https://doi.org/10.61308/GXPW7518

Productivity and stability of a collection of common winter wheat (*Triticum aestivum* L.) cultivars under contrasting growing conditions

Hristo Stoyanov
Dobrudzha Agricultural Institute – General Toshevo, Agricultural academy- Sofia, Bulgaria
E-mail: *hpstoyanov@abv.bg*

Citation: Styanov, H. (2025). Productivity and stability of a collection of common winter wheat (*Triticum aestivum* L.) cultivars under contrasting growing conditions. *Bulgarian Journal of Crop Science*, *62*(1) 37-50

Abstract: A collection of 52 common winter wheat cultivars were studied under three contrasting environments (2018/2019, 2019/2020 and 2020/2021) with the aim to determine some peculiarities in the productivity-adaptability-stability system. Adaptability and stability were evaluated using six parameters using different statistical approaches. A new approach for evaluation was developed based on the standard deviation of the yield results. An integrated approach was applied to consolidate the effects of the stability parameters in the form of an average rank. The obtained results showed that the three environments were drastically contrasting, which determined the high variability in the response of the respective genotypes. With the highest values of yield, averaged for the period, were cultivars Korona, Antonovka, Kalina, Merilin and Rada, and with the lowest – Anapurna, Ingenio, Avenue, Solveig and Mulan. The parameters used for assessment of stability and adaptability lead to different conclusions with regard to the stability of the investigated cultivars. Nevertheless, cultivars Bozhana and Exotic followed a tendency toward high stability regardless of the approach used. The combination of the data on productivity and stability showed that cultivars with productivity close to the mean could be considered more stable. Good and compromise combinations of productivity, adaptability and stability based on the mean ranks and the applied integrated multiple approach were demonstrated by cultivars Antonovka, Kalina, Kiara, Bolyarka and Kristy. In spite of fact that the combination of productivity and stability is one of the pending problem, cultivars such as Bolyarka and Exotic, which follow a tendency toward higher productivity and stability, could be successfully used for improvement of these characteristics in the contemporary breeding programs.

Key words: adaptability; biplot graph; common winter wheat; productivity; stability

INTRODUCTION

The climate changes and the resulting change in the meteorological conditions, particularly the effects of drought, are the main reason for the decreased yields from crop plants, especially for common wheat (Liu et al., 2020; Obembe et al., 2021; Zhang et al., 2022; Uhr et al., 2022). Therefore, it is necessary the developed varieties to possess high productivity, but also high yield stability together with wide adaptability allowing the genotype to respond favorably under contrasting conditions of growing. In common winter wheat, the breeding process is rather dynamic, determining the need of fast, precise and clear methods for selection of high-yielding, stable and adaptable genotypes or for their distribution. Therefore, a number of methods, models and approaches are used for evaluation of stability and adaptability, which are applied with different degree of efficiency to the breeding and post registration processes of the varieties.

There are numerous researches providing information on stability and combinations of productivity, stability and adaptability (for example: Ayalneh et al., 2014; Bornhofen et al., 2017; Alemu et al., 2021; Dias et al., 2022; Bai et al., 2023, etc.). In the recent years, in the world database and in the scientific literature as a whole, these researches are focused on study of regionally distributed common winter wheat varieties (for example Hagos and Abay, 2013; Mladenov et al., 2012; Heidari et al., 2016; Alam et al., 2017; Najafi Mirak et al., 2020; Omrani et al., 2022), large collections of varied genotypes being studied comparatively rarely (for example Tekdal and Kendal, 2018; Khan et al., 2020). On the other hand, the researchers, the users of information and the producers frequently rely primarily on the productivity results and the related parameters. Many researches in this direction, which, although asking the correct questions on the formation of productivity in certain genotypes, do not allow determining how the contrasting environments affect a given genotype. Such assumptions occur against the fact that the genotypes are grown and the tendencies among them are formed under different conditions, but these genotypes are characterized based on their mean values. On the one hand, this does not allow for their proper diversification, and on the other – distorts their ranking and causes imprecisions when determining their breeding value.

In contrast to other crop plants, common winter wheat comprises a huge amount of differing genotypes, which cannot be encompassed in a single study and there is no respective data on their behavior under contrasting growing conditions. This imposes the necessity to differentiate them according to such criteria as geographic origin or breeding center, and compare them to established local genotypes. Data from such studies are reported by Mihova (2020), but again the results on the productivity are based on a generalizing but not analytical principle. In the cited research, the general tendencies of the genotypes are highlighted according to their geographic origin, which is a basis for their further investigation on their stability and adaptability. Desheva and Deshev (2021a), although investigating a rich and varied collection of genotypes, also characterize the genotypes according to their mean values, without giving data on stability. Another study of Desheva and Deshev (2021b) focuses on the stability and adaptability of a large collection of varieties and lines, but the collection is comprised of landraces and advanced lines only. A serious contribution in this respect are the studies of Tsenov et al. (2020), which, although providing a thorough analytical and integrated approach on the behavior of large sets of common winter wheat genotypes, are again focused on landraces without sufficient degree of diversification concerning the formation of productivity. Uhr et al. (2021) also provided information on the stability of the genotypes they studied, but they clearly pointed out that their research involved the most promising lines and candidate-varieties.

The tendency shows that in practice, there are no thorough studies in Bulgaria on the complexities of stability and adaptability of collections of varied genotypes according to different criteria. This imposes the necessity of purposeful experimentation or analytical study on the data from such experiments encompassing a multitude of genotypes under contrasting growing conditions.

The aim of this research was to determine the productivity and stability of a collection of common winter wheat genotypes under contrasting environments and to select genotypes combining sustainably high productivity, stability and adaptability.

MATERIAL AND METHODS

Plant material and method of growing

To realize the above goal, 52 Bulgarian and foreign common winter wheat cultivars (as indicated in Table 1) were used, 42 Bulgarian and 10 foreign. The cultivars were grown as a whole area crop, in experimental plots of 10 m^2, in three replications, according to a standard block design. Sowing was mechanized within the standard dates for common winter wheat, at density 550 seeds/m^2. Harvesting was also mechanized, done at full maturity, and the yield was registered by replication, cultivar and year of growing.

Growing conditions

The experiment was carried out for three consecutive harvest years - 2018/2019, 2019/2020 and

2020/2021.The data on the average monthly air temperatures and the total monthly precipitation (Table 2) reveal the significant and highly contrasting conditions of the environments during the three growing periods. The highest differences according to the long-term tendency with regard to temperature were observed during November – March, and with regard to precipitation – during January, April and June. The differences during these periods give us sufficient evidence to consider that the vegetative growth occurred differently over years. Clearly outlined were certain phenomena and processes in meteorological aspects; they were of single occurrence and were not repeated over periods; they were also able to strongly influence the physiological processes in the plant organisms.

Worth mentioning is 2020/2021 growing period, when highly intensive and long rainfalls in January, considerably long-lasting warm weather in January and February and rather untypical low temperatures and snowfalls during the first two decades of March were observed. 2019/2020 growing period was highly unfavorable for growing of common winter wheat due to the long drought during March-April. 2018/2018 was also characterized by an unfavorable period of drought, which, however, was not as long, and the drought was not as intensive as in the following harvest year.

Processing of data and statistical analysis

The yield values were averaged over cultivars and investigated periods. To assess the stability and adaptability of the cultivars, the models and methods adopted in general practice were applied – the regression model of Eberhart and Russell (1966), Shukla's variance (1972), ecovalence according to Wricke (1962), AMMI analysis according to the methodology described by Gauch

Table 1. Common winter wheat cultivars used in this study

Origin of the genotype	Cultivar
Bulgaria – Dobrudzha Agricultural Institute – General Toshevo (33)	Aglika, Albena, Antonovka, Bolyarka, Demetra, Dragana, Enola, Iveta, Karina, Kristi, Lazarka, Merilin, Milena, Neda, Pryaspa, Slaveya, Kristal, Korona, Goritsa, Stoyna, Bozhana, Kiara, Kalina, Pchelina, Rada, Tina, Kosara, Pliska, Katarzhina, Sladuna, Svilena, Zhana, Fani
Bulgaria – Institute of Plant and Genetic Resources – Sadovo (9)	Gines, Gea, Diamant, Momchil, Petya, Pobeda, Sadovo 1, Tsarevets, Yunak
Foreign (10)	Sobel, Sofru, Solveig, Avenue, Anapurna, Andalu, Exotic, Mulan, Midas, Ingenio

Table 2. Meteorological conditions (Average monthly temperature (AMT) and Total monthly precipitation (TMP)) during the investigated period

Parameter	Year	Aug	Sep	Oct	Noe	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
AMT, °C	2018/2019	23,60	17,70	13,30	5,40	1,20	1,00	3,50	8,20	9,00	16,00	22,30	22,00
	2019/2020	22,80	17,90	13,40	11,70	5,20	1,80	5,10	8,00	10,00	15,40	19,60	22,30
	2020/2021	22,60	19,40	15,30	6,30	5,30	3,00	4,00	4,20	8,80	15,80	18,90	22,80
	1960/2021	21,13	16,92	11,74	6,76	2,02	-0,16	1,24	4,70	9,85	15,25	21,94	21,42
TMP, mm	2018/2019	1,10	54,70	11,70	66,20	43,80	19,20	16,30	16,10	49,40	31,70	37,50	54,00
	2019/2020	7,80	36,70	27,60	35,40	21,80	2,80	28,10	28,30	5,80	48,00	51,30	2,70
	2020/2021	3,50	34,10	52,90	26,00	74,40	109,70	13,20	22,20	44,60	63,60	162,70	29,70
	1960/2021	36,95	46,06	42,26	43,12	42,20	37,55	33,74	35,25	39,97	52,19	62,60	50,99

(1992), and the stability parameter S_{EAYM} of the model developed for ranking of yield EAYM (according to Stoyanov (2021)). The ratio between the absolute mean deviation of each genotype to its standard (mean square) deviation was used as an additional criterion for assessment of the stability of the genotypes. Since according to Geary (1935) this ratio equals $\sqrt{2/\pi}$ under normal distribution, then the deviation from this value would allow determining to what degree the yield can be characterized by a certain predictability. The lower/higher the values of this ratio are according to the given value, the less predictable the yield is, and the genotype is respectively less stable according to the stability definition of Mariotti et al. (1976). The ratio can be mathematically expressed by Formula 1.

$$w_{Yi} = \frac{\frac{1}{E}\sum_{j=1}^{E}\left|\bar{x}_{ij} - \bar{x}_{i.}\right|}{\sqrt{\frac{1}{E-1}\sum_{j=1}^{E}\left(\bar{x}_{ij} - \bar{x}_{i.}\right)^2}} \quad (1)$$

An integrated approach was applied with the aim to determine the stability of the genotypes and their ranking, using the method of the mean ranking value for a set of parameters described by Stoyanov et al. (2017). In this method, based on all stability and adaptability parameters, the set of genotypes was ranked from 1 to n, rank 1 being given to the most stable genotype, and rank n – to the least stable one, according to the specificity of each parameter. The average ranking value was the mean value of all rankings for each applied parameter of stability and adaptability. Subsequently, the mean rank was also ranked, most stable being the genotype with rank 1, and most unstable – the one with rank n. In order to determine the best combinations between productivity and stability, the data on the mean ranking value were presented on a biplot graph together with the data on productivity.

To summarize the data, MS Office Excel, 2003 was used, for the analyses according to Eberhart and Russell, Shukla and Wricke – software StabilitySoft (Pour-Aboughadareh et al., 2019), for AMMI analysis – AMMISOFT v.1.0, and for correlation analysis IBM SPSS Statistics, v.19 was applied.

RESULTS

Productivity of the investigated genotypes

The results obtained on the studied genotypes (Table 3) revealed the wide variability of responses to the conditions of the environment. Evident were certain tendencies between the contrasting growing periods with regard to yield, which were related to the direct effect of the soil and climatic conditions during the vegetative growth of the plants. Lowest mean yield was registered in 2019/2020 (508.8 kg/da) as a result from the severe soil and air drought during March – May of 2020. During this period, the plants suffered from extreme water deficiency not allowing their proper development and formation of high yields. The drought in the spring of 2019 harvest year also had a certain effect but due to its lower intensity, especially with regard to soil moisture, the productivity results were on the average higher according to year 2020. The highest results were obtained in harvest year 2021 because the meteorological conditions allowed for the normal growth and development of the plants. The time from heading to maturity was characterized by very good water reserves in soil and the greater part of the genotypes performs productivity exceeding 700 kg/da. Regardless of the results thus formed, certain genotypes did not follow the tendency of the mean values, which was related to the effect of the genotype x environment interaction and the different stability and adaptability of the individual varieties. Therefore, it was necessary to consider in detail the results over cultivars in order to determine if the high or low productivity in some of them was a tendency or resulted from specific conditions of the environment.

In 2018/2019 growing period, the highest productivity was performed by cultivars Korona, Antonovka, Merilin, Kiara and Fani, and the lowest – by Anapurna, Ingenio, Avenue, Solveig and Mulan. Among the investigated genotypes, 23 had significantly higher productivity than the mean value of the studied set of cultivars, while only 14 were with significantly lower values. A peculiarity of this period was that cultivars Avenue and Anapurna were characterized by very low productivity regardless of them being also a standard at the national Executive Agency for Variety Testing, Field Inspection and Seed Control. In practice, only cultivar Solveig was with higher productivity.

The highest values of yield in 2019/2020 growing period were those of cultivars Kalina, Fani, Bolyarka, Kristi, Exotic and Andalu, and the lowest - of Bozhana, Anapurna, Ingenio, Solveig and Mulan, respectively. In comparison to the mean value of the investigated set of cultivars, with significantly higher values were Korona, Antonovka, Kalina, Merilin, Fani, Bolyarka, Kristi, Momchil, Pryaspa, Kosara, Iveta, Diamant, Svilena, Neda, Yunak, Exotic, Zhana, Slaveya, Sobel, Andalu, Tsarevets. Similar to the previous period, in this growing period too, the standards Avenue and Anapurna were with very low productivity showing that the conditions of drought affected negatively their productivity.

In 2020/2021 growing period, the greater part of the studied genotypes perform productivity higher than the values of the previous two periods. The highest yields were those of cultivars

Table 3. Productivity of common winter wheat genotypes over economic years and averaged for the period of study

No	Genotype	2018/ 2019	2019/ 2020	2020/ 2021	Average	No	Genotype	2018/ 2019	2019/ 2020	2020/ 2021	Average
1	Korona	869,0	572,8	919,0	786,9	29	Sadovo 1	610,5	499,5	813,5	641,2
2	Antonovka	813,2	565,2	837,0	738,4	30	Lazarka	640,0	462,7	820,3	641,0
3	Kalina	754,7	616,7	829,3	733,6	31	Albena	599,2	478,7	838,2	638,7
4	Merilin	806,8	576,3	788,2	723,8	32	Petya	593,3	496,5	822,8	637,6
5	Rada	780,5	486,7	864,0	710,4	33	Zhana	635,0	525,8	723,0	627,9
6	Kiara	804,8	514,0	801,7	706,8	34	Kristal	696,3	466,8	714,0	625,7
7	Fani	822,3	599,3	688,9	703,5	35	Pobeda	652,0	435,8	780,5	622,8
8	Bolyrka	693,0	625,8	772,3	697,1	36	Slaveya	655,8	541,3	658,8	618,7
9	Kristi	710,0	598,5	759,8	689,4	37	Enola	697,0	464,8	693,7	618,5
10	Momchil	638,7	532,3	886,3	685,8	38	Tina	579,5	489,7	773,5	614,2
11	Pryaspa	659,0	541,2	855,2	685,1	39	Sobel	482,3	534,7	820,2	612,4
12	Katarzhina	741,2	523,7	785,2	683,3	40	Karina	615,7	508,8	705,3	609,9
13	Kosara	697,0	537,7	802,9	679,2	41	Pliska	640,8	485,2	685,3	603,8
14	Iveta	718,8	555,7	758,2	677,6	42	Geya	586,5	489,3	726,5	600,8
15	Dragana	708,3	503,8	806,3	672,8	43	Aglika	607,8	496,3	696,3	600,2
16	Diamant	657,2	540,2	812,7	670,0	44	Sofru	535,5	523,0	721,2	593,2
17	Svilena	679,2	536,2	788,3	667,9	45	Andalu	420,0	594,5	763,3	592,6
18	Goritsa	718,3	444,2	824,0	662,2	46	Midas	578,3	453,7	703,5	578,5
19	Demetra	635,3	524,2	825,8	661,8	47	Tsarevets	468,8	536,2	624,5	543,2
20	Milena	710,0	474,2	791,8	658,7	48	Anapurna	309,5	421,7	803,3	511,5
21	Gines	686,3	504,8	780,2	657,1	49	Ingenio	361,5	310,5	843,8	505,3
22	Neda	676,0	557,7	737,3	657,0	50	Avenue	319,7	470,2	707,2	499,0
23	Bozhana	757,2	409,7	794,0	653,6	51	Solveig	317,7	400,7	658,8	459,1
24	Stoyana	719,3	520,7	712,2	650,7	52	Mulan	350,8	394,2	576,8	440,6
25	Iunak	552,8	549,8	840,2	647,6		**Average**	**633,7**	**508,8**	**768,9**	**637,1**
26	Exotic	611,8	620,2	706,3	646,1		*LSD0,05*	*36,12*	*16,86*	*18,86*	*18,36*
27	Sladuna	647,2	454,7	832,3	644,7		*LSD0,01*	*47,48*	*22,16*	*24,79*	*24,13*
28	Pchelina	730,8	489,2	710,7	643,6		*LSD0,001*	*60,65*	*28,31*	*31,67*	*30,83*

Korona, Rada, Momchil, Pryaspa, Yunak and Albena, while Slaveya, Pliska, Tsarevets, Solveg and Mulan were with the respective lowest yields. Out of the 52 investigated genotypes, 23 were with a mean value significantly above the mean of the studied set of cultivars, while 19 genotypes were significantly below this value. The standard Avenue was at the level of the standard Enola. Standard Anapurna was at the level of Sadovo 1.

Averaged for the studied period, cultivars Korona, Antonovka, Kalina, Merilin, Rada and Kiara were with the highest productivity. With respective lowest productivity were Tsarevets, Anapurna, Ingenio, Avenue, Solveig and Mulan. Twenty-two of the studied cultivars had productivity significantly higher than the mean value of the investigated set of cultivars, while 17 had significantly lower values of yield. Most of the investigated cultivars were practically above the standards Avenue and Anapurna. Significantly lower values were registered in Solveig and Mulan.

A close analysis of the above results reveals several main tendencies under the influence of the varied genotypes and conditions of the environment. Actually, the greater part of the genotypes (38) followed the tendency of the mean values of the investigated set of cultivars – the highest productivity was registered in 2019/2020, followed by 2018/2019, reading the highest yields during the favorable season 2020/2021. Such a tendency was missing in 14 cultivars, the deviation being present in two different ways. The highest productivity of cultivars Merilin, Kiara, Fani, Stoyana, Pchelina and Enola was in 2018/2019. The lowest productivity of the same year was performed by cultivars Exotic, Sobel, Andalu, Tsarevets, Anapurna, Avenue, Solveig and Mulan. Such a tendency allowed for the assumption that the origin of the genotype was in this study a prerequisite for a differentiation model in the formation of productivity under different environments.

Yield stability and stability ranking

Regardless of the direct effect of the environmental conditions on the productivity and the grouping of genotypes, the tendencies formed in the individual cultivars allowed analyzing their stability, i.e. to what degree their response was predictable under the specific conditions of the environment. The results obtained from the used parameters of stability and adaptability gave varied information on the behavior of the common winter wheat genotypes we investigated; nevertheless, certain tendencies were noticeable.

The two parameters calculated according to Eberhart and Russell (1976) revealed rather significant differences among the genotypes involved in this study. Regardless of their geographic origin, cultivars Antonovka, Kiara, Katarzhina, Kosara, Diamant, Svilena, Guiness, Kristal, Tina, Gea, Midas, Avenue and Solveig were characterized by wide/close to wide adaptability expressed through parameter b_i. With narrow adaptability to favorable environments were cultivars Korona, Rada, Momchil, Pryaspa, Dragana, Goritsa, Demetra, Milena, Bozhana, Yunak, Sladuna, Sadovo 1, Lazarka, Albena, Petya, Pobeda, Sobel, Anapurna and Ingenio. All other studied genotypes were characterized by narrow adaptability, but to unfavorable conditions of the environment. Worth mentioning among them are cultivars Fani and Exotic. Such a reaction, in combination with their high productivity, implied that these cultivars responded better to unfavorable environments in comparison to the rest of the varieties.

Concerning the stability parameter s^2d_i, which was calculated according to the same model, (Table 4), a significant variability in the values was observed, showing also the varied response of the genotypes to the contrasting conditions of growing. The highest stability was registered in cultivars Kalina, Bolyarka, Kosara, Diamant, Svilena, Neda, Sladuna, Lazarka, Zhana, Karina, Gea, Aglika and Midas.

Similar tendency was observed also in the values of the parameters of the stability variance according to Shukla (1972) and of the ecovalence according to Wricke (1962) (Table 5). The two parameters provide unidirectional information on the stability regardless of the different mathematical approaches applied for their calculation. With highest stability according to both parameters were characterized cultivars Kalina, Kosara, Diamant, Svilena, Demetra, Guiness, Zhana, Tina, Karina, Gea, Aglika and Midas.

The values of IPCA1 from the AMMI analysis carried out (Table 5) also showed varied behavior of each genotype to the contrasting environments. This study assumed that the genotypes with IPCA1 values between 0 and 2 (-2) interacted weakly to moderately with the conditions of the environment, while the genotypes with values above 2 (-2) had significantly stronger interaction. Weak to moderate reaction was registered in cultivars Kalina, Bolyarka, Kristi, Pryaspa, Kossara, Dragana, Diamant, Svilena, Demetra, Guiness, Neda, Exotic, Sladuna, Sadovo 1, Lazarka, Zhana, Pobeda, Tina, Karina, Gea, Aglika and Midas. Among these cultivars, the weakest interaction with the conditions of the environment was that of Bolyarka, Exotic, Sladuna, Lazarka, Karina, Aglika and Midas. Rather impressive were cultivars Kiara, Fani, Bozhana, Yunak, Pchelina, Sobel, Andalu, Anapurna, Ingenio, Avenue and Solveig; their interaction with the environment was quite high and they reacted strongly to the contrasting changes of the meteorological conditions.

Table 4. Stability and adaptability parameters of the studied cultivars according to Eberhart and Russell, Shukla and Wricke

Genotype	b_i	s^2d_i	σ^2_i	W_i^2	Genotype	b_i	s^2d_i	σ^2_i	W_i^2
Korona	1,32	1607,68	7500,85	14667,67	Sladuna	1,45	11,90	3486,82	6948,39
Antonovka	1,03	1313,87	4675,10	9233,54	Pchelina	0,84	1740,95	6674,64	13078,82
Kalina	0,81	122,76	932,63	2036,48	Sadovo 1	1,21	150,62	1205,70	2561,61
Merilin	0,80	1577,86	6311,29	12380,05	Lazarka	1,37	2,97	2346,89	4756,22
Rada	1,44	1207,42	7659,29	14972,37	Albena	1,39	258,65	3453,92	6885,12
Kiara	1,09	2218,09	8091,30	15803,15	Petya	1,26	341,36	2309,26	4683,84
Fani	0,33	3083,25	19091,79	36957,95	Zhana	0,76	20,03	990,32	2147,43
Bolyrka	0,56	0,94	3232,75	6459,79	Kristal	0,94	1168,55	4192,82	8306,09
Kristi	0,62	110,34	2864,10	5750,84	Pobeda	1,32	244,49	2564,41	5174,52
Momchil	1,37	384,86	3648,02	7258,39	Slaveya	0,45	321,08	6451,04	12648,81
Pryaspa	1,21	103,52	1029,15	2222,11	Enola	0,87	1423,42	5364,32	10558,98
Katarzhina	1,00	804,47	2802,24	5631,89	Tina	1,10	205,62	782,96	1748,67
Kosara	1,02	97,20	232,04	689,19	Sobel	1,12	3417,99	12554,65	24386,52
Iveta	0,77	412,91	2294,47	4655,41	Karina	0,75	14,98	993,38	2153,32
Dragana	1,16	334,09	1522,28	3170,44	Pliska	0,76	337,16	2089,01	4260,29
Diamant	1,05	18,26	-17,87	208,59	Geya	0,91	26,55	102,20	439,51
Svilena	0,97	45,84	59,94	358,23	Aglika	0,77	22,76	910,80	1994,51
Goritsa	1,45	800,87	6363,14	12479,77	Sofru	0,77	650,59	3171,35	6341,71
Demetra	1,16	108,26	733,86	1654,23	Andalu	0,67	6216,61	24364,46	47097,70
Milena	1,21	660,39	3071,30	6149,31	Midas	0,96	2,06	-90,27	69,37
Gines	1,05	230,95	764,86	1713,85	Tsarevets	0,35	1147,60	11477,19	22314,49
Neda	0,69	97,83	1953,67	4000,02	Anapurna	1,50	8308,43	34461,49	66515,06
Bozhana	1,46	2527,96	12811,23	24879,95	Ingenio	2,07	4003,53	34631,32	66841,65
Stoyana	0,73	1082,58	5143,21	10133,76	Avenue	0,94	6649,53	24146,07	46677,71
Iunak	1,13	1772,17	6622,30	12978,16	Solveig	1,01	4076,20	14714,04	28539,20
Exotic	0,34	235,54	8493,80	16577,20	Mulan	0,72	1635,57	7255,43	14195,72

The EYAM model allows determining the degree of stability of the genotype under the effect of the changeable environments based on the difference between the values of yield and EAYM. In this respect, according to parameter S_{EAYM} higher stability was found in genotypes Kalina, Bolyarka, Kristi, Iveta, Neda, Stoyana, Exotic, Zhana, Slaveya, Karina, Pliska, Aglika and Tsarevets. On the other hand, lower stability was registered in Rada, Momchil, Goritsa, Bozhana, Sladuna, Lazarka, Albena, Pobeda, Anapurna, Ingenio, Avenue and Solveig.

The use of parameter w_{Yi} allowed evaluating the stability according to a mathematical approach, which differed considerably from the other approaches applied in conventional analyses. In this respect, the values, which were closer to the ideal parameters of normal distribution were determined in genotypes Korona, Antonovka, Merilin, Kiara, Katarzhina Bozhana, Stoyana, Yunak, Exotic, Pchelina, Kristal, Slaveya, Enola, Sofru and Ingenio. The presented results differed drastically from the values of the rest of the parameters, indicating that the differential approach of determining stability was crucial for the final choice of stable genotypes.

The calculated average rank estimate (ARE) and its ranking (Table 5) clearly demonstrated

Table 5. Model parameters of stability and adaptability of the common winter wheat genotypes included in this study

Genotype	IPCA1	S_{EAYM}	w_{Yi}	ARE	Genotype	IPCA1	S_{EAYM}	w_{Yi}	ARE
Korona	3,67	21,12	0,76290	44	Sladuna	-0,18	28,18	0,67094	13
Antonovka	3,61	14,61	0,76738	22	Pchelina	4,39	13,29	0,76762	34
Kalina	1,33	7,81	0,72225	14	Sadovo 1	-1,48	20,78	0,72153	32
Merilin	4,23	10,84	0,76775	33	Lazarka	-0,26	25,47	0,66852	15
Rada	2,99	26,35	0,75253	46	Albena	-2,07	27,96	0,72687	40
Kiara	4,64	18,63	0,76977	27	Petya	-2,16	23,52	0,73698	37
Fani	6,38	9,15	0,70590	49	Zhana	0,73	7,75	0,68920	9
Bolyrka	0,41	3,89	0,68434	3	Kristal	3,52	14,41	0,76822	25
Kristi	1,50	4,86	0,73395	19	Pobeda	1,20	23,98	0,71552	36
Momchil	-2,41	25,68	0,73609	42	Slaveya	2,45	3,52	0,76960	12
Pryaspa	-1,27	19,13	0,71473	28	Enola	3,96	13,58	0,76974	24
Katarzhina	2,86	13,73	0,76024	10	Tina	-1,56	18,07	0,73197	20
Kosara	0,97	13,00	0,70664	6	Sobel	-6,02	29,79	0,76179	41
Iveta	2,32	8,23	0,75678	26	Karina	0,67	7,93	0,68521	8
Dragana	1,66	17,26	0,72998	31	Pliska	2,13	8,84	0,75237	29
Diamant	-0,49	14,29	0,69575	2	Geya	-0,42	12,16	0,70299	5
Svilena	0,72	11,93	0,69440	4	Aglika	0,75	8,35	0,69070	11
Goritsa	2,33	27,91	0,74132	45	Sofru	-2,30	11,03	0,76858	23
Demetra	-1,24	18,34	0,71689	18	Andalu	-7,57	25,34	0,67032	52
Milena	2,34	19,86	0,74574	38	Midas	0,19	13,65	0,66711	1
Gines	1,47	14,59	0,72527	16	Tsarevets	-2,65	5,69	0,69454	39
Neda	1,36	6,25	0,72510	17	Anapurna	-9,76	78,52	0,75152	51
Bozhana	4,53	32,08	0,76689	48	Ingenio	-7,62	109,97	0,76691	50
Stoyana	3,64	9,34	0,76941	30	Avenue	-8,14	41,49	0,71040	47
Iunak	-4,39	23,48	0,76977	21	Solveig	-6,45	38,96	0,74857	35
Exotic	-0,77	2,17	0,76736	7	Mulan	-3,74	17,77	0,75714	43

those genotypes, which, under the conditions of the environment considered in this study, were characterized by a certain stability. This integrated approach was based on multiple parameters, which differed by their mathematical nature and allowed the accumulation of effects, which would not have yielded adequate information if used independently.

From this point of view, most stable were cultivars Midas, Diamant, Bolyarka, Svilena, Geya and Kossara. Most unstable were Avenue, Bozhana, Fani, Ingenio, Anapurna and Andalu, respectively. Among the investigated genotypes, Enola ranked 24th, while Sadovo 1 was characterized as more unstable under the conditions of the experiment and was ranked 32nd. The results obtained on this parameter clearly showed that the genotypes ranked rather differently by stability and by productivity, without any particular tendency being observed; this gave sufficient ground to search for genotypes, which successfully combined both yield stability and productivity.

Combining productivity and stability in the studied genotypes

An efficient tool for determining combinations between high productivity and high stability is their graphic presentation on a biplot. The use of such a tool, however, is possible only if the data on the two combined parameters are in a weak correlation or if there is no correlation between them at all.

The combinations of productivity, stability and adaptability obtained from the analyses applied to the investigated cultivars gave, on the one hand, independent, but on the other hand rather contradictory information about which of them were the most adequate to the growing conditions considered in the analysis. The applied integrated multiple approach based on the mean rank allows accumulating in a single parameter the effects of all methods, models and approaches used in this analysis. The results, presented in Figure 1, indicate that 20 out of the 52 varied investigated genotypes combine productivity and stability higher

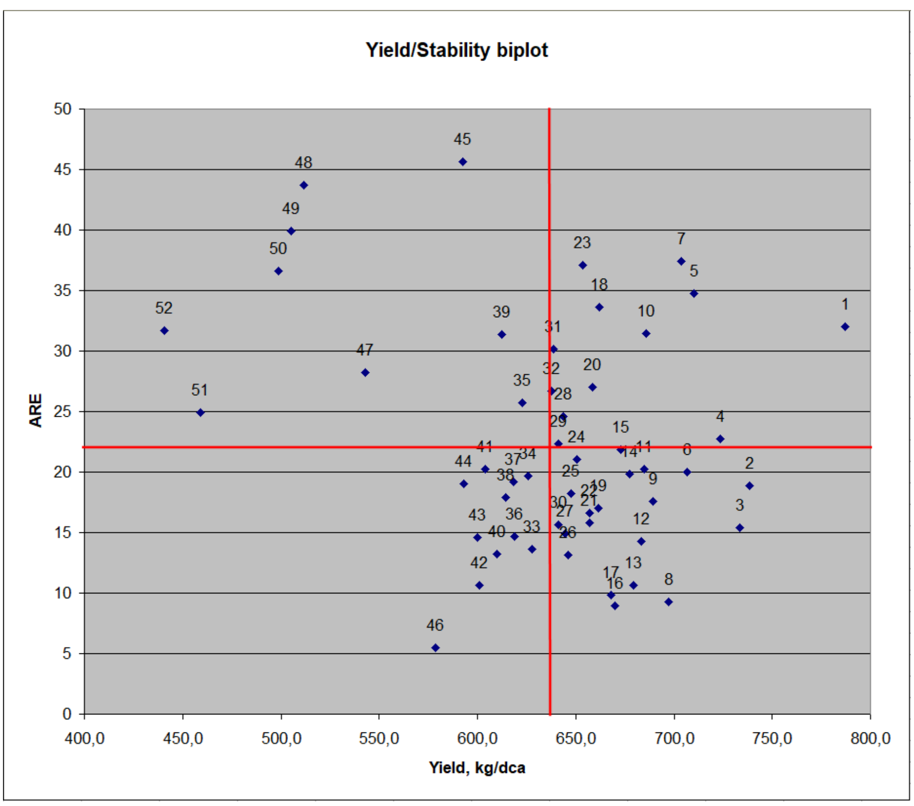

Figure 1. Biplot combining the mean rank value of stability and yield

than the average of the studied set of cultivars. These are cultivars Antonovka, Kalina, Kiara, Bolyarka, Kristi, Pryaspa, Katarzhina, Kosara, Iveta, Dragana, Diamant, Svilena, Demetra, Guiness, Neda, Stoyana, Yunak, Exotic, Sladuna and Lazarka.

The two cultivars standing apart from the rest and characterized simultaneously by high productivity and high stability were Kalina and Bolyarka. Figure 9 allows determining those genotypes, which, in spite of their higher than the average values, can be define as compromise. These are Antinovka, Kiara, Kristi, Katarzhina, Kosara, Diamant and Svilena.

DISCUSSION

Productivity

The results we obtained under the contrasting conditions of this experiment decisively confirmed that the studied cultivars did not follow identical tendencies, but were characterized by strict manifestations under changing conditions of the environment. Nevertheless, the yield values registered entirely coincided with the production potential of each cultivar, although their ranking differed from the ranking in previous studies involving similar sets of cultivars. The tendencies determined by Chamurliyski and Tsenov (2013), Tsenov and Atanasova (2015) and Mihova and Dimitrova-Doneva (2020) coincided to some extent with our ranking of the cultivars by productivity, although differences were observed related to both the growing periods and the location of the respective experiment.

Concerning the separate groups of cultivars, according to their preliminary affiliation (Bulgarian or foreign), considerable differences were observed under the investigated conditions of the environment. The Bulgarian cultivars, regardless of the breeding center, demonstrated significantly higher productivity, especially under distinct drought. The common wheat of foreign breeding was characterized by low productivity under the investigated conditions revealing low tolerance under stress, with the exception of cultivar Exotic. Under favorable conditions, however, these cultivars performed considerably high yield values. This has been also emphasized in the research of Mihova (2020), where the highest yields were from genotypes with origin from France. Nevertheless, the cultivars of foreign breeding varied within a rather wide range of productivity, according to this author, the highest mean yield within four years being realized by the Bulgarian cultivars in the study quoted above. Tsenov et al. (2021), investigating 40 genotypes during harvest years 2017 and 2018, indicated mean productivity of cultivar Anapurna 773 kg/da, and Avenue 814 kg/dca. Desheva and Deshev (2021) reported productivity of Andalu similar to what we observed during 2018 – 2020. According to Vasilev et al. (2021), at location Madara, Shumen region, during 2019/2020 growing period, the yields obtained from cultivars Avenue and Anapurna (the study was without replications and productivity was registered as a single value) were above750 kg/da; however, the rainfalls during April-May (92.3 mm) considerably exceeded the precipitation in our investigation (53.8 mm).

The results we obtained and the researches discussed above emphasize the fact that the cultivars developed outside Bulgaria are characterized by higher requirements to the studied environment. These genotypes do not tolerate well high levels of stress and in practice performed rather varied productivity under highly contrasting conditions of the environment.

Stability

According to Khan et al. (2023a), stability and plasticity are largely dependent on the level and duration of stress. In this respect, the use only of the yield values does not give correct information, and the studied genotypes under contrasting environments cannot be properly ranked (Stoyanov, 2021). According to Tsenov and Gubatov (2018), the high stability of yield (or other parameters) is often related to lower productivity.

Nevertheless, according to these authors, there is a sufficient number of methods and tools to identify the genotypes, which combine compromise values of productivity and stability. The results we obtained from the different parameters, methods and models did not give identical information. According to Tsenov et al. (2022), this relates to the use of a certain statistical approach, in which each of the obtained parameters is characterized as a certain combination of yield and stability. The investigations of Tsenov and Gubatov (2018), Desheva & Deshev (2021) and Chamurliyski et al. (2015) show that the results on the stability we obtained coincided partially but were too dependent on the conditions of growing.

Combining productivity and stability

In world literature there are limited number of studies combining the parameters of adaptability and stability used in our study with the yield values on biplot graphs. However, some sources (Tsenov and Gubatov, 2018; Tsenov et al., 2017) provide partial idea about the degree to which the two values combine in a genotype.

Similar to the cited researches, in our data, too, the combining of yield with the stability parameters gives different results leading to different compromise combinations. According to Tsenov and Gubatov (2018), this is related to the differentiated significance of yield in each stability parameter. Regardless of this, our results show that there are genotypes, in which similar tendencies are observed in spite of the different approaches. Such genotypes were cultivars Antonovka, Kalina, Bolyarka, Kristi, Iveta and Dragana, which combined high productivity, as well. On the other hand, the results from our investigation showed that high-yielding genotypes as Korona, Merilin, Rada and Fani were characterized as cultivars with lowered stability. This implied that the stability and the parameters used for its evaluation should be considered a subjective but not objective criterion.

According to Eberhart & Russell (1966), ideal genotypes can be considered those having values of b_i close to 1.00 and values of s^2_{di} close to 0.00. Various studies, however, demonstrated that such genotypes realize lower productivity under unfavorable environments in comparison to genotypes characterized by narrow adaptability and slightly higher values of stability. In our investigation, the genotypes, which corresponded to such parameters, were Kalina, Bolyarka, Kristi, Iveta, Neda, Exotic and Stoyana. Khan et al. (2020) combined the results they obtained on b_i and s^2_{di} in a biplot graph. The resulting combinations did not follow a particular tendency but demonstrated that the greater part of the genotypes were with narrow adaptability to unfavorable conditions of the environment; such results were observed in the set of cultivars we studied, too. Results similar to ours were also obtained by Aktaş (2016) when investigating 25 common wheat genotypes.

IPCA1 as a product of AMMI analysis provides information about the degree of interaction of a genotype with the conditions of the environment, and only with regard to one of the principal components of this interaction. Stoyanov (2021) pointed out that each of the principal components of the interaction can be related to specific climatic conditions or a combination of them. In this case, the genotypes with IPCA1 values close to 0.00 (positive or negative) and which combine high productivity, would be the most valuable from a breeding point of view. In this particular case, these were cultivars Bolyarka, Kossara, Diamant, Exotic, Sladuna and Lazarka.

If compared to the data on b_i, s^2_{di}, S^2_i and W_i, the conclusion can be made that only Bolyarka and Exotic follow specific tendencies with regard to the considered parameters. After careful estimation of the data on yield and the IPCA1 values, it becomes evident that they are in positive correlation, i.e. there is a tendency between productivity and the interaction with the environment. Such interpretation of other sets of wheat genotypes can be found in the results reported by Mladenov et al. (2012), Bayisa et al. (2015), Alam et al. (2017), Omrani et al. (2022). In the results obtained by Bacha et al. (2015), there is no clear tendency, similar to our results, while in the results of Kizilgeci et al. (2019), Ahmed et al. (2020) on common wheat and Heidari et al. (2016) on durum wheat, a tendency opposite to our was observed. The tendency we determined showed that the genotypes with low and high productivity, were characterized by the highest interaction with the conditions of the environment, i.e. the genotypes with yield approximating the average were the most stable. This indicated that productivity and stability were actually in a compromise combination in the genotypes we studied.

If we load the results with the action of the environment through EAYM and apply the stability criterion S_{EAYM}, it becomes clear that all of the above cultivars can be identified as high-yielding and stable, with the exception of Exotic, which is characterized by EAYM values lower than the average of the investigated set of cultivars. On the other hand, the application of criterion w_{Yi} to the same cultivars showed that only Kristi, Iveta, Stoyana and Exotic followed a tendency towards high stability and productivity.

If we simultaneously apply all criteria for stability to the above genotypes, neither of them follow a strict tendency towards high productivity and stability according to the methodology adopted in this research. Only the two cultivars Bolyarka and Exotic come closest to the breeding task of our study. This result and the data on the high-yielding cultivars (Korona, Merilin, Rada and Fani) revealed that the yield and the stability of the 52 genotypes we examined did not correspond, indicating that achieving high stability and productivity is still a high-priority issue of contemporary breeding, an opinion shared by other researchers, as well (Calderini et al., 1998; Tsenov and Gubatov, 2018, Merrick et al., 2020; Bonfil et al., 2023; Khan et al., 2023b).

The investigated collection of common winter wheat genotypes can be characterized as rather varied with regard to the determined combinations of productivity and stability. A certain tendency was observed the more highly productive and the low-productive cultivars to be less stable, the cultivars with average productivity demonstrating the most compromise combinations. On the other hand, the results we obtained on the set of high-yielding Bulgarian cultivars allow using them as initial material in different breeding programs and involving them as a basis for developing new varieties suitable for the soil and climatic specificity of Bulgaria.

CONCLUSIONS

Based on the presented results, the following conclusions could be drawn:

1. The three periods of growing the collection of common winter wheat cultivars were drastically contrasting and conditioned extremely varied responses of the genotypes with regard to each investigated environment, and averaged for the entire period of study.
2. The highest mean productivity was registered in 2020/2021 growing period, and the lowest – in 2019/2020. With the highest yield values, averaged for the period, were characterized cultivars Korona, Antonovka, Kalina, Merilin and Rada, and with the lowest – Anapurna, Ingenio, Avenue, Solveig and Mulan.
3. The parameters used for assessment of stability and adaptability lead to various conclusions with regard to the stability of the investigated cultivars. However, a tendency towards high stability regardless of the applied approach was found in cultivars Bozhana and Exotic.
4. The combination of the data on the productivity and stability showed that the greater part of the cultivars with very high or very low productivity were characterized by lower yield stability, and the varieties with productivity close to the average can be considered more stable.
5. Good and compromise combinations of productivity, adaptability and stability based on the mean ranks of the used integrated multiple approach were demonstrated by cultivars Antonovka, Kalina, Kiara, Bolyarka and Kristi.
6. The results from this study showed that the combining of productivity with stability is still an issue in the breeding of common winter wheat, which needs further clarifications. Nevertheless, cultivars such as Bolyarka and Exotic, which follow a tendency towards high productivity and stability, can be efficiently used for improvement of these traits in the contemporary breeding programs.

REFERENCES

Ahmed, A., Tawfelis, M. B., Sayed, M. A., Mahdy, R. E., & Mostafa, M. O. (2020). Stability Analysis of

Bread Wheat Genotypes for Heading Time and Grain Yield Using AMMI Model. *Assiut Journal of Agricultural Sciences*, *51*(2), 24-42.

Aktas, H. (2016). Tracing highly adapted stable yielding bread wheat (Triticum aestivum L.) genotypes for greatly variable South-Eastern Turkey.

Alam, M. A., Farhad, M., Hakim, M. A., Barma, N. C. D., Malaker, P. K., Reza, M. M. A., ... & Li, M. (2017). AMMI and GGE biplot analysis for yield stability of promising bread wheat genotypes in Bangladesh. *Pak. J. Bot*, *49*(3), 1049-1056.

Alemu, G., Geleta, N., Dabi, A., Delessa, A., & Duga, R. (2021). Stability models for selecting adaptable and stable bread wheat (*Tritium aestivum* L.) varieties for grain yield in Ethiopia. *J. Agric. Sci. Eng*, *7*, 14-22.

Ayalneh, T., Letta, T., & Abinasa, M. (2014). Assessment of stability, adaptability and yield performance of bread wheat (*Triticum aestivum* L.) cultivars in south estern Ethiopia. *Plant Breeding and Seed Science*, *67*(1), 3-11.

Bacha, T., Alemerew, S., & Tadesse, Z. (2015). Genotype x environment interaction and yield stability of bread wheat (Triticum aestivum L.) genotype in Ethiopia using the ammi analysis. *Journal of biology, agriculture and healthcare*, *5*(11), 129-140.

Bai, L., Huang, X., Li, Z., Li, S., Lv, C., Zhang, K., & Dai, J. (2023). Stability and adaptability of wheat cultivars with low cadmium accumulation based on farmland trials. *European Journal of Agronomy*, *144*, 126764.

Bayisa, T., Abera, M., Letta, T., & Mulugeta, B. (2020). Stability Analysis of Bread Wheat Genotypes Using the AMMI Stability Model. In *Regional Review Workshop on Completed Research Activities of Crop Research Directorate held at Adami Tulu Agricultural Research Center, Adami Tulu, Oromia,Ethiopia 2020*, 61-69.

Bonfil, D. J., Abbo, S., Degen, D., Simchon, Y., & Ben-David, R. (2023). Towards stable wheat grain yield and quality under climatic instability. *Agronomy Journal*. 115:1622–1639.

Bornhofen, E., Benin, G., Storck, L., Woyann, L. G., Duarte, T., Stoco, M. G., & Marchioro, S. V. (2017). Statistical methods to study adaptability and stability of wheat genotypes. *Bragantia*, *76*, 1-10.

Calderini, D. F., & Slafer, G. A. (1998). Changes in yield and yield stability in wheat during the 20th century. *Field Crops Research*, *57*(3), 335-347.

Chamurliyski, P., & Tsenov, N. (2013). Yield stability of contemporary Bulgarian winter wheat cultivars (*Triticum aestivum* L.) in Dobrudzha. *Agricultural science and technology*, *5*(1), 16-21.

Chamurliyski, P., Penchev, E. & Tsenov, N. (2015). Productivity and stability of the yield from common winter wheat cultivars developed at IPGR Sadovo under the conditions of Dobrudzha region. *Agricultural science and technology*, 7(1), 19-24.

Desheva, G., & Deshev, M. (2021). Evaluation of the stability and adaptability of yield in varieties and breeding lines of common winter wheat. *Rastenievadni nauki, 58*(1) 3-13 (Bg).

Desheva, G., & Deshev, M. (2021). Morphological and agronomical comparative study of genetic diversity of common winter wheat cultivars. *Rastenievadni nauki, 58*(4) 11-20.

Dias, C., Santos, C., & Mexia, J. T. (2022, November). Adaptability and stability analysis of common wheat production. In *AIP Conference Proceedings* (Vol. 2611, No. 1). AIP Publishing, 2-4.

Eberhart, S. T., & Russell, W. A. (1966). Stability parameters for comparing varieties 1. *Crop science*, *6*(1), 36-40.

Gauch Jr, H. G. (1992). *Statistical analysis of regional yield trials: AMMI analysis of factorial designs*. Elsevier Science Publishers.

Geary, R. C. (1935). The ratio of the mean deviation to the standard deviation as a test of normality. *Biometrika*, *27*(3/4), 310-332

Hagos, H. G., & Abay, F. (2013). AMMI and GGE biplot analysis of bread wheat genotypes in the northern part of Ethiopia. *Journal of Plant Breeding and Genetics*, *1*(1), 12-18.

Heidari, S., Azizinezhad, R., & Haghparast, R. (2016). Yield stability analysis in advanced durum wheat genotypes by using AMMI and GGE biplot models under diverse environment. *Indian Journal of Genetics and Plant Breeding*, *76*(03), 274-283.

Kizilgeci, F., Albayrak, O., Yildirim, M., & Akinci, C. (2019). Stability evaluation of bread wheat genotypes under varying environments by AMMI model. *Fresenius Environmental Bulletin*, *28*(9), 6865-6872.

Khan, M. A. U., Mohammad, F., Khan, F. U., Ahmad, S., Raza, M. A., & Kamal, T. (2020). Comparison among different stability models for yield in bread wheat. *Sarhad J. Agric*, *36*(1), 282-290.

Khan, M. A., Ayyub, M. U., Bashir, A., & Alam, B. (2023a). Characterization of Bread Wheat Genotypes Using Morpho-Phenological Attributes Related to Yield Under Terminal Heat Stress. *Gesunde Pflanzen*, 1-9.

Khan, I., Gul, S., Khan, N. U., Fawibe, O. O., Akhtar, N., Rehman, M., ... & Rauf, A. (2023b). Stability analysis of wheat through genotype by environment interaction in three regions of Khyber Pakhtunkhwa, Pakistan. *SABRAO J. Breed. Genet*, *55*(1), 50-60.

Liu, W., Ye, T., & Shi, P. (2021). Decreasing wheat yield stability on the North China Plain: Relative contributions from climate change in mean and variability. International Journal of Climatology, 41, E2820-E2833.

Merrick, L. F., Lyon, S. R., Balow, K. A., Murphy, K. M., Jones, S. S., & Carter, A. H. (2020). Utilization of evolutionary plant breeding increases stability and adaptation of winter wheat across diverse precipitation zones. *Sustainability*, *12*(22), 9728.

Mihova, G. (2020). Peculiarities in the Structure of Yield in Common Wheat Accessions from Different Ecological and Geographic Origin. *International Journal of Innovative Approaches in Agricultural Research*, *4*(4), 436-446.

Mihova, G., & Dimitrova-Doneva, M. (2021). Analysis for grain yield and some quality traits in bulgarian bread wheat (Triticum aestivum L.). *Agricultural Sciences/Agrarni Nauki*, *13*(29), 12-21.

Mladenov, V., Banjac, B., & Eviã, M. M. (2012). Evaluation of yield and seed requirements stability of bread wheat (Triticum aestivum L.) via AMMI model. *Turkish Journal of Field Crops*, *17*(2), 203-207.

Najafi Mirak, T., Agaee Sarbarzeh, M., Moayedi, A., Kaffashi, A., & Sayahfar, M. (2021). Yield Stability Analysis of Durum Wheat Genotypes Using AMMI Method. *Journal of Agricultural Science and Sustainable Production*, *31*(2), 17-28.

Obembe, O. S., Hendricks, N. P., & Tack, J. (2021). Decreased wheat production in the USA from climate change driven by yield losses rather than crop abandonment. *Plos one*, *16*(6), e0252067.

Omrani, A., Omrani, S., Khodarahmi, M., Shojaei, S. H., Illés, Á., Bojtor, C., ... & Nagy, J. (2022). Evaluation of grain yield stability in some selected wheat genotypes using AMMI and GGE biplot methods. *Agronomy*, *12*(5), 1130.

Pour-Aboughadareh, A., Yousefian, M., Moradkhani, H., Poczai, P. & Siddique K. H. M. (2019). STABILITYSOFT: A new online program to calculate parametric and non-parametric stability statistics for crop traits. *Applications in Plant Sciences 7*(1), e1211. doi:10.1002/aps3.1211

Shukla, G. K. (1972). Some statistical aspects of partitioning genotype-environmental components of variability. *Heredity*, *29*(2), 237-245.

Stoyanov, H., Baychev, V., Petrova, T., & Mihova, G. (2017). Triticale cultivars suitable for growing under high level of abiotic stress. *Journal of Mountain Agriculture on the Balkans (JMAB)*, *20*(6), 223-242.

Stoyanov, H. (2021). Environment adjusted yield model for ranking and stability assessment of winter triticale (X *Triticosecale* Wittm.) Genotypes. *International Journal of Innovative Approaches in Agricultural Research*, *5*(1), 141-157.

Tekdal, S., & Kendal, E. (2018). AMMI model to assess durum wheat genotypes in multi-environment trials. *Journal of Agricultural Science and Technology*, *20*(1), 153-166.

Tsenov, N., & Atanasova, D. (2015). Influence of environments on the amount and stability of grain yield in the modern winter wheat cultivars II. Evaluation of each variety. *Bulgarian Journal of Agricultural Science*, *21*(6), 1128-1139.

Tsenov, N., Atanasova, D., & Gubatov, T. (2016). In uence of Environments on The Amount and Stability of Grain Yield in The Modern Winter Wheat Cultivars II. Evaluation of Each Variety. *Ekin Journal of Crop Breeding and Genetics*, *2*(1), 57-73.

Tsenov, N., Gubatov, T., Raykov, G., Ivanova, A., & Chamurliiski, P. (2017). New approaches for evaluation the grain yield of winter wheat in contrasting environments. *International Journal of Current Research, 9*(1), 44487-44495.

Tsenov, N. & Gubatov, T. (2018). Comparison of basic methods for estimating the size and stability of grain yield in winter wheat. Rastenievadni nauki, 55(6), 9-19 (Bg).

Tsenov, N., Gubatov, T., & Yanchev, I. (2021). Genotype selection for grain yield and quality based on multiple traits of common wheat (Triticum aestivum L.). *Cereal Research Communications*, *49*(1), 119-124.

Tsenov, N., Gubatov, T. & Yanchev, I. (2022). Indices for assessing the adaptation of wheat in the genotype x environment interaction. *Rastenievadni nauki 59*(2) 16-34 (Bg).

Uhr, Z., Dobrikova, A., Borisova, P., Yotsova, E., Dimitrov, E., Chipilsky, R. &. Popova, A. V. (2022). Assessment of drought tolerance of eight varieties of common winter wheat – a comparative study. *Bulg. J. Agric. Sci., 28 (4), 668–676*

Uhr, Z., Dimitrov, E., & Delchev, G. (2021). Characteristics of perspective lines common winter wheat. 1. Yield and stability. *Rastenievadni nauki, 58*(4) 3-10 (Bg).

Vasilev, D., Raykov, S., & Nikolova, Z. (2021). A study of some foreign wheat cultivars in Bulgaria (*Triticum aestivum* l.). *Scientific Papers. Series A. Agronomy*, *64*(1), 614-619.

Verma, A., & Singh, G. P. (2020). Simultaneous Use of AMMI Model and Yield for Stability Analysis of Wheat Genotypes Evaluated Under Central Zone of the India. *European Journal of Agriculture and Food Sciences*, *2*(6), 1-7.

Wricke, G. (1962). Uber eine methode zur erfassung der okologischen streubreite in feldversucen. *z. Pflanzenzuchtung*, *47*, 92-96.

Zhang, T., He, Y., DePauw, R., Jin, Z., Garvin, D., Yue, X., ... & Yang, X. (2022). Climate change may outpace current wheat breeding yield improvements in North America. *Nature communications*, *13*(1), 5591.

Received: October, 03, 2024*; Approved:* December, 11, 2024*; Published:* February, 2025