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Parametric and nonparametric stability of grain yield and grain protein content in durum wheat genotypes with various origins

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Abstract. Identification of genotypes that can maintain a good yield and quality performance under climatic variability is critical for ensuring future food security. The aim of this study was to determine the stability of fifty-four durum wheat varieties with different geographical origins conceming the traits grain yield and grain protein content by parametric and nonparametric assessments. The varieties were tested in three consecutive years 2019–2021 in a randomized block design in three replications. Four nonparametric stability assessment, four parametric stability assessment, the coefficient of variation and the simulated assessment of yield and stability by Kang were determined. The analysis of variance revealed a significant influence of genotypes, environment and the genotype and environment interaction (GxE) on the expression of both studied traits. The environment showed a greatest influence on the variation of both traits. Eleven genotypes achieved average yield above 6.00 t ha^{-1}. The genotypes with a high average yield and grain protein content and high stability as determined by the most stability assessments were identified as Melina (BG), Raylidur (BG) and Beloslava (BG) - for grain yield and varieties as Cesare and Beloslava (BG) - for grain protein content. The Bulgarian variety Beloslava was the most valuable combination high yield and grain protein content along with high stability for both traits across different seasons. Beloslava can be recommended for involvement in durum wheat breeding programs for simultaneously improvement of productivity and grain quality and to develop new durum wheat varieties well adapted to changing climate conditions.

Key words: durum wheat, grain protein content, grain yield, stability.

INTRODUCTION

Durum wheat (*Triticum turgidum* subsp. *Durum* Desf.) is the second most important cereal crop and occupies about 5% (about 17 million ha) of the total area of wheat grown in the world, and in 2019 production was about 38 million tons (Xynias et al., 2020). Canada is the largest producer in the world, followed by Italy and Turkey. However, the largest consumers are the Mediterranean countries, where most of the production process takes place (Sabella et al., 2020). Although world production of durum wheat is quite low compared to bread wheat, its importance will increase as it is used to produce healthy foods with a low glycemic index, such as pasta. Global demand for pasta has increased rapidly in recent years, indicating growing demand for durum wheat.

Durum wheat breeding programs is aimed at increase of genetic variation and creation of new varieties with high yield and improved yield related traits, grain quality traits, tolerance to biotic and abiotic stress factors (Dragov & Dechev, 2015; Dragov et al., 2019; Taneva et al., 2019).

The success of the breeding program is based on the knowledge of the factors influencing the expressions of quantitative traits: the genotype, the environment and the interaction between them. Changes in the relative performance of genotypes across different environments are referred as genotype-environment interaction (GxE). Genotype-environment interaction is dependent from the genetic nature of the trait and the genetic constitution of the genotypes. Different environmental factors as soil type, moisture, temperature, rainfall and agronomic practices have important role in the expression of the genes controlling the traits of interest. The magnitude of the observed genetic variation as an expression of GxE interaction changes from one environment to another and usually is larger in better conditions than in poorer (Przystalski et al., 2008; Saltz et al., 2018).

The presence of genotype-environment interaction complicates the breeding of superior genotypes. Therefore, understanding the ecological and genotypic reasons for reliable genotype-environment interactions is important at all stages of the breeding process (Dhungana et al., 2007). The presence of negative correlations between some agronomic and quality traits can additionally complicate the breeding work. It is well known that the selection of genotypes with high grain protein content is hampered by the existing negative correlation with yield and the significant influence of environmental conditions on the variation of this traits (Blanco et al., 2006; Wurschum et al., 2016).

Determining the effect of GxE interaction on the performance of genotypes is based on studies of adaptability and stability and allows to make predictions regarding the breeding values of the genotypes in other environments (Burgueno et al., 2011). The adaptability is defined as the ability of a genotype to respond advantageously to its environment, while its stability is related to the predictability of its behavior (De Souza et al., 2020).

To this end, many stability parameters have been developed for genotypes grown in different environments, and each has its advantages and limitations. In various methods, GxE interactions are used to characterize the response of genotypes to changing environment together with the mean value of the quantitative traits studied (Mohammadi et al., 2009; Christov et al., 2010; Hilmarsson et al., 2021).

The regression coefficient b_i and the squared deviation from regression S^2d_i (Finlay & Wilkinson, 1963; Eberhart & Russel, 1966) are widely used to assess phenotypic stability. Wricke ecovalence (W_i^2) (Wricke, 1962) and stability variance (σ^2_i) (Shukla, 1972) are very similar to each other (Becker & Leon, 1988). They have been proposed to make a selection based on the contribution of each genotype to the genotype-environment interaction. Francis & Kannenberg (1978) recommended the coefficient of variation (CV_i), to select stable genotypes based on low variance. Parametric estimates rely on absolute data and the assumption of normal dispersion distribution and homogeneity. Nonparametric stability approaches are suggested based on genotype ranking with no assumptions related to data distribution. Two nonparametric indices are recommended by Huehn (1979) and Nassar & Huehn (1987). S^1 is the mean of absolute rank difference over environment, S^2 is the variance of the ranks. Thennarasu (1995) recommend two nonparametrics indices NP^1 and NP^2 which are determined based on the ranks of adjusted genotypes means in each environment. Most reliable method for simultaneous assessment of grain yield and stability is parameter Ys_i of Kang (1988). This parameter gives a weight of one to both yield and stability to identify high-yielding and stable genotypes at the same time. These different parameters select stable genotypes based on two stability concepts. Bouchared & Guendouz (2022) reveal that the parametric and nonparametric methods proved to be suitable tools to identify the most stable genotypes at various environmental conditions. The determination of the parametric and nonparametric stability allows the complete evaluation of the studied genotypes. Stable varieties can be successfully identified and included in the durum wheat breeding improvement work. On the other hand, stable varieties are of great interest to farmers and can increase their economic efficiency.

Recently the global change of climate especially drought and heat stress affect grain yield and quality in cereals and increase genotype-environment interaction (Rharrabti et al., 2003; Xiong et al., 2020; Mariem et al., 2021). In one large-scale study Kahiluoto et al. (2018) reported on a decline in the climate resilience of European wheat and especially for durum wheat. Their observations reveal that all wheat varieties grown in farmers fields in most European countries manifested relatively similar yield response to different weather events. Therefore the identification of genotypes that are able to maintain a good yield and quality performance under climatic variability is very important for future food security.

The aim of this study was to determine the yield and grain protein content performance and stability of fifty-four durum wheat varieties with different geographical origin by parametric and nonparametric assesments during three harvest years.

MATERIALS AND METHODS

Fifty-four genotypes of durum wheat have been studied in the experimental field of Field Crops Institute Chirpan, Bulgaria. Old and new varieties originating from Bulgaria, Italy, Hungary, Germany, Austria, France, Russia, Ukraine and the United States are included with predominating of modern Bulgarian varieties.

The experiments were conducted in the field conditions in the period 2018–2021. Three harvest years were realized: 2019, 2020 and 2021. The experiment were organized in a randomized block design in three replications with the size of the experimental plot of 15 m^2. Harvesting was done with a small breeding harvester separately for each replication. The soil type is Pellic Vertisols. The varieties were sown in the optimal time for the country in the period 20.10–30.10 of the respective years. Genotypes were sown with 550 germinated seeds per m^2 and the corresponding seeding rate for each. The predecessor is winter peas harvested for green mass. After harvesting the predecessor for soil preparing four or five treatments with heavy disc harrow are done until the soil is in garden condition. The standard growing technology adopted in the country has been applied. Basic fertilization with 0.08 t ha^{-1} active substance of phosphorus and early spring nourishing with 0.1 t ha^{-1} active substance nitrogen was applied. Heading time is in the second half of May. There was no treatment with fungicides and insecticides.

Two economically important traits: grain yield and grain protein content were traced. Yield was recorded from each replication and its mean value for each genotype was calculated in ton per hectare. The grain protein content (GPC,%) was estimated by measuring N according to the Kjeldahl method (BDS ISO 20483: 2014).

The mathematical processing of the results was performed using the statistical processing programs Statistica 10 (Statistica 10) and Stabilitysoft (Pour-Aboughadareh et al., 2019). Analysis of variance (ANOVA) and correlation analysis by Lidanski (1988) was performed to determine the significance and influence of individual factors. Parametric and nonparametric statistical estimates were made. Nonparametric statistical estimates of phenotypic stability include the proposed parameters of Nassar & Huehn (1987) S^1 – the mean of absolute rank differences of genotype in all tested environments and S^2 – deviation between ranks in all tested environments. Also alternative nonparametric stability assessment NP^1 and NP^2 defined by Thennarasu (1995). These parameters are based on the ranks of adjusted means of the genotypes in each environment. Low values of these statistics reflect high stability. Parametric stability estimates include. Wricke's ecovalence W_i (Wricke, 1962). Ecovalence as the contribution of each genotype to the GE interaction sum of squares. The ecovalence (W_i) of the i^{th} genotype is its interaction with the environments, squared and summed across environments. Thus, genotypes with low values have smaller deviations from the mean across environments and are more stable. Regression coefficient b_i (Finlay & Wilkinson, 1963), the slope regression (bi) is the response of the genotype to the environmental index that is derived from the average performance of all genotypes in each environment. Deviation from regression S^2d_i (Eberhart & Russel, 1966), in addition to slope regression, variance of deviations from the regression (S^2d_i) has been suggested as one of the most-used parameter for the selection of stable genotypes. Hence, genotypes with lower values are the most desirable. Shukla stability variance σ_i^2 (Shukla, 1972) suggested the stability variance of genotype i as its variance across environments after the main effects of environmental means have been removed. According to this statistic, genotypes with minimum values are intended to be more stable. Coefficient of variation (CV_i) (Francis & Kannenberg, 1978), stability statistic through the combination of the coefficient of variation, mean yield, and environmental variance. Kang (1988) rank sum (Ys_i). Assessment of Kang gives a weight of one to both yield and stability statistics to identify high-yielding and stable genotypes.

RESULTS AND DISCUSSION

The meteorological characteristics of the years in terms of average monthly daily air temperatures and average monthly amount of precipitation for the growing periods are shown in Table 1. The three years are characterized as warmer than the multi-year norm. It should be noted that for January during the three years of the study not negative average daily temperatures were reported. October was significantly warmer than normal. November was characterized by an average daily air temperature around the norm and only in the 2020 harvest year was is significantly higher. The months of December, January, February and March in two of the three years have an average daily temperature above the norm. In the months April and May the temperature in all three years was around the norm. Temperatures relative to the norm for the months of June and July were also observed. Rainfall during the growing season is more determinant for grain yield (Table 1). Precipitation is extremely unevenly distributed during the growing period of durum wheat. The highest amount of precipitation (529.3 mm) had 2021, with about 40 mm above the norm for a multi-annual period. The other two years are drier and deviate from the norm by 20 mm each. In 2020 the precipitation is relatively evenly distributed in the individual months. In 2019 and 2021 there is a large amount of precipitation over 100 mm for June 2019 and January 2021. The precipitation in 2019 is extremely unevenly distributed during the individual months of the growing season. During the winter period from December to March, the monthly amount of precipitation was about 55% less than the average for the multi-year period. The month of May was also unusually dry, with rainfall about 67% below the long-term average. The low rainfall in winter months and in May in the first year of investigation resulted in drought stress, which was a limiting factor for durum wheat production in the south-central Bulgaria.

Table 1. Meteorological characteristics during the vegetation of durum wheat in FCI-Chirpan for the 2019, 2020 and 2021 harvest years and the average meteorological date for the multiannual period

Years/ Months	Average daily air temperature, °C				Montly amount of precipitation, mm			
	2018–2019	2019–2020	2020–2021	Norm 1928–2021	2018–2019	2019–2020	2020–2021	Norm 1928–2021
October	14.0	15.0	15.2	12.7	25.4	48.2	67.3	38.6
November	7.5	11.2	6.6	7	82.3	82.4	7.4	47.3
December	0.7	3.6	5.8	1.4	23.5	21.6	70.4	54.0
January	1.7	1.4	3.2	-0.2	28.9	1.5	108.6	44.3
February	4	5.3	4.5	1.7	24.5	55.5	25.8	37.7
March	9.4	8.3	5.2	5.7	3.3	67.4	39.1	37.0
April	11.2	10.5	10.3	11.8	51.4	62.2	84.0	45.2
May	17.2	16.6	16.9	16.9	21.4	50.3	34.9	64.1
June	22.7	20.5	20.6	20.7	123.2	62.6	42.8	65.4
July	23.5	24.7	25.6	23.2	77.5	12.0	49.0	54.1
Sum	111.9	117.1	113.9	100.9	461.4	463.7	529.3	487.7

The average values of grain yield and grain protein content in studied varieties by years are presented in Table 2. The mean yields varied from 4,073 t ha^{-1} to 6,320 t ha^{-1} in different years, indicating large variation in yield potential of genotypes. In the first year the varieties realized the lowest mean grain yield - 4,073 t ha^{-1}, ranging from 1,502 t ha^{-1} to 5,786 t ha^{-1} due to severe drought during the most important phases of durum wheat development. In the second year the average grain yield was 5,009 t ha^{-1}, with the minimum of 2,164 t ha^{-1} and the maximum 7,978 t ha^{-1}. In the third year the mean grain yield was 6,320 t ha^{-1}, with the minimum of 4,652 t ha^{-1} and the maximum 7,656 t ha^{-1}. The highest average yield of genotypes was formed in the third year of experiments, characterized by the most favorable weather conditions for obtaining a high yield in durum wheat. The mean value of grain protein content in the first year of study was 16.1% and ranged from 13.8% to 17.4%. In the next 2 years, the studied genotypes realized a lower grain protein content compared to the 2019 harvest year. The mean value for 2020 was 13.4%, and for 2021 - 14.3%. The highest grain protein content was reported in the first year of experminets. The correlation between the traits is shown in Table 2. The correlation between both traits in all three years is positive but non significant. In two of the years tending to zero and in the third is low.

Table 2. Origins and mean values of grain yield (GY) t ha^{-1} and grain protein content GPC) % by years

No of and Genotype	ORIGIN	2019 y.		2020 y.		2021 y.	
		GY	GPC	GY	GPC	GY	GPC
1. Corallo	ITA	1,502	15.0	3,025	12.8	5,535	13.3
2. Cleto	ITA	2,004	16.1	2,236	13.3	5,896	13.3
3. Cliodur	ITA	2,747	16.3	2,835	13.7	5,446	14.3
4. MVPennedur	HUN	3,546	16.0	2,613	14.0	5,468	14.7
5. Cuspide	ITA	2,509	16.6	3,337	12.6	4,991	13.6
6. Spartaco	ITA	1,942	15.4	4,055	12.7	6,844	13.8
7. Progres	BG	3,622	16.9	5,027	13.6	4,652	15.1
8. Provenzal	ITA	1,921	15.5	2,164	13.7	6,432	13.3
9. MVHundur	HUN	4,386	17.1	2,992	14.6	5,909	15.0
10. Lloyd	USA	4,039	14.5	4,134	13.8	6,118	14.7
11. Duramar	GER	2,865	16.0	4,175	13.0	5,853	14.0
12. Wintergold	GER	3,426	16.1	4,546	14.3	6,321	14.3
13. Claudio	ITA	3,576	15.3	3,674	13.0	5,563	13.9
14. AliyParus	UK	3,782	15.6	3,266	12.6	5,385	14.1
15. Saturn-1	BG	4,173	15.5	4,246	14.1	6,484	14.3
16. Achile	ITA	3,449	13.8	4,609	11.6	4,947	13.2
17. Cesare	ITA	3,877	16.6	4,432	13.8	5,132	14.8
18. Mirela	BG	4,324	16.4	3,731	14.3	6,298	14.3
19. MVMakaroni	HUN	4,407	16.9	4,657	14.0	5,171	15.2
20. Ovidio	ITA	3,421	16.0	3,825	13.4	6,156	14.3
21. M.Aurelio	ITA	3,967	16.6	4,694	13.7	6,043	14.9
22. GKJulidur	HUN	4,560	16.5	4,284	14.0	6,095	14.5
23. Anvergur	FRA	3,525	16.2	5,078	12.9	6,858	14.5
24. Mirabel	BG	4,907	16.3	4,048	13.4	6,713	14.2
25. Malena	BG	4,615	15.0	3,562	12.7	6,646	13.6
26. Duramant	GER	4,365	15.4	5,886	12.8	6,330	14.3
27. Troubadur	AT	4,358	14.7	3,902	12.5	5,778	13.8
28. Prowidur	AT	2,972	16.3	5,757	12.7	6,561	13.9
29. M.Meridio	ITA	4,631	16.1	5,444	13.9	6,187	15.3
30. Snowglenn	USA	3,805	15.8	5,289	13.2	6,577	13.8
31. Alena	RUS	5,219	15.5	4,588	14.3	6,935	14.5
32. Severina	BG	4,053	15.6	4,636	12.9	6,150	14.3
33. Auradur	AT	4,942	15.6	5,354	12.4	6,347	14.5
34. Melina	BG	4,946	15.1	5,326	12.5	7,054	14.0
35. Gelios	RUS	5,282	16.6	5,379	13.4	6,456	14.4
36. Trakiets	BG	4,391	16.7	7,095	12.9	6,678	15.0
37. Deni	BG	5,786	16.5	5,913	13.4	6,816	14.8
38. Predel	BG	3,636	16.5	7,352	12.9	7,339	14.5
39. Victoriya	BG	4,956	16.0	7,075	12.7	7,429	15.1
40. Reyadur	BG	4,053	16.1	7,064	12.9	7,656	14.9
41. Saya	BG	5,053	16.2	7,978	14.4	7,528	14.6
42. Heliks	BG	4,775	15.3	7,228	14.0	7,291	13.4
43. Kehlibar	BG	4,451	16.8	6,532	14.5	6,953	14.3
44. Raylidur	BG	5,303	16.9	6,501	13.5	6,891	13.8
45. Viomi	BG	5,044	15.8	6,674	13.8	6,680	14.6
46. Elbrus	BG	5,011	15.6	4,976	12.5	6,623	14.2

Table 2 (continued)

47. Beloslava	BG	4,257	17.2	5,579	14.4	6,635	15.3
48. Cerera	BG	4,939	17.2	6,108	13.3	6,438	14.3
49. Vazhod	BG	3,562	16.9	6,355	14.8	6,515	15.4
50. Zvezditsa	BG	4,905	17.4	5,340	14.8	6,064	15.0
51. Deyana	BG	4,392	16.2	5,804	14.0	6,104	14.6
52. Dechko	BG	4,925	16.2	6,897	13.1	6,964	13.9
53. Deyche	BG	4,539	16.5	6,703	14.0	6,902	14.0
54. Chirpanche	BG	4,326	16.5	6,513	14.3	6,452	14.3
Mean	-	4,073	16.1	5,009	13.4	6,320	14.3
Standart error of mean	-	0.12	0.1	0.19	0.1	0.09	0.08
Correlation	-	0.20		0.09		0.06	
Min	-	1,502	13.8	2,164	11.6	4,652	13.2
Max	-	5,786	17.4	7,978	14.8	7,656	15.4
CV%	-	23.23	4.54	28.6	5.37	10.8	3.9

The presented analysis of the variance (Table 3) shows that the genotypes, the environments and the genotype-environment interaction (GxE) have a significant influence on the expression of both studied traits. Much of the phenotypic variation in the grain yield trait is due to environment (40.22%) and genotype (35.05%), less to genotype-environment interaction (GxE). The variation of the grain protein content is determined to a greater extent by the environment (72.13%) and less by the genotype and the genotype-environment interaction (GxE). The established highly significant genotype-environment interaction for both studied traits allows a stability analysis of studied genotypes to be performed.

The presence of statistically significant genotype - environment interaction (GxE) reveals that genotypes react differently when changing environments. Many authors have reported for significat genotype-environment interaction for grain yield in durum wheat in different environments and genotypes (Karimizadeh et al., 2012; Sabaghnia et al., 2012; Hassan et al., 2013; Mekliche et al., 2013; Bassi & Sanchez-Garcia, 2017).

Our results for grain protein content are in confirmation of a number of previous studies, showing that the variation of this important grain quality trait is greatly influenced by the conditions of the years. But also the genotype-environment interaction has a significant influence on the general variation of the trait (Sakin et al., 2011; Baranda & Sharma, 2020; Temtme & Tesfaye, 2021).

Table 3. ANOVA for grain yield and grain protein content

Grain yield, t ha^{-1}					
Source	SS	df	MS	Significant	η^2%
Genotype	359.65	53	6.79	***	35.05
Environment	412.78	2	206.39	***	40.22
GxE	182.88	106	1.73	***	17.82
Error	70.77	324	0.22		
Grain protein content, %					
Source	SS	df	MS	Significant	η^2%
Genotype	148.5	53	2.8	***	18.65
Environment	574.1	2	287.1	***	72.13
GxE	69.3	106	0.7	***	8.70
Error	4.0	324	0.01		

*** *Significant at p* < 0.001; SS – Sum of squares; df – degree of freedom; MS – Mean squares; η^2-factor influence.

Grain yield (GY): In Table 4 are presented the average yields over three years and calculated parametric and nonparametric indicators for the stability assessment of the tested genotypes. Eleven genotypes: (36, 37, 38, 39, 40, 41, 42, 44, 45, 52, 53 - Table 2) have mean yield of three years over 6,00 t ha^{-1}. The yield formed is relatively high and these genotypes are of interest for breeding improvement work. The above-mentioned genotypes are Bulgarian varieties created in the last 10–12 years at the Field Crops Institute - Chirpan under the same pedo-climatic conditions and management practice under which the present experiment was performed. Variety Saya (Genotype 41) has the highest yield on average for the three years - 6,853 t ha^{-1}. Twenty-five genotypes: 26, 29, 31, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54 have achieved yields above the average of all studied varieties of the three years. In addition to the eleven Bulgarian varieties listed above, this group also includes five foreign varieties: 26 Duramant (GER), 29 M. Meridio (ITA), 31 Alena (RUS), 35 Gelios (RUS), one Bulgarian variety 34 Melina and seven more Bulgarian varieties from Field Crops Institute - Chirpan - 46 Elbrus, 47 Beloslava, 48 Cerera, 49 Vazhod, 50 Zvezditsa, 51 Deyana and 54 - Chirpanche.

Table 4. Mean values for trait grain yield in t ha^{-1} and parametric and non-parametric stability assessments

No	Mean	S^1	S^2	NP^1	NP^2	W_i^2	σ^2_i	S^2d_i	b_i	CV_i	Ys_i
1	3,354	5.3	16.3	25.6	5.1	16,578	8,497	23.1	1.80	60.7	51
2	3,378	7.3	34.3	26.6	3.5	29,066	14,981	1,820	1.80	64.6	53
3	3,676	2	2.3	20.6	6.3	8,709	4,411	1,012	1.25	41.7	45
4	3,875	6.6	25	16.6	3.2	19,936	10,241	2,835	0.94	37.5	50
5	3,612	3.3	6.3	9.6	3.9	615.2	208.9	39.9	1.11	34.9	29
6	4,280	26	399	26.6	0.8	35,404	18,272	4.8	2.17	57.4	52
7	4,433	18	183	17.6	1.0	15,144	7,752	898	0.41	16.4	46
8	3,505	17	217	31.3	1.6	47,835	24,726	2,524	2.08	72.3	54
9	4,429	17	174	22.3	1.2	28,433	14,652	3,881	0.77	32.9	49
10	4,763	4	9	8	0.8	3,958	1,944	560	0.96	24.6	24
11	4,297	6.6	25	14.6	1.9	2,747	1,316	4.0	1.32	34.8	30
12	4,764	9.3	54.3	15.3	1.1	2,231	1,048	6.9	1.29	30.6	20
13	4,271	3.3	8.3	9	1.7	3,676	1,798	502	0.92	26.2	35
14	4,144	8	44.3	18	2.0	10,581	5,383	1,321	0.77	26.6	46
15	4,967	8.6	42.3	13	0.6	5,358	2,671	746	1.07	26.4	27
16	4,335	14	111	12.3	1.1	5,192	2,585	271	0.64	18.1	37
17	4,480	10	85.3	13	1.3	5,005	2,488	0.9	0.55	14.0	32
18	4,784	10	69.3	12.3	0.8	13,295	6,792	1,889	0.94	28.0	44
19	4,745	19	220	22	0.8	11,012	5,607	4.3	0.34	8.2	42
20	4,467	8	39	18.3	1.6	5,204	2,591	509	1.25	33.0	36
21	4,901	7.3	30.3	0.3	0.2	247	17.6	17.8	0.93	21.4	12
22	4,979	13	121	17	0.5	7,414	3,739	790	0.72	19.5	32
23	5,153	20	241	18.3	0.4	5,937	2,972	25.6	1.47	32.3	25
24	5,222	18	244	20	0.5	17,493	8,972	2,449	0.88	26.0	40
25	4,941	19	271	17	0.6	23,815	12,255	3,402	0.99	31.7	46
26	5,527	9.3	50.3	12.6	0.2	3,912	1,920	465	0.84	18.6	6
27	4,679	12	97.3	22.6	1.2	9,797	4,976	1,035	0.68	20.9	41
28	5,096	19	247	17	0.5	18,263	9,372	1,571	1.53	36.9	42
29	5,420	11	79	7.6	0.1	2,715	1,299	25.6	0.68	14.3	8

Table 4 (continued)

30	5,223	10	60.3	5.6	0.2	1,924	888.4	102	1.21	26.5	6
31	5,580	19	240	17.6	0.2	12,697	6,482	1,708	0.82	21.7	30
32	4,946	2.6	4.3	3.3	0.3	626.4	214.7	79.5	0.94	21.8	12
33	5,547	12	92.3	11.3	0.2	3,612	1,765	28.2	0.63	13.0	4
34	5,775	12	93	5.3	0.2	1,672	757.9	233	0.96	19.4	1
35	5,705	14	137	17.6	0.2	6,362	3,192	144	0.54	11.4	17
36	6,054	12	94.3	30	0.2	20,382	10,472	2,894	0.93	24.0	32
37	6,171	9.3	61	20.3	0.1	7,668	3,871	86.0	0.47	9.0	10
38	6,109	24	409	25.6	0.2	38,681	19,974	4,459	1.54	35.0	37
39	6,486	3.3	6.3	17.6	0.1	7,891	39,87	1,119	1.04	20.6	5
40	6,257	20	277	19.6	0.2	22,212	11,422	2,152	1.52	30.8	27
41	6,853	2.6	4.3	29	0.02	23,703	12,196	3,385	1.00	22.9	23
42	6,431	8	41.3	23	0.1	13,108	6,695	1,863	1.05	22.3	18
43	5,978	8	41.3	16.3	0.1	7,230	3,643	1,018	1.06	22.4	15
44	6,231	6.6	30.3	11	0.2	4,503	2,227	271	0.68	13.2	2
45	6,132	6.6	26.3	18.3	0.1	8,527	4,317	849	0.68	15.3	15
46	5,536	14	112	14.3	0.2	4,859	2,412	470	0.75	16.9	10
47	5,490	6.6	33.3	7	0.1	771	290.2	103	1.04	21.7	3
48	5,828	10	72.3	13.6	0.1	5,253	2,616	280	0.64	13.5	8
49	5,477	18	201	24.6	0.5	17,578	9,016	2,305	1.23	30.3	39
50	5,436	16	160	15.3	0.2	5,927	2,967	2.1	0.51	10.7	22
51	5,433	13	108	14.3	0.2	5,116	2,546	461	0.72	16.8	18
52	6,262	3.3	8.3	18.6	0.1	8,882	4,501	1,189	0.85	18.4	12
53	6,048	7.3	34.3	19.6	0.1	9,196	4,664	1,313	0.99	21.6	20
54	5,763	10	80.3	22.6	0.3	11,543	5,883	1,598	0.88	21.6	25

According to Nassar & Huehn (1987) low values for the nonparametric indicators S^1 and S^2 determine the stability of genotypes. Eight genotypes 3, 5, 10, 13, 32, 39, 41, 52 show the lowest values for S^1 and three of them 3, 32, 41 also have the lowest values for the indicator S^2. The group with low values for S^1 includes three Italian varieties - Cliodur (3), Cuspide (5) and Claudio (13), one American - Lloyd (10) and one Bulgarian - Severina (32), created in Dobrudja Agricultural Institute, which are low- to moderate yielding and three Bulgarian high-yielding varieties, among which is the the variety Saya (41) realized the highest yield across all years. The low values for the indicators NP^1 and NP^2 determine high stability (Thennarasu, 1995). Two genotypes (21 and 32) have low values with respect to NP^1 and eleven: 29, 37, 39, 41, 42, 43, 45, 47, 48, 52, 53 with respect to NP^2. Genotype 41 has three low nonparametric stability assessment and achieves the highest yield among all studied genotypes. Nonparametric evaluation S^2 can be used as an alternative to others nonparametric and consequently as a useful index for selecting stable genotypes in the crops (Mohammadi et al., 2009). Wricke's ecovalence W_i^2 measures the contribution of the genotype to the genotype by environment interaction. Values close to zero are an indicator of stability and conversely high values of W_i^2 are an indicator of unstability. A genotype with low ecovalence is considered ideal in terms of yield stability. Low W_i^2 suggests that this genotype is stable given its weak contribution to the interaction. According to the quantitative evaluation of the parameter W_i^2, four genotypes (5, 21, 32, 47) are stable, while according to the Shukla parameter σ^2_i - six genotypes (5, 21, 30, 32, 34, 47). Genotypes 5, 21, 32 and 47 have low values for both parameters and have high stability but they are characterized by low to medium high yields. Five genotypes (6, 11, 17, 19 and 50) have low values for S^2d_i and are considered stable according to this parameter. The b_i parameter is one of the most commonly used to assess stability. The genotypes with values equal to unity should be noted, as they have agronomic or dynamic stability and those with values greater than unity are responsive to the specific conditions of favorable environments. Genotypes 10, 15, 25, 34, 39, 41, 42, 43, 47, 53 have values around unity or equal to unity and are stable. Those genotypes are extremely valuable in terms of this growing area. Genotypes 1, 2, 6, 8, 23, 28, 38, 40 have values above unity and they are responsive to the specific conditions of favorable environments. These genotypes are valuable in terms of the regression coefficient b_i for the grain yield trait. Genotype 41 has achieved the highest yield and respectively regression coefficient $b_i = 1.00$. Based on the two parameters S^2d_i and b_i Hassan et al. (2013) identified several stable genotypes in terms of grain yield. In terms of the coefficient of variation CV_i genotypes with values below ten are stable, and on the other hand, genotypes with values from ten to twenty show a higher grain yield under better conditions. Two genotypes (19 and 37) have values below ten, and sixteen genotypes (7, 16, 17, 22, 26, 29, 33, 34, 35, 44, 45, 46, 48, 50, 51, 52) – between ten and twenty. The Kang parameter Ys_i combines both yield and stability, and low–ranking genotypes have high stability. Fourteen genotypes are defined as stable: 21, 26, 29, 30, 32, 33, 34, 37, 39, 44, 46, 47, 48, 52. These genotypes are very valuable in terms of complex assessment of stability and grain yield. They must be included in the durum wheat breeding improvement. Genotype 47 (Beloslava) has the most low parameters of stability and good mean grain yield. It appears to be extremely valuable for breeding in terms of grain yield.

Genotype 36 (Trakiets) has achieved mean grain yield for the three years of 6,054 t ha^{-1} and has no definite stability assessment. Genotype 37 (Deni) has achieved mean grain yield of 6,171 t ha^{-1} and has low values for NP^2, CV_i and has a low ranking-sum of Kang. Genotype 38 (Predel) achieved mean grain yield of 6,109 t ha^{-1} and is responsive in terms of the regression coefficient b_i. Genotype 39 (Victoriya) has achieved mean grain yield of 6,486 t ha^{-1}, has two low nonparametric estimates S^1 and NP^2, is defined as stable by the regression coefficient b_i and has a low ranking-sum of Kang. Genotype 40 (Reyadur) achieved mean grain yield of 6,257 t ha^{-1} and is responsive according to the regression coefficient b_i. Genotype 41 (Saya) has achieved mean grain yield of 6,853 t ha^{-1} and has low values on the nonparametric assessment S^1, S^2 and NP^2 and at the same time has a value of 1.00 for the regression coefficient b_i. Genotype 42 (Heliks) achieved mean grain yield of 6,431 t ha^{-1} and a low value for NP^2 and a value equal to unity for the regression coefficient b_i. Genotype 44 (Kehlibar) has achieved mean grain yield of 6,231 t ha^{-1} and has a low value for the nonparametric assessment NP^2 and a low ranking-sum of Kang. Genotype 45 (Viomi) achieved mean grain yield of 6,132 t ha^{-1} and a low nonparametric NP^2 assessment. Genotype 47 (Beloslava) has achieved mean grain yield of 5,490 t ha^{-1} and has a low non-parametric NP^2 assessment, two low parametric assessment, a regression coefficient b_i close to unity and a low ranking-sum of Kang. Genotype 52 (Dechko) achieved mean grain yield of 6,262 t ha^{-1} and has two low nonparametric assessment for S^1 and NP^2, as well as a low ranking-sum of Kang. Genotype 53 (Deyche) has low value for NP^2 and a regression coefficient b^i of close to unity. Bulgarian varieties Melina, Raylidur and Beloslava characterized with lowest ranking-sum of Kang and therefore they are the highest-yielding and most stable among all studied genotypes. Usually, the number of genotypes identified with both high and stable yields is not large in such studies with a large number of different genotypes in different environments and locations. Using parametric assessment, Karimizadeh et al. (2012) identified two stable genotypes in their study. Based on various parametric and nonparametric estimates, five durum wheat genotypes were identified as stable (Mohammadi & Amri, 2022).

Grain protein content (GPC): The average grain protein content over three years and calculated parametric and non-parametric indicators for the stability assessment of the tested genotypes are presented in Table 5. Fourteen genotypes 7, 9, 17, 18, 19, 21, 22, 29, 41, 43, 47, 49, 50 and 54 have mean value above 15% for this trait. Two Hungarian varieties - MVHundur (9) and MVMakaroni (19) and three Bulgarian varieties - Beloslava (47), Vazhod (49) and Zvezditsa (50) showed the highest grain protein content.

Table 5. Mean values for trait grain protein content in percentage (%) and parametric and non-parametric stability assessments

No	Mean	S^1	S^2	NP^1	NP^2	W_i^2	σ^2_i	S^2d_i	b_i	CV_i	Ys_i
1	13.7	6.6	28	14.6	2.9	0.1	0.05	0.005	0.86	8.4	41
2	14.2	14.6	154	20	1.3	0.6	0.33	0.08	1.14	11.3	49
3	14.8	7.3	37	5.3	0.1	0.05	0.02	0.007	1.01	9.2	15
4	14.9	13.3	121	14	0.2	0.2	0.10	5.6	0.76	6.8	23
5	14.3	23.3	408	30.6	0.9	1.2	0.61	0.01	1.55	14.5	53
6	14.0	0.6	0.3	6.3	2.6	0.02	0.008	0.003	1.01	9.7	34
7	15.2	12.6	109	14	0.1	0.3	0.14	0.01	1.23	10.8	19
8	14.2	19.3	220	27	1.2	0.8	0.43	0.09	0.77	8.2	51
9	15.6	4	10.3	9.3	0.2	0.1	0.06	0.02	0.99	8.6	12
10	14.3	25.3	417	18	0.7	2.4	1.27	0.04	0.21	3.2	51
11	14.3	3.3	7	13	1.1	0.07	0.03	1.5	1.14	10.6	7
12	14.9	16	171	24.6	0.4	0.5	0.24	0.03	0.73	6.9	21
13	14.1	8	36.3	6.6	1.0	0.06	0.03	0.001	0.87	8.2	38
14	14.1	8	37.3	14.6	1.6	0.2	0.1	0.02	1.10	10.6	42
15	14.6	22	286	24.6	0.5	0.7	0.4	0.006	0.55	5.1	45
16	12.9	0	0	24.6	50	0.6	0.3	0.07	0.77	8.8	54
17	15.1	5.3	19	3.6	0.2	0.01	0.005	0.002	1.06	9.4	3
18	15.0	16	145	21.3	0.3	0.4	0.2	0.04	0.86	8.08	30
19	15.4	8.6	44.3	7.3	0.2	0.06	0.02	0.004	1.09	9.5	5
20	14.6	3.3	7	2.3	0.3	0.01	0.003	4.5	0.99	9.0	19
21	15.1	8.6	46.3	6	0.2	0.06	0.02	0.004	1.09	9.6	2
22	15.0	4	9.3	9.3	0.1	0.07	0.03	0.01	0.98	8.8	5
23	14.5	12	89.3	11.3	0.5	0.3	0.16	0.02	1.22	11.3	39
24	14.6	8.6	42.3	12.6	0.5	0.07	0.03	0.002	1.12	10.2	3
25	13.8	2.6	4	7.6	3.6	0.06	0.03	0.001	0.87	8.4	33
26	14.2	8	39	20.6	1.6	0.2	0.13	0.03	0.94	9.2	14
27	13.7	3.3	8.3	19.3	5.3	0.3	0.2	0.02	0.79	8.1	50
28	14.3	16	165	23.6	1.0	0.5	0.3	2.2	1.37	12.8	47
29	15.1	18.6	196	21.6	0.2	0.4	0.2	0.04	0.78	7.4	26
30	14.3	9.3	52	5.3	0.7	0.05	0.02	0.007	1.01	9.5	22
31	14.8	22.6	294	24.6	0.5	1	0.5	0.003	0.47	4.3	31
32	14.3	4.6	16.3	16.6	1.2	0.2	0.07	0.02	0.99	9.5	9
33	14.2	20	228	25.3	1.1	0.7	0.4	0.09	1.14	11.4	28
34	13.9	8	39	20.3	2.4	0.2	0.1	0.03	0.94	9.4	32

Table 5 (continued)

35	14.8	10.6	65.3	19	0.3	0.2	0.09	0.005	1.23	11.0	26
36	14.9	21.3	331	16.6	0.3	1	0.5	0.06	1.38	13	42
37	14.9	11.3	74.3	10	0.2	0.2	0.08	0.01	1.15	10.4	10
38	14,6	14.6	137	18.6	0.6	0.5	0.3	0.01	1.34	12.3	42
39	14.6	27.3	444	28	0.5	1.1	0.6	0.15	1.16	11.6	48
40	14.6	20	233	23	0.5	0.6	0.3	0.07	1.15	11.0	25
41	15.1	14	111	23.3	0.2	0.7	0.2	0.015	0.72	6.5	18
42	14.2	22	342	32	0.9	1.3	0.7	0.01	0.58	6.8	34
43	15.2	20	258	17	0.1	0.6	0.3	0.09	0.95	9.1	23
44	14.7	26	381	26	0.5	0.9	0.5	0.06	1.37	12.7	46
45	14.7	12.6	104	10	0.2	0.2	0.1	0.001	0.75	6.8	13
46	14.1	10.6	67	16.6	1.7	0.3	0.2	0.03	1.13	11.0	17
47	15.6	2	3	8.6	0.3	0.02	0.007	0.001	1.06	9.1	1
48	14.9	20.6	301	29	0.4	1.01	0.5	0.009	1.51	13.5	40
49	15.7	4.6	14.3	14.6	0.2	0.13	0.06	0.001	0.81	6.9	10
50	15.7	5.3	19	12	0.2	0.3	0.15	0.04	1.05	9.1	15
51	14.9	6,6	30.3	12.3	0.1	0.08	0.04	0.001	0.85	7.6	8
52	14.4	10.6	64.3	18.6	0.9	0.2	0.09	0.005	1.20	11.1	36
53	14.8	15.3	162	14	0,2	0.5	0.23	0.06	1.02	9.7	37
54	15.0	16	147	18.6	0.2	0.38	0.19	0.05	0.90	8.4	28

Genotypes 6, 16, 25, 47 have low values on the two nonparametric assessments S^1 and S^2 and they are stable, but only of them has a high protein content (47). With regard to NP^1 with low values are seven genotypes: 3, 6, 13, 17, 20, 21, 30 and for NP^2 five genotypes: 3, 7, 22, 43, 51. Two genotypes from the first group - 17 and 21 and three from the second - 7, 22 and 43 are also characterized by grain proteincontent above 15%. According to the assessment of the parameter on Wricke W_i^2 six genotypes (3, 6, 17, 20, 30, 47) have low values, and in relation to the parameter of Shukla σ^2_i - four (6, 17, 20, 47). Genotypes 6, 17, 20 and 47 have high stability by both parameters, but only one of them is with high grain protein content (47). With low values for S^2d_i are six genotypes (13, 25, 45, 47, 49, 51) they are considered stable according to this parameter, but the majority of theme have a GPC content below 15%. It should be noted that genotypes with b_i values close or equal to unity are considered to be with the highest stability and those with a value greater than unity are responsive to the specific conditions of favorable environments. The obtained results shows that twelve genotypes (3, 6, 9, 17, 20, 22, 30, 32, 43, 47, 50, 53) have values close to or equal to unity and they are stable and suitable for the conditions of the region in terms of grain protein content. Ten genotypes 5, 7, 23, 28, 35, 36, 38, 44, 48, 52 are responsive to specific conditions of favorable environments with regression coefficient $b_i > 1$. All genotypes have a CV_i value between zero and twenty. Genotypes (2, 5, 7, 11, 14, 23, 24, 28, 33, 35, 36, 37, 38, 39, 40, 44, 46, 48, 52) have values between ten and twenty and respond positively to better growing conditions. All other genotypes in the study have values below ten and are stable for this trait. Acco rding to the ranking-sum of Kang, there are 11 stable genotypes: 11, 17, 19, 21, 22, 24, 32, 37, 47, 49, 51. These genotypes are very valuable in terms of grain protein content because they have a high to medium level of the trait and high stability. They must be included in the durum wheat breeding improvement work. Italian varieties Cesare (17) and Bulgarian one Beloslava (47) have the most low stability assessments, low regression coefficients and low ranking-sum of Kang, and they are extremely valuable for breeding programs in terms of grain protein content.

Genotype 7 (Progres) has achieved mean value 15.2% grain protein content and has a low non-parametric assessmnent NP^2 which defines it as a stable and regression coefficient above unity and it is responsive to favorable environment conditions. Genotype 9 (MVHundur) has achieved mean value 15.6% grain protein content and have low CV_i. With respect to the regression coefficient b_i is stable with a value very close to unity. Genotype 17 (Cesare) has achieved mean value 15.1% grain protein content. There is one low nonparametric assessment NP^2 and two low Shukla and Wricke`s parametric assessment. It also has a low CV_i, a regression coefficient b_i close to unity, and a low ranking-sum of Kang. Genotype 18 (Mirela) has achieved mean value 15.0% grain protein content and has a low CV_i. Genotype 19 (MVMakaroni) has achieved mean value 15.4% grain protein content and has a low CV_i and low ranking-sum of Kang. Genotype 21 (M. Aurelio) has achieved mean value 15.1% grain protein content and has a low non-parametric assessment NP^1. He has a low CV_i and a low ranking-sum of Kang. Genotype 22 (GKJulidur) has achieved mean value 15.0% grain protein content and has a low nonparametric assessment NP^2, low CV_i, regression coefficient b_i closer to unity and low ranking-sum of Kang. Genotype 29 (M.Meridio) has achieved mean value 15.1% grain protein content and a low CV_i. Genotype 41 (Saya) has achieved mean value 15.1% grain protein content and a low CV_i. Genotype 43 (Kehlibar) has achieved mean value 15.2% grain protein content and has a low nonparametric assessment NP^2, low CV_i and a regression coefficient close to unity. Genotype 47 (Beloslava) has achieved mean value 15.6% grain protein content and had two low nonparametric assessment S^1 and S^2. It is defined as stable by the parameters of Shukla, Wricke and by the deviation from the regression S^2d_i. Its regression coefficient is close to unity and is stable. It also has a low CV_i and the lowest ranking-sum of Kang. Genotype 49 (Vazhod) has achieved mean value 15.7% grain protein content and has a low S^2d_i, low CV_i and low ranking-sum of Kang. Genotype 50 (Zvezditsa) has achieved mean value 15.7% grain protein content and has a low CV_i and regression coefficient close to unity. Genotype 54 (Chirpanche) has achieved mean value 15.0 grain protein content and has a low CV_i. Variety Beloslava (47) has a high average protein content over the three years of testing and most assessments characterize it as stable and is extremely valuable in terms of breeding programs related to grain protein content. Genotypes 17 (Cesare) and 47 (Beloslava) with respect to this trait are highly stable and have a grain protein content of more than 15% and are defined as extremely valuable with regard to this trait and should be included in durum wheat breeding programs. Temtme & Tesfaye (2021) identified five stable genotypes based on grain protein content. In another study, Sakin et al. (2011) identified three stable genotypes with respect to this trait.

The success of crop improvement activities largely depends on the identification of superior varieties for mass production. A genotype can be considered superior if it has potential for high yield under favorable environment, and at the same time has a great deal of phenotypic stability. The genotype by environment interaction (GxE) is a major problem in the study of quantitative traits because it complicates the interpretation of genetic experiments and makes predictions difficult (Kadhem et al., 2010). Breeders permanently looking for efficient method of developing cultivars with improved yield. For that reason they should be include new genotypes in various cross combination in order to produce recombination of desirable genes. For breeders is very important to estimate genotype by environmental interaction through phenotypic variability (Knezevic et al., 2008).

Genotypes with low S^2d_i have higher stability than other genotypes. According to Sabaghnia et al. (2006), the ideal genotype is the one with the highest grain yield associated with a regression coefficient b_i that does not deviate from unity and an S^2d_i value of zero or close to zero. Among the genotypes evaluated in this study, only a few genotypes are close to this definition. According to Baranda & Sharma (2020) the regression technique was slightly improved by adding one more parameters i.e. deviation from regression by Eberhart & Russell (1966). According to them, both linear (b_i) and nonlinear (S^2d_i) function should be considered while judging the phenotypic stability of genotype. Tsenov & Gubatov (2018) and Desheva & Deshev (2021) established that the use of simple approaches for assessing the level and stability of grain yield such as regression coefficient (b_i), deviation from regression (S^2d_i) or coefficient of variation (CV_i) is close in efficiency to the capabilities of large statistical programs designed specifically for these purposes.

The idea of stability is to build 'a picture' of a genotypes performance against reference varieties over multiple seasons that allows the breeder to select desirable genotypes for improvements in one or more traits associated with grain yield and grain quality traits (Sissons et al., 2020). According to Bendjama et al. (2019) the mean grain yield of a genotype significantly positively correlated with the regression coefficient (b_i) and environmental variance (S^2). Therefore, selection for increased yield in durum wheat would be expected to change yield stability by increasing b_i and S^2.

Grain yield and grain protein content in durum wheat are two of the most important traits (Rapp et al., 2018). Their simultaneous improvement is an extremely difficult task, as they are negatively correlated (Taneva et al., 2019). Temtme & Tesfaye (2021) reveal that one genotype can be stable in one trait and unstable in another. Nevertheless, in our study we found one genotype 47 (Beloslava variety) shows high values on both traits and high parametric and non-parametric stability assessments, i.e. this variety has a complex breeding value (high average level and high stability) on both important agronomic traits. The Beloslava variety is extremely valuable for the durum wheat breeding improvement work and should be used in the breeding programs for this crop. Of the varieties tested, there are other valuable genotypes in terms of grain yield and stability or in terms of grain protein content and stability. In most cases, they are Bulgarian varieties created in FCI-Chirpan, which is expected, as durum wheat is a crop of micro-climate. In view of the fact that the experiments were conducted in Central Southern Bulgaria, the created varieties behave best where they were created. Grain yield being a polygenic trait shows association with a number of characters and these characters are greatly influenced by environmental conditions (years). Therefore, extensive research work is required to develop such varieties which could give high yield across different environments (Khan et al., 2012). The established stable varieties with regard to both traits are suitable for growing in the area of the experiments, i.e. Central Southern Bulgaria. The highly adaptable varieties can be grown in other areas.

All tested foreign varieties showed, under the specific pedo-climatic conditions of Central Southern Bulgaria, lower average grain yield in comparison with the best Bulgarian genotypes. However, some of them MVHundur (HUG) and MVMakaroni (HUG), Cesare (ITA), are distinguished by high and stable grain protein content and yields around average and can be included in our breeding program. The identified in this study most stable high yielding and with high grain protein content durum wheat varieties can be proposed for inclusion in the list of regional varieties well adapted to climate change and seeds of theme could be offered to farmers.

CONCLUSION

Analysis of variance reveal a significant influence of genotypes, environment and the interaction between genotype and environment (GxE) on the expression of both studied traits. The environment has the greatest influence on the variation of grain yield and grain protein content. Genotypes, with a high average level values and high stability in most stability assessments, are available for both traits. In terms of grain yield with a complex assessment of stability are the varieties Melina, Raylidur and Beloslava, and for the grain protein content are the varieties Cesare and Beloslava. These genotypes are of great importance for the durum wheat breeding improvement work for the separate traits. The Bulgarian variety Beloslava has a high average level values and high stability for the both studied traits grain yield and grain protein content, which characterizes it as very stable in different environments and this makes it very valuable for the breeding programs. The identified in this study most stable high yielding and with high grain protein content durum wheat varieties can be proposed for inclusion in the list of regional varieties well adapted to climate change and seeds of theme could be offered to farmers.

The obtained results will be contribute further to adjust the breeding strategy for simultaneously improvement of productivity and grain quality and creation of new durum wheat varieties well adapted to changing climate conditions.

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