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Original article

Environment Adjusted Yield Model for Ranking and Stability Assessment of Winter Triticale (X *Triticosecale Wittm*.) Genotypes

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Abstract

Obtaining high yields from crops such as triticale is directly related to the interaction of the used genotypes with the conditions of the environment. Therefore, the breeding of the crop is targeted toward reducing the effects, which various stress factors have on productivity. One of the shortcomings of the interaction of the genotype with the environment is that under contrasting growing conditions the different cultivars are ranked in a different way according to their yield value. This considerably hinders their evaluation and the possibility to choose the most suitable cultivars for the respective geographic area and micro region. In order to adequately assess the different triticale genotypes under contrasting conditions of the environment, a model for yield ranking was developed. It is based on the ratio between the reaction of the genotype under specific conditions of the environment with the mean productivity of the same genotype under the rest of the conditions of testing. This allowed increasing the contrast between differing genotypes and their more adequate ranking under certain conditions, or as a whole during the tested contrasting periods. On the other hand, the model allowed grouping of the genotypes with identical reaction to the conditions of the environment. The model was applied to eleven Bulgarian winter triticale cultivars (Kolorit, Atila, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Lovchanets, Doni 52, Blagovest and Borislav) and to six contrasting periods of growing (2015 – 2020). The results from the model values showed that the cultivars were grouped in different ways during the individual periods in comparison to their grouping according to yield values. Cultivars with similar productivity having identical ranks contrasted better with each other when applying the model. The genotypes, which possessed high stability, were characterized with lower ranks according to the results from the used model, especially in periods with clearly expressed drought. The ranks of the model values remained significantly high regardless of the conditions of the environments in cultivars Bumerang and Doni 52. The developed model demonstrated considerable similarities to the HARV and Hi models and can be reliably used in practical breeding work under contrasting environments.

Keywords: Environment, Model, Triticale, Stability, Yield.

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INTRODUCTION

Developing highly adaptive genotypes is a key task in the breeding of the cereal crops (Randhawa et al., 2015; Kendal and Sayar, 2016; Ramazani et al., 2016; Tsenov and Gubatov, 2018; Rao et al., 2019). This is related to the potential of a given cultivar to realize high yields regardless of the conditions of the environment, or the decrease of yield resulting from unfavorable conditions to be minimal. Such a task requires testing of the developed breeding materials under different environments in order to determine to what degree a given genotype interacts with them (Beres et al., 2020). This is necessary since the availability of an interaction of the genotype with the conditions of the environment makes difficult the grouping and ranking of the best performing genotypes according to certain parameters (Kaya and Ozer, 2014; Lule et al., 2014; Osei et al., 2019). Such difficulties relate to different nature of the expression of the interaction, but mostly to two major peculiarities. Firstly, the ranking of the separate genotypes changes under different growing conditions, which does not allow determining the best genotype as a whole (Kaya and Ozer, 2014). On the other hand, the mean values obtained from all growing conditions, can be rather misleading since they accumulate various effects, which can camouflage the actual grouping of the investigated cultivars (Tsenov et al., 2014; Stoyanov and Baychev, 2016a). In such cases, especially when studying a large number of locations or multiple periods, the data on the individual genotypes are insignificantly contrasting. In order to properly assess such effects, it is necessary to develop methods and models allowing the ranking of the investigated genotypes under variable environments.

A considerable number of methods and models for ranking of the genotypes according to their productivity (Aggarwal et al., 1995; Palanisamy et al., 1995; Wade, 1995; Tsenov et al., 2014; Stoyanov et al., 2017a) are known. A part of them are based on conventional statistical approaches such as the regression analysis (Dogan et al, 2011; Bolandi et al., 2012; Gurung et al., 2012; Chamurliyski and Tsenov, 2013; Sousa et al., 2017; Tsenov and Gubatov, 2018; Ahmed et al., 2019; Srivastava et al, 2020). A large number of researches (Goyal et al., 2011; Chimonoyo et al., 2014; Ali et al., 2015; Tsenov and Atanasova, 2015; Kendal et al., 2016; Stoyanov et al., 2017b; Szareski et al., 2018; Das et al., 2019; Azam et al., 2020), including our previous results, allow ranking the studied genotypes on the basis of AMMI, GGE-analysis, or a combination of both. At the same time another part of the investigations are focused on ranking based on different groups of parameters of yield stability (Alberts, 2004; Tsenov et al., 2008; Kaya and Ozer, 2014; Lule et al., 2014; Kaya and Turkoz, 2016). Tsenov et al. (2014) suggested the combined use of different approaches. In the above study, the authors used and evaluated the applicability of four different methods to common winter wheat. The method for rank assessment based on a scale according to the realized relative yield these authors suggested is with good efficiency and high applicability. This method combines the advantages of the non-parameter methods and the efficiency of the relative yield as a value. Stoyanov et al. (2017a), investigating different triticale genotypes, applied five methods for ranking – HARV (Heritability Adjusted Relative Value according to Yan and Holland (2010)), Hi-parameter (according to Martynov, 1990), RE (ranking evaluation according by a rank scale according to Tsenov et al. (2014)), RV (relative yield according to the mean value for all studied genotypes), AY (relative yield according to an adopted mean standard of landraces). The authors determined high applicability for ranking of the investigated genotypes based on the parameters HARV, Hi and AY. The HARV parameter is based on the broad sense heritability (the ratio of the genotypic to the phenotypic variance), and Hi – on the deviation of the genotype under specific conditions according to the mean values. Both approaches imply the use of the phenotypic variance in calculating the parameters, which allows determining the potential genotype effects and more efficient ranking of the investigated genotypes. All these parameters are calculated on the basis of actual yield values, in which multiple effects of the environment are accumulated. Contrasting conditions can often considerably distort the ranking of the studied cultivars. Therefore, it is necessary to correct the yield values according to the specific stress factor. The obtained corrected values allow ranking the studied genotypes according to the yield results.

The aim of this study was to develop a model for ranking of a group of investigated genotypes according to their yield based on the effects of the environment and the genotype x environment interaction under contrasting conditions of growing.

MATERIALS and METHODS

Plant material

To realize the above aim, eleven Bulgarian triticale cultivars were used (Table 1). They were grown as a whole area crop in trial plots of 10 m^2, in four replications in a standard block design within a competitive varietal trial. Sowing was mechanized within the standard dates for planting of triticale with 550 seeds/m^2. Besides the above cultivars, the competitive varietal trial also involved the standard varieties AD-7291, Vihren and Rakita, as well as the world standards Lasko and Presto. The plots were harvested at full maturity, reading the yield from each of them separately.

Growing conditions

The trial was carried out in six successive harvest years – 2014/2015, 2015/2016, 2016/2017, 2017/2018, 2018/2019, 2019/2020. The data presented on the mean monthly air temperature and the sum of precipitation (Table 2) reveal the contrasting nature of the studied period. The highest differences according to the long-term tendency with regard to temperature were observed during December-March, and with regard to rainfalls – in December and May. The differences in this period gave sufficient ground to assume that vegetative growth occurred in a different way during each of the years. Certain phenomena and processes were clearly outlined in a meteorological respect; they were of single occurrence and were not repeated at any given interval; they were also able to affect the physical processes in the plant organism.

Table 1. Cultivars used during the investigation

No	Name	Origin	Year of registration
1	Kolorit	BGL "S" – BGC / 568-343	2005
2	Atila	AD 8x(Ep 1034/79 x Harkovska 60) /F_1[F_1(Yuzhnaya zrya / Harkovska 60) / 804-503]	2007
3	Akord	MT-3 / F_2 populations	2007
4	Respekt	1262-12-2-10 / Veleten	2008
5	Bumerang	LP 3090.91 / 2853-1044	2009
6	Irnik	5252 - 131 / 2853-1044	2011
7	Dobrudzhanets	Chrono / 2853-1044	2012
8	Lovchanets	F_1 (Tornado / 3493-699) / Zaryad	2013
9	Doni 52	5279-131 / 3370-190	2014
10	Blagovest	32/99 / Zaryad	2015
11	Borislav	46/95-96 / 129/98	2016

Table 2. Average monthly temperature and Total monthly precipitation during the investigated period

Parameter	Year	Sep	Oct	Noe	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
AMT, ºC	2014/2015	17.5	11.2	5.6	3.1	1.4	2.0	5.0	10.1	16.4	19.4	22.4
	2015/2016	19.5	10.9	9.3	3.4	-0.8	7.3	6.8	13.2	14.7	20.9	22.8
	2016/2017	18.1	10.6	6.5	-0.6	-4.1	2.0	7.3	8.7	15.0	20.2	21.8
	2017/2018	19.0	11.8	7.5	4.7	1.7	1.1	4.6	13.4	17.7	20.4	22.2
	2018/2019	17.7	13.3	5.4	1.2	1.0	3.5	8.2	9.0	16.0	22.3	22.0
	2019/2020	17.9	13.4	11.7	5.2	1.8	5.1	8.0	10.0	15.4	19.6	22.3
	1960/2019	16.9	11.7	6.8	2.0	-0.2	1.1	4.7	9.9	15.2	22.0	21.4
TMP, mm	2014/2015	31.4	57.9	33.2	87.0	33.2	79.5	67.7	8.5	12.9	31.3	27.2
	2015/2016	20.8	78.3	55.1	0.4	86.3	40.7	52.7	20.8	117.1	55.7	2.8
	2016/2017	35.8	72.2	43.3	12.5	48.4	27.4	48.9	38.4	29.0	87.7	66.3
	2017/2018	69.9	50.5	57.2	55.8	75.4	48.8	4.9	30.9	90.8	59.6	59.6
	2018/2019	54.7	11.7	66.2	43.8	19.2	16.3	16.1	49.4	31.7	37.5	54.0
	2019/2020	36.7	27.6	35.4	21.8	2.8	28.1	28.3	5.8	48.0	51.3	2.7
	1960/2019	46.3	42.1	43.4	41.7	36.9	34.2	35.6	40.5	52.1	58.7	52.2

AMT – Average monthly temperature TMP - Total monthly precipitation

Growing years 2015/2016, 2017/2018 and 2018/2019 are worth of special mentioning; in them, extreme intensive and long-lasting rainfalls in July (2017/2018), untypical daily intermittent rainfalls in June (2017/2018) and severe droughts during February-March (2018/2019) were observed, respectively. Highly unfavorable for growing of triticale was also growing year 2019/2020 due to the long drought in March-April. At the same time, the conditions in 2014/2015 were the most favorable for triticale growing, with the lowest number of negative events during the vegetative growth of the crop.

Developing an Environment Adjusted Yield Model (EAYM)

In the field, where it is not possible to control the conditions under which the vegetative growth occurs, the yield from such plants as triticale may vary within a wide range (Stoyanov, 2018). This is related to various expressions of the weather such as different precipitation norms and their distribution by phenophases, air temperature during certain periods of the development, air humidity, wind speed, condition of the sol, etc. When growing a certain genotype in a given location during different vegetative growth periods, this genotype forms a certain tendency towards a specific mean yield. In such cases, the yield deviates from the mean yield typical for the given growing region depending on whether the environmental conditions are favorable for the crop development or not. The more different the conditions of the environment are from the typical for the region, the more the yield will differ from the mean long-term yield. It should be emphasized that the different conditions of the environment do not necessarily mean higher yield since it is possible conditions, which are rather different from the long-term tendency, to be considerably more favorable for growing of a given genotype. In this case, the obtained yields will be higher than the mean long-term yields. This correlation is valid also when growing a given genotype during *E* (number of) specific periods. The yield from a specific period within the investigated *E* periods would differ significantly from the mean yield from the other *E*-1 periods. The deviation of the yield from the specific year according to the long-term mean yield may be represented by Formula 1.

$$\overline{d}_{ij} = \frac{\overline{x}_{ij}}{\dfrac{\left(\sum_{j=1}^{E} \overline{x}_{ij}\right) - \overline{x}_{ij}}{E-1}} \quad (1)$$

, where

$\overline{d}_{ij}$ - deviation of the yield from a given genotype *i* for a specific period *j* according to the mean yield for the other investigated periods

$\overline{x}_{ij}$ - yield from a specific genotype *i* for a specific growing period *j*

E – number of growing periods

Values of $\overline{d}_{ij}$ lower than 1.00 indicate that the yield in a specific period is lower than the long-term mean yield for the other investigated *E*-1 periods. For values higher than 1.00, the yield during the investigated period is higher than the long-term mean data for the other *E*-1 periods.

If coefficient $\overline{d}_{ij}$ is applied with regard to the mean values of yield $\overline{x}_i$ from a given genotype for all (*E* in number) periods, a model value $\overline{z}_{ij}$ of the yield for the investigated period will be obtained. This value represents the yield that would be obtained if the mean value for the yield from a given genotype is compared to the deviation from the specific conditions of the environment. The mathematical expression of this model parameter is given in Formula 2:

$$\bar{z}_{ij} = \bar{d}_{ij}.\bar{x}_i \Rightarrow \bar{z}_{ij} = \frac{\bar{x}_{ij}}{\frac{\left(\sum_{j=1}^{E} \bar{x}_{ij}\right) - \bar{x}_{ij}}{E-1}} \bar{x}_i \quad (2)$$

The parameter thus calculated allows determining the differences between those genotypes, which realized similar yields during a given period of the investigation, but in other periods reacted to the conditions of the environment in rather different ways. In practice, the method allows to achieve greater contrast between the studied genotypes based on their specific expression under the contrasting conditions of the environment. On the other hand, the method registers as similar those genotypes, which react in a similar way regardless of the conditions of the environment.

Statistical analysis

The model was applied to the investigated triticale genotypes. The actual and model values of the yield were averaged by cultivar and period of study. The cultivars were ranked based on the mean values of the actual and model yields. The differences were determined between the ranks over years and as a whole. Based on the differences between the real and model values of each cultivar, the stability of the separate genotypes was estimated. To evaluate the adequacy of the model, a comparison was made between the developed method and the method suggested by Martynov (1990) and Yan and Holland (2010). A comparison was made between the ranks of the developed model and the ranks obtained through the methods applied for comparison. A Pearson correlation analysis between the values of the investigated models was performed, and the Spearman rank correlations between the ranks of the same parameters were determined. To summarize the data, to calculate the model values, to rank the separate parameters and to calculate the parameters of Hi and HARV, MS Office Excel, 2003 was used, and for the correlation analysis – IBM SPSS Statistics, v.19.

RESULTS and DISCUSSION

The results obtained on the yield of the studied cultivars expressly established the contrasting periods in which they were grown (Table 3). The average yields from all genotypes over years differed considerably. At the same time, a tendency was observed the individual genotypes not to decrease or increase their yield proportionally (Appendix 1, Figure 1). This is related to the presence of a very high effect of the genotype x environment interaction. Nevertheless, the mean values from the six investigated periods allowed ranking the cultivars in a certain way. Doni 52, Bumerang and Borislav were with the highest mean yields, and Respekt, Lovchanets and AD-7291 – with the lowest, respectively. Cultivars Irnik, Akord, Presto, Blagovest, Atila and Rakita were characterized with mean yields for the six investigated periods exceeding 600 kg/da, while cultivars Kolorit, Dobrudzhanets, Lasko and Vihren were below those values.

Table 3. Yield values by genotype and year and ranking by genotype

Cultivar	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020	Average	Rank
AD-7291	589	596	602	637	507	483	569	3
Vihren	609	540	631	745	513	477	586	4
Rakita	725	529	735	717	608	570	647	13
Lasko	765	455	614	631	561	547	596	5
Presto	777	436	681	624	612	596	621	10
Kolorit	691	543	644	661	504	531	596	6
Atila	763	632	757	609	476	564	633	12
Akord	767	552	691	584	549	568	618	9
Respekt	704	320	679	563	406	478	525	1
Bumerang	779	424	776	745	608	631	660	15
Irnik	793	521	603	634	495	556	600	8
Dobrudzhanets	643	469	770	664	579	468	599	7
Lovchanets	649	378	564	624	476	490	530	2
Doni 52	803	611	745	700	603	574	673	16
Blagovest	747	543	713	636	532	567	623	11
Borislav	839	605	711	602	601	572	655	14
Average	728	510	682	649	539	542	608	

Table 4. Model values of EAYM by genotype and year and ranking by genotype

Cultivar	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020	Average	Rank
AD-7291	593.17	601.71	609.06	652.60	496.19	468.83	570.26	3
Vihren	613.85	531.68	640.88	787.81	500.55	459.91	589.12	4
Rakita	742.82	510.34	755.46	732.77	600.70	556.70	649.80	13
Lasko	811.16	434.49	617.83	638.60	554.56	538.61	599.21	6
Presto	818.12	411.49	694.43	624.61	610.24	590.86	624.96	10
Kolorit	713.84	533.56	654.62	675.82	488.95	519.90	597.78	5
Atila	795.53	631.71	787.72	604.33	453.46	551.70	637.41	12
Akord	805.72	540.39	707.61	577.57	536.95	558.31	621.09	9
Respekt	755.55	296.83	721.35	571.29	388.40	469.03	533.74	1
Bumerang	808.00	395.67	804.13	764.57	598.49	625.22	666.01	15
Irnik	847.41	507.59	603.55	641.20	478.23	547.53	604.25	8
Dobrudzhanets	652.62	449.51	816.68	678.77	575.18	448.59	603.56	7
Lovchanets	679.46	357.48	571.29	646.90	466.47	482.69	534.05	2
Doni 52	835.37	600.00	761.37	705.74	590.76	557.64	675.15	16
Blagovest	777.97	529.40	734.21	638.67	516.90	556.99	625.69	11
Borislav	888.94	595.90	723.37	592.41	591.25	557.86	658.29	14
Average	758.72	495.48	700.22	658.35	527.96	530.65	611.90	

Such values indicate that regardless of the highly unfavorable conditions of the environment observed, the greater part of the cultivars realized productivity around and above the average, which emphasizes the serious breeding achievements in this crop (Stoyanov, 2018). However, the ranking of the cultivars over the separate periods significantly differed from the ranking of the mean values (Table 5). This shows that a certain genotype is not possible to be determined as the best one regardless of the conditions of the environment. Certain tendencies were observed in cultivars Doni 52 and Bumerang toward the higher values in the ranking during all periods of growing.

The results obtained from the applied model (Table 4) show that the studied cultivars differed significantly by their response to the conditions of the environment. The better contrast observed in the model values of the yield allows considerably more adequate ranking of the genotypes. The ranks of the mean-model values demonstrated a much higher degree of similarity with the ranks of yield.

This is due to several main reasons. On the one hand, in spite of the significantly high effect of the genotype x environment interaction on the variation of yield and its values, a considerable effect of the genotypes themselves on the formation of productivity was also observed (Appendix 1, Table 8). This implies accumulation of less random effects on the expression of certain elements of productivity. On the other hand, the absence of a high difference in the ranking of the genotypes indicates that in periods of highly contrasting nature and with highly unfavorable environmental conditions, all genotypes responded to such a change, although to different degrees. In the favorable periods, yield increased in all cultivars, while during the unfavorable ones it decreased. An exception from this tendency was observed in the wheat types of triticale AD-7291 and Vihren, and in certain cases in cultivars Dobrudzhanets and Kolorit. In these cultivars a much earlier development was registered, heading and anthesis also occurred considerably earlier thus avoiding some unfavorable events, which considerably influenced the productivity of the rest of the cultivars. Simultaneously, the small differences in the ranking between the yield and the calculated model values can be related to the fact that none of the investigated contrasting periods of growing leads to a clear and distinct decrease or increase of the mean yield from a given genotype in comparison to the rest of the cultivars.

In contrast to the ranks of the mean values of yield and the mean model values, the ranking of yield and the model values over periods differed to a higher degree (Table 5). This allowed determining to what degree a given genotype is able of realizing its productivity potential under favorable environments as compared to other conditions. At the same time, the differences allowed determining those varieties, which, under unfavorable conditions, manage to maintain high yield values to a higher degree.

In growing year 2014/2015, a positive change in the ranking between yield and model values (toward higher values) was observed in cultivars Lasko, Presto, Respekt and Irnik, and a negative change (toward lower values) – in cultivars Rakita, Akord, Bumerang and Doni 52. Such a change is related to the fact that cultivars as Respekt and Irnik under favorable conditions of the environment manage to realize much of their productivity potential, while under unfavorable environments their yields sharply drop down. At the same time, cultivars such as Rakita and Doni 52, which are characterized as stable genotypes, under favorable conditions of the environment (as in 2014/2015) do not succeed in achieving a high productivity potential. In this respect, cultivars Irnik and Respekt exceed Rakita and Doni 52 in periods of suitable conditions of the environment.

During the next growing year (2015/2016), a positive difference between the ranking by yield and by model values was observed in the two cultivars of wheat type AD-7291 and Vihren, as well as in cultivar Kolorit, while a negative change was registered in Doni 52, Blagovest and Borislav. The cultivars of wheat type, under such conditions of the environment as were observed in 2015/2016, reacted much more adequately, which ranked them higher according to the ranking by yield. This is related to their earlier development, anthesis, formation and filling of grain. Therefore, the unfavorable effects of the later spring rainfalls influenced them to a lesser degree. Similar was the reaction of cultivar Kolorit due to its earlier development. In Doni 52, Blagovest and Borislav the change in the ranks according to the ranking of yield was related to the fact that during this period of growing these genotypes demonstrated an extremely strong response according to the rest of the periods. Simultaneously, in cultivar Borislav 1000 kernel weigh was the main component of yield, and since during this period the late spring rainfalls impeded the proper nutrition of grain, it can be assumed that the cultivar had a significant response according to the other periods of study.

Table 5. Ranks and difference between yield and EAYM

Cultivar	2014/2015			2015/2016			2016/2017			2017/2018			2018/2019			2019/2020		
	R-Y	R-M	R-C	R-Y	R-M	R-C	R-Y	R-M	R-C	R-Y	R-M	R-C	R-Y	R-M	R-C	R-Y	R-M	R-C
AD-7291	1	1	0	13	15	2	2	3	1	10	10	0	6	6	0	4	3	-1
Vihren	2	2	0	9	10	1	5	5	0	15	16	1	7	7	0	2	2	0
Rakita	7	6	-1	8	8	0	12	12	0	14	14	0	14	15	1	12	10	-2
Lasko	10	12	2	5	5	0	4	4	0	7	6	-1	10	10	0	7	7	0
Presto	12	13	1	4	4	0	8	7	-1	5	5	0	16	16	0	15	15	0
Kolorit	5	5	0	10	11	1	6	6	0	11	11	0	5	5	0	6	6	0
Atila	9	9	0	16	16	0	14	14	0	4	4	0	2	2	0	9	9	0
Akord	11	10	-1	12	12	0	9	8	-1	2	2	0	9	9	0	11	14	3
Respekt	6	7	1	1	1	0	7	9	2	1	1	0	1	1	0	3	4	1
Bumerang	13	11	-2	3	3	0	16	15	-1	15	15	0	14	14	0	16	16	0
Irnik	14	15	1	7	7	0	3	2	-1	8	8	0	4	4	0	8	8	0
Dobrudzhanets	3	3	0	6	6	0	15	16	1	12	12	0	11	11	0	1	1	0
Lovchanets	4	4	0	2	2	0	1	1	0	5	9	4	2	3	1	5	5	0
Doni 52	15	14	-1	15	14	-1	13	13	0	13	13	0	13	12	-1	14	12	-2
Blagovest	8	8	0	10	9	-1	11	11	0	9	7	-2	8	8	0	10	11	1
Borislav	16	16	0	14	13	-1	10	10	0	3	3	0	12	13	1	13	13	0

R-Y – Ranks of Yield; R-M – Ranks of EAYM values; R-C – Rank changes

In growing year 2016/2017, higher ranks of the model values according to the ranking of the yield were observed in cultivars AD-7291, Respect and Dobrudzhanets, and lower – in Presto, Akord, Bumerang and Irnik. Reciprocal ranking was determined in AD-7291, and in Irnik, Bumerang and Dobrudzhanets. Due to its early development, AD-7291 outranked Irnik, which could not manage to form a good seed set under the conditions of 2016/2017. Similar behavior was observed also between

Bumerang and Dobrudzhanets. At the same time, Respekt was with higher ranking than Presto and Akord, because the yield it realized significantly exceeded the yield according to other conditions of the environment.

Cultivar Lovchanets was with the highest positive difference between the ranks by yield and those of the model values in growing year 2017/2018. This indicated that under the specific growing conditions the cultivar responded considerably better in comparison to the other growing periods. A positive difference in the ranks was also observed in cultivar Vihren, which, according to the ranking of model values, was the genotype with the highest model yield. Simultaneously, cultivars Blagovest and Lasko responded negatively to the conditions of 2017/2018, having meanwhile rather low model values. In this growing period, the main characteristics of the model values became clearly evident. Cultivars Presto and Lovchanets had the same ranks for yield, but the ranking by model values allowed differentiating the two cultivars, Lovchanets having a significant advantage.

The higher contrast between the cultivars compared by the model values was observed in growing year 2018/2019, too. Cultivars Atila and Lovchanets, and Rakita and Boomerang received the same ranks for yield. The Ranking of their model values gave advantage to cultivars Rakita and Lovchanets. The two cultivars responded to the growing conditions considerably better than Atila and Bumerang, although the yield from Bumerang was rather high. A negative response according to the ranks was registered in Doni 52, and a positive one – in Borislav, observing reciprocal ranking in the two cultivars. This was due to the fact that due to the early spring drought Doni 52 could not realize its productivity potential in contrast to Borislav, which has a lower seed set but a considerably better nutrition of grain due to the later spring rainfalls.

In growing year 2019/2020 significant changes in the ranks of the studied genotypes were observed. Cultivars Rakita and Doni 52 were with negative differences between ranking by yield and by model values. The results from these two cultivars emphasize the thesis that cultivars characterized with higher stability of yield respond much more unfavorably under drought. At the same time cultivars like Akord, Respekt and Blagovest, which do not give considerably high yields under favorable conditions, reacted positively to the specific growing conditions. This was related to the fact that these cultivars had a later development in growing year 2019/2020. Therefore, the late rainfalls in May favored the better development and formation of yield. Hence, their yield was higher in comparison to other unfavorable conditions, which determined the difference in the ranks of yield and the model values.

Averaged for the investigated periods, the only difference observed between the ranks of the yield and the values of the developed model was the reciprocal ranking of Lasko and Kolorit. The model values of Kolorit determined its lower evaluation according to Lasko. This was related to the very high variation of Kolorit over periods of growing on the one hand, and on the other – to the higher productivity potential of Lasko under favorable conditions of the environment.

The differences observed both between the ranking of the yields and the model values during the separate periods of the investigation, and averaged for the entire set of environmental conditions show that the developed model allows determining the degree to which a given genotype interacts with the growing conditions. This makes it possible to use the EAYM parameter for determining of the adaptability of the studied genotypes.

At the same time, the difference between the values of the yield and the model values allows estimating the degree to which a given genotype responds to changes in the environmental conditions. According to the dynamic stability concept (Alberts, 2004; Becker and Leon, 1988), the higher the reaction of a given genotype to the conditions of the environment, the less stable it is. In this respect, the calculated difference allows to determine to what degree a given genotype is stable. An expression of the difference between the yield and the model value is presented in Formula 3:

$$S_{EAYM} = \overline{z}_i - \overline{x}_i \tag{3}$$

The presented values of S_{EAYM} of the investigated genotypes (Table 6) show that with lowest stability according to the applied model are characterized cultivars Presto, Respekt, Bumerang, Irnik and Dobrudzhanets. Respective high stability was determined in AD-7291, Rakita, Kolorit, Akord, Doni 52 and Blagovest. Such characterization of these cultivars has been made in other researches of ours during different periods of growing, applying varied approaches for investigation of stability (Stoyanov and Baychev, 2016a; Stoyanov and Baychev, 2016b; Stoyanov et al., 2017a; Stoyanov, 2018; Stoyanov et al., 2018; Stoyanov, 2020).

In spite of the similarities in the ranking of the investigated values by their stability, it is necessary to check to what degree the developed model is adequate and applicable in comparison to other models, which take into account the effect of the environment. Such are the models adopted by Yang and Holland (2010) Heritability Adjusted Relative Value and also Hi, developed by Martynov (1990). The values of the two parameters and the ranks according to these values for a 6-year period of investigation are given in Table 6.

Significant similarities are observed between the ranks of Hi and HARV and the developed model. Quite different, however, is the ranking by the stability parameter based on EAYM and the other two indices. EAYM is based on the dynamic stability concept that the genotype is more stable if it differs less from the mean value of a given set. On the other hand, S_{EAYM} is of hybrid nature; one of the components is dynamic but since it represents the difference between two values, it is characterized also as static. Simultaneously, this stability parameter takes the unit of the studied parameter, which allows determining the degree, to which the genotype x environment interaction influences the value of yield itself.

Table 6. Values and ranking by parameters Hi, HARV in comparison to the developed model

Cultivar	Hi	HARV	EAYM	S_{EAYM}	R-Hi	R-HARV	R-EAYM	R-S_{EAYM}
AD-7291	-4.08	82.29	570.26	1.26	3	3	3	16
Vihren	-2.02	84.03	589.12	3.28	4	4	4	10
Rakita	3.95	92.26	649.80	2.47	14	13	13	14
Lasko	-0.99	84.46	599.21	3.65	6	5	5	8
Presto	1.67	87.76	624.96	4.01	12	9	10	4
Kolorit	-1.27	85.39	597.78	2.09	5	7	6	15
Atila	1.66	91.45	637.41	3.94	11	12	12	6
Akord	0.63	88.57	621.09	2.67	9	10	9	12
Respekt	-7.61	73.91	533.74	8.82	1	1	1	1
Bumerang	5.89	93.06	666.01	5.54	16	14	15	2
Irnik	-0.89	85.70	604.25	3.97	7	8	8	5
Dobrudzhanets	-0.87	85.32	603.56	4.70	8	6	7	3
Lovchanets	-6.90	74.96	534.05	3.88	2	2	2	7
Doni 52	5.78	96.43	675.15	2.48	15	16	16	13
Blagovest	1.26	89.13	625.69	2.69	10	11	11	11
Borislav	3.80	93.96	658.29	3.29	13	15	14	9

Hi – Stability parameter according to Martynov (1990); HARV – Heritability Addjusted Relative Value according to Yan and Holland (2010); EAYM – Environment Adjusted Yield Model; S_{EAYM} – Stability parameter of EAYM; R-Hi – Ranks of Hi; R-HARV – Ranks of HARV; R-EAYM – Ranks of EAYM values; R-SEAYM – Ranks of S_{EAYM}.

These features determine the peculiar character of S_{EAYM}, and therefore its ranks will differ significantly from both the EAYM values and the values of HARV and Hi. The results from the correlation analysis (Table 7) carried out confirmed the similarity of EAYM to the other two models and demonstrated the differences to the developed stability parameter.

Table 7. Correlations between the values and the ranks of the developed model and the parameters Hi and HARV

Pearson	Hi	HARV	EAYM	S_{EAYM}
EAYM	0.995^{**}	0.991^{**}	1	-0.318
S_{EAYM}	-0.312	-0.418	-0.318	1
Spearman	**R-Hi**	**R-HARV**	**R-EAYM**	**R-S_{EAYM}**
R-EAYM	0.979^{**}	0.991^{**}	1.000	0.074
R-S_{EAYM}	0.003	0.153	0.074	1.000

Hi – Stability parameter according to Martynov (1990); HARV – Heritability Addjusted Relative Value according to Yan and Holland (2010); EAYM – Environment Adjusted Yield Model; S_{EAYM} – Stability parameter of EAYM; R-Hi – Ranks of Hi; R-HARV – Ranks of HARV; R-EAYM – Ranks of EAYM values; R-S_{EAYM} – Ranks of S_{EAYM}.

The results from the yield and the results from the applied model fully proved the model adequacy for increasing the precision level of the ranking and arrangement of a group of studied genotypes. At the same time, the model values allow for determining of the adaptability of a specific genotype under certain growing conditions by comparing their ranks to the values of yield. Furthermore, the developed model allows determining the stability of the investigated set of genotypes, which would contribute to their proper grouping. The use of the model can complement the evaluation of a certain set of genotypes by allowing their adequate ranking under contrasting environments. Its application to Bulgarian triticale varieties makes it possible to reliably evaluate and group them under the specific conditions, which is important for their distribution in production under the varied soil and climatic conditions in the country.

Conclusion

Based on the presented results, the following conclusions can be formulated:

The results on the model values showed that the cultivars are grouped in different ways during the separate investigated periods in comparison to their grouping by yield values. The differences in the ranks allow determining the degree to which a given genotype is adaptable to a certain environment. The observed ranks of the mean values for the entire investigated period and the ranks of the mean model values differed slightly, which indicates the strong genotype effect, the lack of great increases and decreases in the yield of a given genotype in comparison to the rest genotypes and the presence of a tendency in the yield change under contrasting environments. Cultivars with similar productivity, which have identical ranks, such as Presto and Lovchanets, Atila and Lovchanets and Rakita and Bumerang contrasted better with each other when applying this model, which allows ranking them more adequately by their reaction to the environment. The genotypes with high stability (Rakita and Doni 52) are characterized with lower ranks according to the results from the applied model, especially in periods with clearly expressed drought. A clear tendency the ranks of the model values to remain significantly high regardless of the conditions of the environment were observed in cultivars Bumerang and Doni 52. This emphasized their importance for distribution in production. he developed model is characterized with a high degree of similarity to known and adopted models such as HARV and Hi, showing that it can be reliably used in practical breeding work for adequate ranking of a studied set of cultivars under contrasting environments.

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APPENDIX 1

Table 8. Two-way ANOVA of the studied genotypes

Source	Sum of Squares	df	Mean Square	F	Sig.	SS%
Genotype (G)	722338.927	15	48155.928	12.526	0.000	13.61
Environment (E)	2456860.134	5	491372.027	127.812	0.000	46.28
G * E	1022659.610	75	13635.461	3.547	0.000	19.26
Error	1107209.963	288	3844.479			
Total	5309068.634	383				

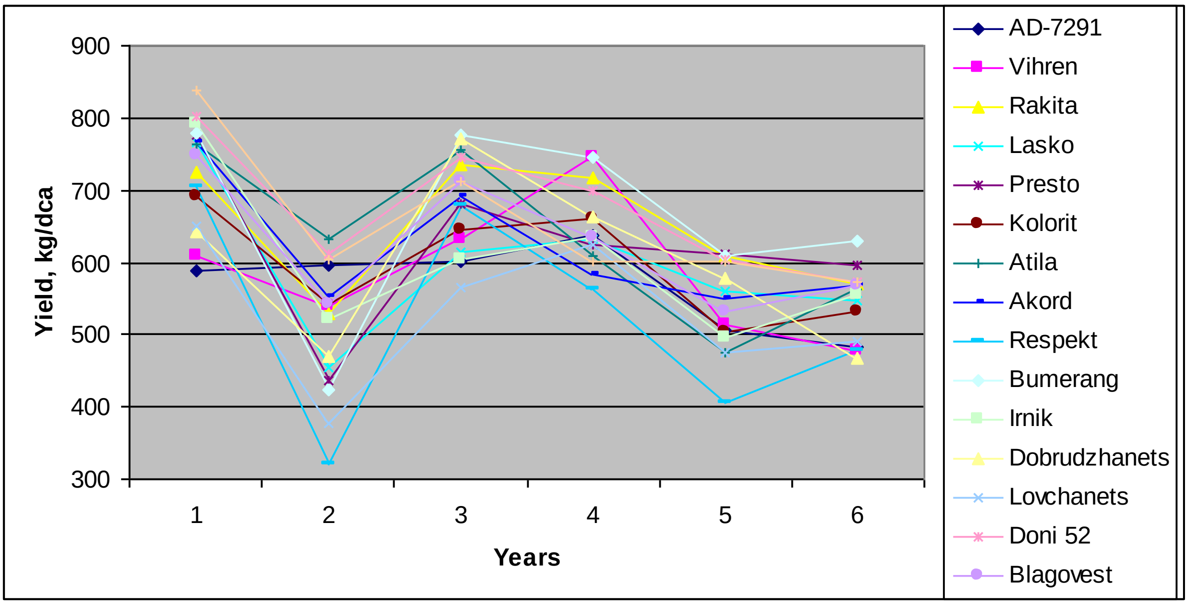

Figure 1. Yield dynamics in the investigated growing periods