stability to this group we can add varieties 13 and 38, whose AR is 11 and 15, respectively.

Table 14. Arrangement of high-grade (rank) varieties up to 20, according to grain yield and stability **

Rank	№	variety	GY	GY-R	AR	Stability**
1	**16**	**ABC 48/716**	**8,88**	**1**	**7**	**++**
2	13	06N137-22	8,54	**2**	11	**+**
3	**9**	**ABC 27/512**	**8,35**	**3**	**1**	**+++**
4	**40**	**ABC NAVO**	**8,22**	**4**	**5**	**+++**
5	**17**	**A 47/415**	**8,21**	**5**	**6**	**+++**
6	38	ABC ZIGMUND	8,21	**6**	15	**+**
7	**31**	**RIANA**	**8,19**	**7**	**9**	**+++**
	21	**LG avenue**	**8,14**	**8**	**34**	**check***
8	35	ABC LOMBARDIA	8,10	**9**	24	**+**
9	**33**	**FAKTOR**	**8,08**	**10**	**14**	**+**
10	**37**	**ABC SPERI**	**8,04**	**11**	**18**	**+**
11	**20**	**05N48-22-8**	**8,01**	**12**	**3**	**++**
12	**26**	**ALISA**	**7,99**	**13**	**16**	**+**
13	**19**	**05N48-22-1**	**7,97**	**14**	**4**	**+**
14	**30**	**RALITSA**	**7,96**	**15**	**12**	**+**
15	36	ABC KLAUSIUS	7,95	**16**	38	**+**
16	24	PRESIYANA	7,92	**17**	30	
17	**15**	**04/255-92-2-1**	**7,90**	**18**	**2**	**+**
18	22	BUL ANETA	7,86	**19**	39	
19	25	OGNYANA	7,85	**20**	20	**+**
	11	**PRYASPA**	**7,61**	33	**27**	**check****

* - check variety; ** - stability variety with score up to 20

The second group of varieties that are stable, but with a slightly lower yield than the French, are № 15 and 20, which are also valuable for production, especially if we compare them with already zoned varieties Factor (33) and Aneta (22).

For the north-eastern part (Dobrich) only one of the already zoned varieties (Vyara) can continue to be grown (Table 15). The other regionalized varieties could easily be replaced with several new ones (31, 35, 36 and 40), and in the future the most promising new lines - 9 and 16 - could be added to them.

Table 15. List of suitable varieties for the **region of Dobrich**

Rank	№	variety	**A**	Peculiarity
1	40	ABC NAVO	**111,1**	New
2	16	ABC 48/716	**107,8**	Candidate variety
3	26	ALISA	**107,3**	New
4	35	ABC LOMBARDIA	**106,0**	New
5	28	VYARA	**106,0**	Already zoned variety
6	31	RIANA	**104,6**	New
7	9	ABC 27/512	**101,9**	New
8	36	ABC KLAUSIUS	***100,3***	New
	21	LG AVENUE	**100,0**	Check variety

Table 16. List of suitable varieties for the **region of Rose**

Rank	№	Variety	B	Peculiarity
1	9	ABC 27/512	103,9	new in Romania as **ARO SANKTI**
2	36	ABC KLAUSIUS	103,5	New
3	31	RIANA	103,4	New
4	38	ABC ZIGMUND	102,2	New
5	16	ABC 48/716*	100,8	Candidate variety in Romania
6	17	A 47/415	100,3	New variety as **ABC VETO**
	21	LG AVENUE	100,0	Check variety

For the regions of Ruse, only the new 3 varieties (31, 36 and 38) and the promising candidate varieties 9 and 17 (Table 16) turn out to be the most suitable. In this region, none of the already regionalized varieties has been able to overcome the competition of the new genotypes. This statement is supported by the high stability of the mentioned varieties.

Table 17. List of suitable varieties for the **region of Yambol**

Rank	№	Variety	C	Peculiarity
1	16	ABC 48/716	144,4	Candidate variety in Romania
2	38	ABC ZIGMUND	137,1	New
3	36	ABC KLAUSIUS	134,2	New
4	35	ABC LOMBARDIA	131,5	New
5	37	ABC SPERI	131,3	New
6	18	ABC 37/716	130,3	new in Romania as **ARO REDMAT**
7	33	FAKTOR	127,9	Already zoned variety
8	34	ABC ALFIO	127,3	New
10	17	A 47/415	125,0	New as **ABC VETO**
11	40	ABC NAVO	124,1	New
12	9	ABC 27/512	121,1	new in Romania as **ARO SANKTI**
13	30	RALITSA	118,8	New
14	31	RIANA	113,1	New
15	28	VYARA	108,9	Already zoned variety
	21	LG AVENUE	100,0	Check variety

The picture of those suitable for the Yambol region is significantly different from that in Dobrich and Ruse (Table 17). Against the background of the good results for the already zoned varieties Vyara and Factor, the newest varieties (31, 35, 36, 37, 38 and 40) and the promising candidate varieties (9, 16, 17 and 18) stand out. Some of these varieties are already in the process of official recognition and already have own names. In addition, the excess of grain yield compared to the standard is very high from 9 to 45%, which is in a sense "shocking". It is obvious that the French variety is not suitable for comparison in the conditions of stress, which is observed in location C (Yambol). In it the average grain yield is 35% lower compared to the optimal conditions of location A (Dobrich), precisely for this reason.

After careful analysis of the results, it was logical to calculate the value of the AR index according to the level of correlations of the indices. The six indices that showed the strongest correlation with GY (Table 12) were included in the calculation of the adjusted average rank, denoted as (AR6).

The correlation between this **AR6** index with the yield turned out to be not only high, but also the highest in comparison with the 6 indices that formed its value (Table 18). The level of definiteness of the correlation (R^2 = 0.78) is significantly higher than that of the highest value of the $NP^{(3)}$ index (R^2 = 0.62). Therefore, the rank in *AR6 index model* could be considered to determine the stability of the genotype.

Table 18. Pearson correlations between selected indexes for ranking varieties by grain yield (GY)

№	Index	GY	p-value	R^2
3	$S^{(6)}$	0,72	< 0,0001	0,52
4	$NP^{(2)}$	0,75	< 0,0001	0,56
6	$NP^{(3)}$	0,78	< 0,0001	0,61
7	$NP^{(4)}$	0,76	< 0,0001	0,58
8	MSI	0,63	< 0,0001	0,39
13	*K*R	0,74	< 0,0001	0,54
	AR6 *	**0,88**	**< 0,0001**	**0,78**

* - average rank obtained from the values of the 6 indices chosen

In order to maximize the verification of such an approach, a parallel verification of the results in Table 18 was performed using Principal Component Analysis (Figure 8). It is extremely clear that the index (AR6) and the others have a strong enough correlation with the yield rank, which is evident from the location of their vectors relative to that of GY. The acute angle with the lowest values observed between these vectors is strong enough evidence for the proven relationship with grain yield.

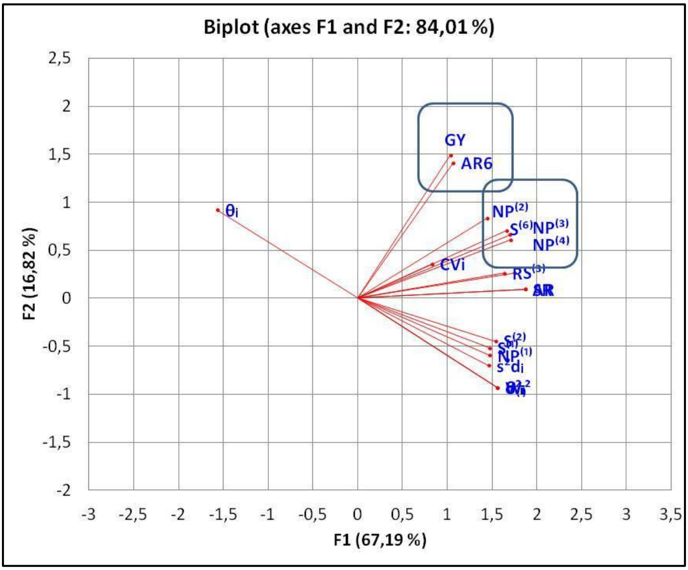

Figure 8. Principal component analysis (PCA) of the indices related to grain yield and grain stability

After all these results, it is logical to reach a climax consisting of sorting the yield and yield stability (Figure 9). The scatter plots module of the statistical package Xlstat 2014 is used, which means "scattered arrangement". The term fully corresponds to the purpose for which it was applied. For the ranking of the varieties their grain yield rankings (GY) and the average rank of stability (AR6) were used. In the quadrant with red color are positioned the varieties that have a rank of both parameters above the average for the whole group (20). In the upper right square are positioned varieties with low and highly variable grain yield, which is to be avoided when zoning.

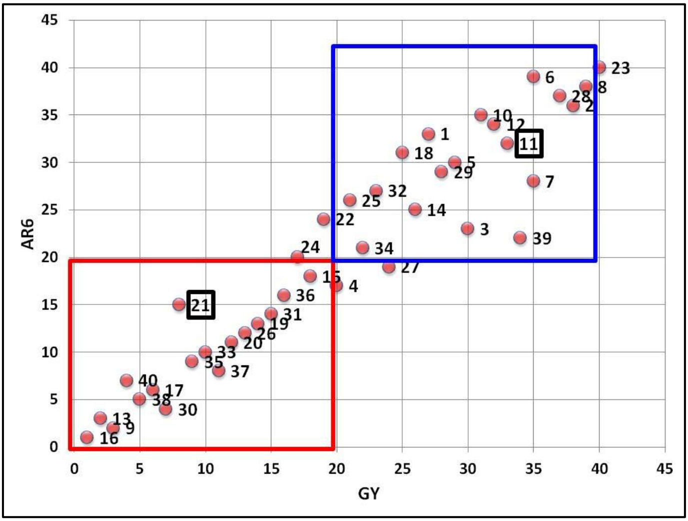

Figure 9. Spatial grouping of the varieties tested according to their grain yield (GY) and the adjusted average rank of stability signed as (AR6)

The varieties that are in the red quadrant could also be subdivided according to their value (Figure 10). The most valuable are the varieties 9, 13 and 16, followed by 38 and 40, in which the grain yield remains high, but reduces its stability. If we compromise on stability, the next most valuable varieties are 17, 30, 33 and 35, and the standard variety LG Avenue is exactly in this last group. In relation to its position from the point of view of stability, but with slightly lower relative yields (> 95%) of it are the varieties with № 19, 20, 26 and 37. Therefore, all new varieties with numbers 33, 35, 36, 37, 38 and 40 fall into the group of the most valuable and according to this visualization.

The two standard varieties are in different quadrants. Pryaspa variety has a high rank in terms of both yield and stability of yield, compared to the LG Avenue standard. The location of this variety shows high yields and stability above the average for the group, which makes it a high standard of comparison. In this situation, if we accept a rank of up to 20 in terms of GY and STAB. We get a group of 15 varieties (40% of all), which are of the rank of the French standard variety. Seven of them exceed it by both criteria, which accounts for 18% of all studied varieties.

In the other group of varieties 23 in number (60%) with low ranks are mainly quality varieties with № 10, 23, 25, 32, 34 and 39, which against the background of the high standard for GY is completely logical. Many of the other varieties, such as № 22, 27, 28, 29, are already zoned varieties that are to be replaced in practice. This is recommended against the background of the excellent results that the new varieties and candidate varieties (Tables 42, 43 and 44) show.

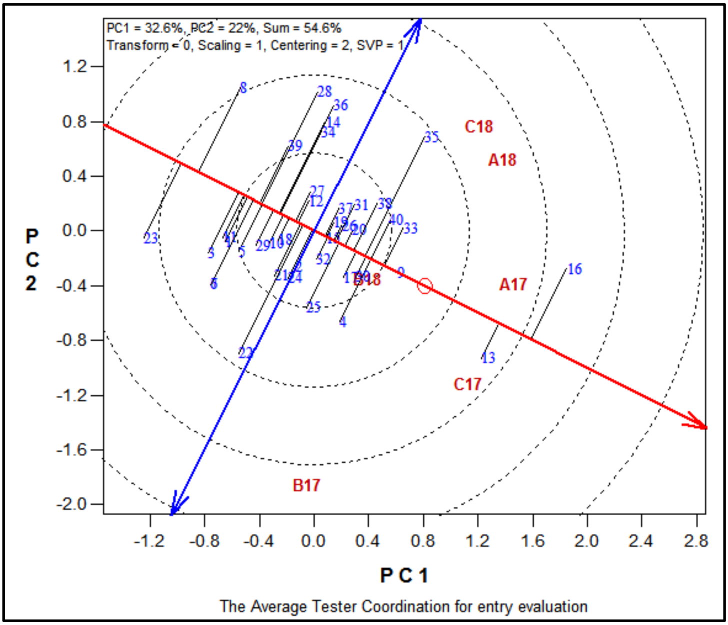

Figure 10. Spatial points of all the varieties and seasons of the field experiment

As there were doubts about the complete objectivity of such a spatial representation, the data were further analyzed with the GGE biplot program, 6.3, which is currently the most widely used in the world for this purpose (Neisse et al., 2018; Quintero et al., 2018).

Figure 10 presents spatially the points of all studied varieties in all locations and years of the field experience. The red circle located on the red (somewhat parallel to the abscissa) line is the place of the "*ideal*" variety in terms of yield and stability. Closest to it are the same varieties - 9, 13, 16 38 and 40. At the opposite end are the points of the same varieties 8, 23 and 28, with low and variable yield, quite similar to their location in Figure 10. Therefore, the approach of spatially represented in the ranks by Figure 10 objectively reflects the relationships between varieties in yield and stability against the background of the group.

In conclusion, we should note that the study is designed to gather sufficient information about the behaviour of a group of varieties in the country. A large amount of data on the productivity and grain quality of winter wheat was collected and analyzed. Due to the great complexity and complexity of the topics related to the analysis of the genotype * environment interactions, this study describes the patterns related only to grain yield.

The main emphasis, of course, was placed on grain yield, due to the presence of very similar information about it in a huge number of scientific articles. In describing the data and analyzing the results, we found that GEI-related topics are very relevant to many areas of science, such as biology (Shao et al. 2015), physiology (Mishra et al. 2015), genetics (Gitonga et al. . 2014), breeding of plants (Ishaq et al. 2015) and animals (Bresolin et al., 2015) medicine (King 2015), (Molenaar et al. 2015), pharmacy (Shewry et al., 2011), etc. This caused additional serious motivation for the most in-depth analysis of each of the aspects of this current problem. University lecturers have already shaped the study of the problem as a discipline (van Eeuwijk et al., 2016), (Salvatore & Dick 2015). Perhaps this has become the main reason for the impossibility to include an analysis of other features, although it has already been done according to the overall idea of the thesis.

The analysis of the grain yield trait was carried out consistently and systematically, as a large part of the known indices (parameters) were studied to assess the effects of the environment. At each stage of the study, a critical analysis of the possibilities of the approaches used was made. The results of each section were compared with previous publications. In our country, in cereals there are a relatively limited number of publications related to the problems of GEI (Tsenov et al., 2004, Tsenov and Atanasova, 2013). A relatively small part of them are specifically cited in the separate sections (Dyulgerova and Valcheva 2011, Valkova and Dechev, 2012, Tsenov et al., 2013). The reason for this is that they are related to the study of the most general aspects of GEI, without making any comparisons between approaches to evaluation and gathering information on the problem. Most research focuses not on assessment methods or approaches, but on direct comparison of varieties in a given group (Chamurliyski et al., 2015, Dyulgerova and Dyulgerov, 2016). The research is mainly related to the selection of cultivated plants (Genchev, 2010, Ganusheva et al. 2011) and a small part to clarifying issues related to cultivation technology (Ivanova and Tsenov, 2010, Ivanova & Tsenov, 2011, Yanchev et al. ., 2013, Ivanova and Tsenov, 2014). The main weakness of some of the studies is the small number of varieties (less than 10) in the studied groups, and the inclusion of test locations is almost absent (Dimova et al., 2006, Valcheva et al., 2009, Savova et al., 2014, Chamurliiski et al., 2015).

In this study, all these weaknesses were avoided. A sufficiently large number of varieties (24 and 40) have been selected. Through a successfully conducted multifactor field experiment, in which there is a sufficient number of environments (1st stage: 4 years and 5 points; 2nd stage: 2 years and 3 points) a comprehensive assessment of the impact of conditions on grain yield was made. The data collected from the experiment are mainly related to the evaluation of a group of varieties. The information gathered here is valuable in terms of verifying the effectiveness and suitability of individual methods and approaches for variety assessment. The regularities that were established in some aspects are original, because they do not confirm the already accumulated knowledge about wheat (Gubatov et al., 2017, Tsenov et al., 2017). Here we must mention that the application of both parametric and non-parametric approaches increases the efficiency of some analyzes. An example of this is the results in sections 5.4. 5.5. and 5.6, in which ranking was the basis for success in attempts at maximally objective evaluation.

6. CONCLUSIONS

1. The variation of the attribute GY is very strong as a result of the influence of the conditions of the year, the test locations and the genotype, as a factor.

2. The interaction of the feature with the environmental conditions is about 32% of its total variation and is mainly due to the combined effect of the year * location interaction (88%)

3. Interaction between the genotype and the environment has a non-linear character with a share of about (20%), which generally makes it difficult to correctly assess the reaction of each variety to others in the group.

4. In general, the Kang model (1993) cannot be accepted as a criterion for assessing the suitability of other models for the analysis of variation in MET experiments,

5. Therefore, it is not possible to make a simultaneous assessment of the level of the trait and its degree of variation by the values of any of the old popular methods studied, especially in a large group of varieties.

6. The studied indices for assessment of the behaviour of the trait in various environmental conditions provide correct information about the stability of each specific variety.

7. The "ASV" index (AMMI Stability Value) does not provide objective information on the variation of varieties when it is necessary to compare them with each other.

8. Relatively informative for grouping varieties by yield and stability are the nonparametric approach of Huhn (1979) and the parametric method of Francis and Kannenberg (1978) in which the relationship between grain yield and its stability is most pronounced.

9. the most effective for differentiation of the varieties according to their variability in the conditions of MET are the models of AMMI and GGE especially through their graphic module.

10. The approach for evaluation by ranking by means of statistical indices is correct and fully applicable for differentiation of valuable varieties from each studied group.

11. The information on the grain yield behaviour of the individual variety is relative to the background of the group in which it is tested and thanks to it can be placed in any of the four groups.

12. The grouping of varieties by compromise between GY and STABILITY can be done by old simple statistical approaches (indices), which have been well known for a long time. However, this grouping is not always similar in the individual approaches, which always causes mistrust and uncertainty in the interpretation of the results obtained. For this reason, we recommend using the latest statistical software programs, which are designed specifically for these purposes (GenStat, GGEBiplot, GEST, Genes, Stable) data to confirm these obtained by the simple methods analyzed here.

13. The ranking of varieties can be successfully used to identify those in the group with the desired high yield and high adaptation to different environmental conditions.

14. The application of different approaches for assessment of the level and stability of the yield gives similar information when arranging the varieties from the studied group, as there is no fundamental difference between them.

15. All applied modern methods for analysis of the interaction genotype * environment are sufficiently informative, therefore they are operative for differentiating the behaviour of varieties in a wide range of growing conditions.

16. The measurement of the change (variation) of the grain yield of the variety grown in different conditions is an action, which is obligatory for its objective assessment, against the background of the rest of the group.

17. The assessment of the stability of individual grain yield varieties is most objective when using the adjusted average index (AR6)

18. The combination of the classical method (averaging of the data from the different conditions) with the correction by the stability of the genotype is a proper approach for grouping the varieties in order to zoning them in specific environmental conditions.

19. The arrangement of the studied varieties by spatial representation of the yield ranks and its stability is an effective way for complex assessment of the genotype.

20. The assessment of the stability of grain yield of each variety can be done quickly, accurately and correctly, using modern statistical packages created for this purpose.

7. CONTRIBUTIONS

Scientific and theoretical contributions:

1. Grain yield in wheat is a productive trait that is highly dependent on environmental conditions due to the complex change in traits from which it is formed.

2. The interaction of the grain yield trait with the environmental conditions has a complex and multi component character, which is difficult to predict and analyze without experiments against the background of the unpredictable conditions of the seasons.

3. The analysis of the change (variation) of the grain yield of the variety, grown in different conditions, is obligatory for its objective assessment, against the background of the other varieties of the group.

4. The information about the grain yield behavior of the individual variety is relative to the background of the group in which it is tested and thanks to it it can be characterized in any of the four groups according to the size of the yield and its stability.

5. Each of the analyzed methods for assessment of the genotype * environment interaction in itself gives part of the information about the behavior of each variety in the conditions of multifactor field experiments, which, however, is not sufficient for its correct comparison with the other studied varieties.

6. Ranking approaches for the evaluation of varieties can be successfully used to identify those varieties of the experiment with high yield and strong adaptability (adaptation) to different environmental conditions.

Scientific applications:

1. Relatively informative for grouping varieties by yield and stability are the non-parametric approach of Huhn (1979) and the parametric method of Francis and Kannenberg (1978) in which the relationship between grain yield and its stability is most pronounced.

2. When applying the indices "ASV" and "GA" it is not possible to obtain correct information about the degree of variation of a particular variety in the group, therefore they should not be used for this purpose.

3. Combining the classical method (averaging the data from the different conditions) with the correction of the stability of the genotype is a correct approach for grouping the varieties in order to zoning them in specific environmental conditions.

4. New varieties created in the last few years exceed yield and stability standards, despite the strong interaction of yield with environmental factors

Scientific publications related to the dissertation:

GUBATOV T., N. Tsenov, I. Yanchev, 2017. Correlation between the ranking of winter wheat genotypes by grain yield and stability through various statistical approaches *Bulgarian Journal of Agricultural Sciences,* **23**(1): 921-101

Tsenov, N. and **GUBATOV, T.** 2018. Comparison of basic methods for estimating the size and stability of grain yields in winter wheat, *Bulgarian Journal of Crop Sciences*, **55**(6): 9-19 (Bg)

GUBATOV, T., V. Delibaltova, 2020. Evaluation of wheat varieties by the stability of grain yield in multi environmental trails. *Bulgarian Journal of Agricultural Sciences,* **26**(2): 384-394

EXTENDED SUMMARY

Todor Gubatov 2020. Interaction between environmental conditions and grain yield in common wheat (*Triticum aestivum* L.) varieties, *PhD Thesis,* Agricultural University, Plovdiv, Bulgaria, pp. 185.

The aim of the study was to investigate as possible detail regularities related to the impact of environmental conditions on the variation and the level of the grain yield in winter wheat.

Material and methods: 24+40 common winter wheat varieties, mainly breeding of "Agronom". Field trials include a study of grain yield in four consecutive seasons (2009 – 2012, 2017-2018) in three to five test locations, typical for grain-producing regions. The influence of environmental conditions on grain yield in the presence of the maximum possible variation of the attribute was studied. Analyzed all existing statistical capabilities to assess the interaction genotype * environment. Each particular variety was rated as behavior of grain yield amid contrasting environmental conditions and other genotypes in the test group. Various approaches to detailed comparison between the level and stability of the variety to others by fundamentally different statistical models and approaches were used. The relationships between grain yield and its stability against the background of different methods to compare were examined.

Key results: Grain yield is a character is strongly influenced by growing conditions. In its interaction genotype x environment is fairly high compared to factor year, and location test as a factor. Interaction between the factors location x year is the most significant, given the influence of genotype on the expression of the trait. The latter effect is only about 5 % while the difference in environments (location and year) is responsible for around 32% of the interaction genotype * environment. The change in yield grain is associated with variation ternary (PCA) which further complicates the assessment of the individual variety in the group.

Key conclusions: ***1)*** The variation of the attribute GY is very strong as a result of the influence of the conditions of the year, the test locations and the genotype, as a factor; ***2)*** The interaction of the feature with the environmental conditions is about 32% of its total

variation and is mainly due to the combined effect of the year * location interaction (88%); ***3)*** Interaction between the genotype and the environment has a non-linear character with a share of about (20%), which generally makes it difficult to correctly assess the reaction of each variety to others in the group; ***4)*** In general, the Kang model (1993) cannot be accepted as a criterion for assessing the suitability of other models for the analysis of variation in MET experiments; ***5)*** Therefore, it is not possible to make a simultaneous assessment of the level of the trait and its degree of variation by the values of any of the old popular methods studied, especially in a large group of varieties; ***6)*** The studied indices for assessment of the behaviour of the trait in various environmental conditions provide correct information about the stability of each specific variety; ***7)*** The "ASV" index (AMMI Stability Value) does not provide objective information on the variation of varieties when it is necessary to compare them with each other; ***8)*** Relatively informative for grouping varieties by yield and stability are the nonparametric approach of Huhn (1979) and the parametric method of Francis and Kannenberg (1978) in which the relationship between grain yield and its stability is most pronounced; ***9)*** The most effective for differentiation of the varieties according to their variability in the conditions of MET are the models of AMMI and GGE especially through their graphic module; ***10)*** The approach for evaluation by ranking by means of statistical indices is correct and fully applicable for differentiation of valuable varieties from each studied group; ***11)*** The information on the grain yield behaviour of the individual variety is relative to the background of the group in which it is tested and thanks to it can be placed in any of the four groups; ***12)*** The grouping of varieties by compromise between GY and STABILITY can be done by old simple statistical approaches (indices), which have been well known for a long time. However, this grouping is not always similar in the individual approaches, which always causes mistrust and uncertainty in the interpretation of the results obtained. For this reason, we recommend using the latest statistical software programs, which are designed specifically for these purposes (GenStat, GGEBiplot, GEST, Genes, Stable) data to confirm these obtained by the simple methods analyzed here; ***13)*** The ranking of varieties can be successfully used to identify those in the group with the desired high yield and high adaptation to different environmental conditions; ***14)*** The application of different approaches for assessment of the level and stability of the yield gives similar information when arranging the varieties from the studied group, as there is no fundamental difference between them; ***15)*** All applied modern methods for analysis of the interaction genotype * environment are sufficiently informative, therefore they are operative for differentiating the behaviour of varieties in a wide range of growing conditions; ***16)*** The measurement of the change (variation) of the grain yield of the variety grown in different conditions is an action, which is obligatory for its objective assessment, against the background of the rest of the group; ***17)*** The assessment of the stability of individual grain yield varieties is most objective when using the adjusted average index (AR6); ***18)*** The combination of the classical method (averaging of the data from the different conditions) with the correction by the stability of the genotype is a proper approach for grouping the varieties in order to zoning them in specific environmental conditions; ***19)*** The arrangement of the studied varieties by spatial representation of the yield ranks and its stability is an effective way for complex assessment of the genotype; ***20)*** The assessment of the stability of grain yield of each variety can be done quickly, accurately and correctly, using modern statistical packages created for this purpose.

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