Uluslararası Tarım Araştırmalarında Yenilikçi Yaklaşımlar Dergisi
International Journal of Innovative Approaches in Agricultural Research 2020, Vol. 4 (4), 436-446
https://doi.org/10.29329/ijiaar.2020.320.5

Original article

Peculiarities in the Structure of Yield in Common Wheat Accessions from Different Ecological and Geographic Origin

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Abstract

Dobrudzha Agricultural Institute (DAI) is the largest breeding center for cereals in Bulgaria. Among the varieties developed here, 36 genotypes were included in the national list, a large part of them being strong and medium strong wheat cultivars with increased strength. It is a disputable question if a plateau has been reached in the breeding of wheat and what are the further methods for increasing of the production potential. Until recently, the increasing of the spike productivity lay at the basis of the breeding strategy, primarily through a higher number of florets and grains formed per spikelet at the expense of a lower number of productive tillers. The contemporary high level of breeding and the market requirements impose the necessity to search for new approaches to increase productivity.

The aim of the investigation was to characterize the structure of the yield in new common winter wheat accessions included in the gene pool of DAI. The investigation was carried out during 2015 – 2019 and encompassed four growth seasons with different combinations of meteorological factors allowing for good differentiation. The trial was designed in two replicates, the size of the harvest plot being 10 m2. Sixty-six accessions from different ecological and geographic origin and with specific combination of the economically important traits were evaluated. The cultivars from France were with the highest coefficient of tillering, followed by the cultivars from Croatia and Germany. The variability with regard to 1000 kernel weight was considerable. The Bulgarian and Serbian accessions were with the highest absolute weight, and the French ones – with the lowest. The differences with regard to the number of grains in spike were significant at a high level, but in the separate group, Athlon (DE), Moison (F), Fani (BG), Fidelius (AT), Iveta (BG) Korona (BG) and Simonida (RS) were with high values of the trait. Within the period, the Bulgarian cultivars, which realized highest yield, were Rada and Dragana, and among the European ones, these were Andalou, Basmati, NS 407 and Sofru.

Keywords: Wheat, genetic Genetic resources, yield Yield structure.

Received: 20 November 2019 * **Accepted:** 15 December 2020 * **DOI:** https://doi.org/10.29329/ijiaar.2020.320.5

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INTRODUCTION

Dobrudzha Agricultural Institute (DAI) is situated in a region where the conditions are suitable not only for obtaining of high and stable yields of cereals, but also allow testing the developed materials under variable types of stress. The portfolio of DAI is exceptionally rich. The breeding strategy goes through different stages, each of which has its peculiarities. They are related to changes in the model and architectonics of the plant, the phenological development, the level and stability of the qualitative parameters, the resistance to abiotic and biotic stress, the nutrition regime and are in accordance with the market requirements (Mihova et al., 2018a). To a large extent, the structure of yield also experiences progress. Its main elements – number of productive tillers, number of grains in spike, and 1000 kernel weight are in a dynamic correlation, and the environmental conditions are a major factor in the total variation. In most cases, the cultivars with different origin possess specific structure resulting from the breeding pressure and the multiple selections in the hybrid populations carried out in the specific region. Until recently, the focus in the wheat breeding program of DAI was on the shorter stem while maintaining the number of internodes and leaves, and lower tillering at the expense of higher spike productivity (Panayotov, 2013). The introduction of new intensive production technologies requires a revision of this strategy.

One of the possibilities is increasing the number of productive tillers while aiming at a balanced structure of yield. A part of the *Rht* genes used in the programs of foreign breeding centers allows for this. Especially interesting are those genes, which have a favorable stem-spike ratio at the high efficiency of nutrients uptake.

Bulgaria is a small territory, which is characterized by varied soil and climatic conditions. Abiotic stress is a main limiting factor for production. Most often, these are unfavorable winter conditions and drought in all its forms. The tolerance to them is related to a large number of morphological (Ozturk, et al., 2014) and phenological peculiarities (Sheehan and Bentley, 2020), to major physiological and biochemical processes (Amudha and Balasubramani, 2011). This determines the complex nature of heritability and imposes the necessity to combine different approaches in the breeding and improvement work (Haak et al., 2017; Sreenivasulu et al., 2007). In the recent decades, genetic and molecular researches on cereals revealed homologous parts of their genome (Hori et al, 2003; Schreiber et al., 2009). Similar genetic systems with key role in their development were identified (Cockram et al., 2007), including those related to their response to stress (Cattivelli et al., 2002; Diab et al, 2007; Galiba et al, 2009). Such researches allow not only better understanding the mechanism of adaptation, but also distinguishing their specificity (Diab et al, 2007). After analysis of the risk factors for each breeding program, it is important to identify suitable sources for developing of genetic variability. This includes also genotypes developed under entirely different conditions, but with high adaptability potential, which can be realized under specific environments.

The aim of the investigation was to describe the structure of yield in new common winter wheat accessions included in the gene pool of DAI. It is a part of a wide-scale study on the available collection, its conservation and management (Mihova et al., 2018b).

MATERIAL and METHODS

Within four growing seasons (2015-2019), 66 new accessions of common winter wheat were evaluated (Table 1). They come from different breeding centers and possess specific phenological and biological traits. The experiment was designed in two replicates, the harvest plot area being 10 m^2. The sowing norm was 550 germinating seeds per m^2. The previous crop was grain pea. At the end of February, fertilization was done with 0.06 $t.ha^{-1}$ active matter of nitrogen. The biometrical measurements were in accordance with the methodology of UPOV (2008). The following parameters were analyzed: productive tillers of 1 m^2 (NPT), number; grains per spike (NGS), number; thousand kernel weight (W_{1000}), g and grain yield (YG) $t.ha^{-1}$.

The quantitative expression of the effect of the yield components on its formation over years is presented through multiple regression models of the type:

$Y=a+ b_1x_1+ b_2x_2+b_3x_3$, where the designations are as follows:

Y grain yield, $t.ha^{-1}$

x_1 productive tillers of 1 m^2, number

x_2 grains per spike, number

x_3 thousand kernel weight, g

The respective weight coefficients were designated with b. For the purpose of comparison, the experimental data were preliminary transformed to logarithms. The statistical processing was done with the help of the software packages Microsoft Excel^{xp} и STATISTICA, release 7.0 (StatSoft Inc., 2004).

Table 1. Core collection of new common winter wheat accessions.

Origin	Accessions
Austria (AT)	1. Albertus; 2. Antonius; 3. Balitus; 4. Fabius; 5. Fidelius; 6. Papageno; 7. Plinius; 8. Rainer; 9. Ubicus and 10. Urbanus.
Bulgaria (BG)	11. **Aglika (St)**; 12. Bozhana; 13. Dragana; 14. Fani; 15. Kalina; 16. Korona; 17. Kristi; 18. Kristalina; 19. Lazarka; 20. Nikodim; 21. Pchelina; 22. **Pryaspa (St)**; 23. Rada; 24. **Todora (St)** and 25. Zhana.
Croatia (HR)	26. Alka; 27. Andelka; 28. Katarina; 29. Kraljica; 30. Lucija; 31. Renata and 32. Srpanjka.
France (F)	33. Anapurna; 34. Andalou; 35. Andino; 36. Apache; 37. Avenue; 38. Basmati; 39. Exotic; 40. Foxil; 41. Solehio and 42. Toskani.
Germany (DE)	43. Athlon; 44. Attraktion; 45. Balaton; 46. Bitop; 47. Eduard; 48. Etana; 49. Felix; 50. Genius; 51. Joker; 52. Joseff; 53. Katarina; 54. Laurenzio; 55. Lukullus; 56. Midas; 57. Mulan; 58. Peppino; 59. Philipp; 60. Tobias and 61. Vulkanus.
Serbia (RS)	62. Ilina; 63. NS 40S; 64. Pannonia; 65. Renesansa and 66. Simonida.

RESULTS

The years of study allowed very good differentiation of the investigated accessions with regard to their development and peculiarities of yield formation (Table 2 and Figure 1). The lowest productivity was formed during the first growth season (2015-2016). The reasons were mass lodging at the wax and economic maturity, strong attack by leaf and yellow rust, which deteriorated grain filling. High mean productivity was registered during 2017-2018. The even distribution of rainfalls after heading facilitated the recovery of the plants after the heavy drought during the first stages of vegetative growth.

The variation between the genotypes was within a wide range and was determined both by their compensatory mechanisms and by some peculiarities of their phenological development. A high mean yield was also formed during the last growth season (2018-2019). Its specific features were late emergence, tillering in spring, strong drought during booting stage but favorable conditions during grain filling. Its longer duration was a key factor for the realized high mean yields.

The determined mean productivity between the groups of different origin was 6.55 and 7.97 $t.ha^{-1}$. In comparing the range of variation, it was observed that in each of them there were accessions with very high potential realized under the conditions of this region. The lowest mean yield was obtained from the Austrian and Croatian accessions. This was not incidental since the predominant part of them were from the group of the quality wheat and a comparison is inappropriate. Similar was the reason for the variation in the German accessions. Among the French cultivars, there was the highest number of medium wheat types and medium wheat types with increased strength. In this group, the highest productivity of 9.24 $t.ha^{-1}$ was determined. The results are in accordance with previous studies of our team (Mihova et al., 2018b), but during the last growth seasons the observations revealed different tendencies, which are especially important in determining the varietal structure. A part of the genotypes, primarily of West European breeding, could not compensate for the absent or weak tillering in the autumn months and their crops remained with low plant density. Others were damaged by late frosts, when during the second half of February, after a period of high daily temperatures, they quickly resumed their vegetative growth. The result was considerable searing of the leaf mass, especially in genotypes with erect rosette type (Figure 2).

Table 2. Key factors determining wheat development (2015-2019).

Growing season	**Extreme min t, °C**	**Extreme max t, °C**	**Sum of rainfalls (X-VI), mm**	**Differentiation factors**
2015-2016	-18.2	+32.0	507.1	Favorable winter conditions; occurrence of leaf and yellow rust; heavy rainfalls reason for mass lodging
2016-2017	-18.0	+34.5	407.8	Late emergence; unfavorable conditions for hardening; favorable conditions during grain filling
2017-2018	-15.0	+32.2	484.2	Drought during emergence and beginning of tillering; occurrence of leaf rust
2018-2019	-13.5	+32.5	291.9	Unsuitable stage for hardening and winter-survival; winter and spring drought; late spring frost; occurrence of leaf and yellow rust.

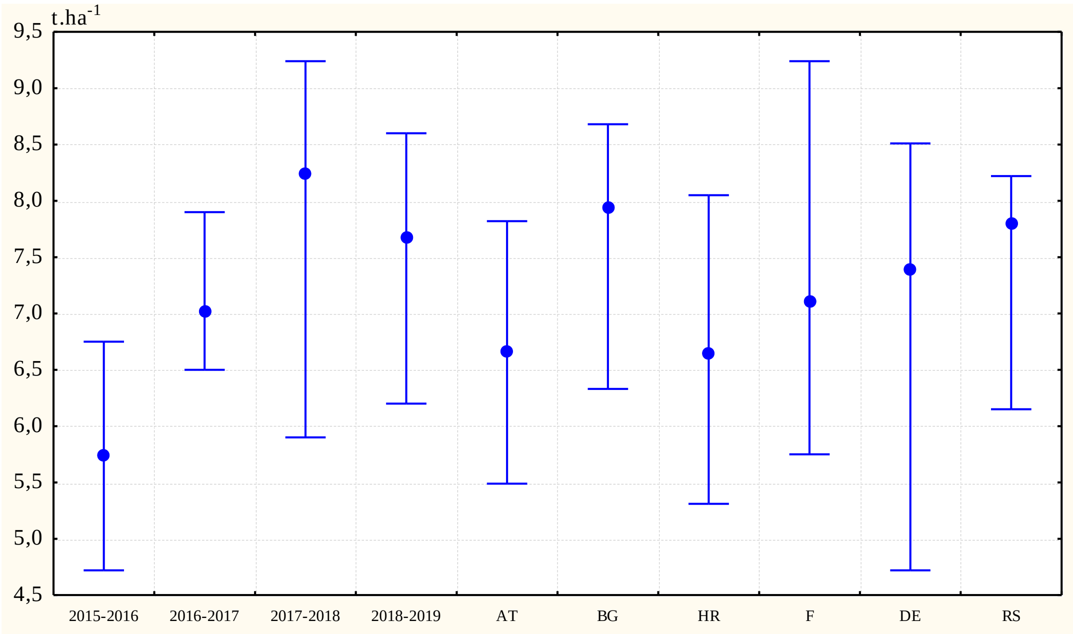

Figure 1. Mean yield (t.ha^{-1}) and range of variation according to growth seasons (Factor A) and wheat accessions from different origin (Factor B).

Year (A): GD P5%= 2.16; GD P1%=2.64; GD P0.1%=3.26

Group accessions (B): GD P5%= 1.24; GD P1%=1.48; GD P0.1%=1.98

Figure 2. Different degrees of damage caused by spring frosts, March 2019.

The analysis of the variance showed good differentiation between the groups of accessions depending on their origin (Figure 3). The genotypic specificity was with the highest percent with regard to the variation of the traits number of grains in spike and number of productive tillers. Lower was the effect on 1000 kernel weight, but the differences were also significant. The variation of the environmental conditions had the lowest effect on the formation of number of grains in spike, a moderate effect on the number of productive tillers and its highest effect was on 1000 kernel weight.

The correct interpretation of the results requires mentioning the fact that during the individual growth seasons different factors affected grain filling. During the first year of investigation, this was the high lodging degree. During the last two years, this was the occurrence of economically important diseases, and the tested accessions considerably differed by rate and type of attack. The significant interaction of the factors was an indicator for the specific reaction of the accessions from the different groups.

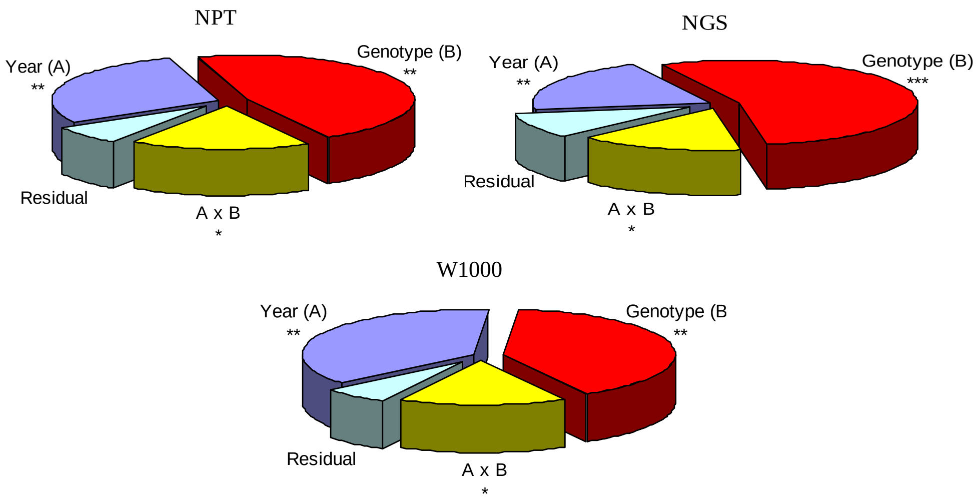

Figure 3. Two-way analysis of variance for yield components depending on environmental conditions (factor A) and genotype (factor B).

* P=5%; ** P=1%; *** P=0.1%

The detailed consideration of the yield structure revealed considerable variability by wheat groups depending on their origin (Figure 4). The Bulgarian cultivars were with high number of grains in spike and high absolute weight of grain. The number of productive tillers was low. The median at the lower boundary shows that the predominant part of the accessions was with low number of tillers, although there were certain accessions in the group, which had higher potential such as Bozhana, Kalina, Pchelina, and Todora.

The investigations showed that the predominant part of the cultivars developed at DAI had a coefficient of tillering within the range of 1-1.2 (Tsenov, 2013). Similar tendencies were observed in the group of Serbian wheat. In the Croatian and French cultivars, the number of productive tillers was a structure-determining trait. The medians of both groups were positioned at the upper boundary values. The reason for the wide variation were the results from harvest year 2018-2019. A part of the cultivars over-wintered at the wrong stage, tillering during the spring months was low and damages were caused by late occurrence of frosts.

Similar response was observed in Alka, Apache, Avenue, Lucija, Sarpanjka, Solehio and Toskani. The traits number of grains in spike and 1000 kernel weight were with low values and low to moderate variation. When compared, greater variation was observed only in the French cultivars, especially with regard to 1000 kernel weight. Anapurna, Andalou, Basmati, and Exotic were with high mean values of the structural components of yield. The accessions from Germany and Austria were with balanced combination of the traits. With the exception of number of grains in spike in the German wheat, the medians were close to the mean values indicating variability within the groups.

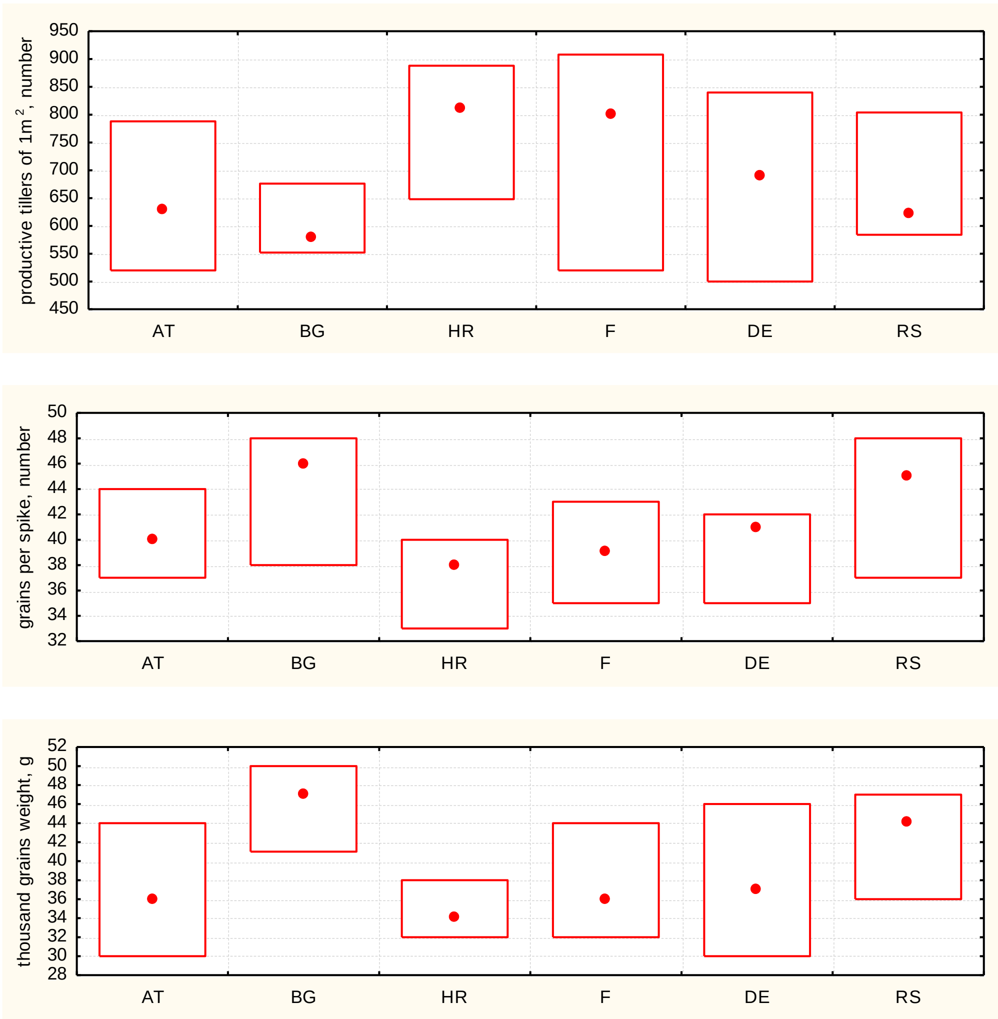

Figure 4. Median, minimal and maximal values of yield components in wheat groups depending on their origin.

Discussion

The obtained results confirmed that the new wheat accessions from the DAI collection excelled not only by their morphological and phenological specificity (Mihova et al., 2018b) but also by their yield structure. The investigation encompassed growth seasons with different combinations of stress factors typical for this region. This allowed comparing the weight coefficients of each structural component of yield on the formation of end productivity (Table 3).

Table 3. Multiple regression models characterizing the effect of the yield's structural components on its formation.

Multiple regression model	**$Y=a+ b_1x_1+ b_2x_2+b_3x_3$**	**R^2**
2015-2016	$Y=1.25-0.235x_1+2.654x_2 + 2.594x_3$	0.798
2016-2017	$Y=2.64+2.987x_1+1.752x_2 + 3.297x_3$	0.815
2017-2018	$Y=4.15-1.154x_1+1.591x_2+4.815x_3$	0.724
2018-2019	$Y=3.85+1.963x_1+2.632x_2+2.128x_3$	0.876

During the first growth season (2015-2016), the higher yield was related to a lower tillering coefficient and similar weight coefficients of number of grains in spike and 1000 kernel weight. A probable reason for this was the high level of tillering of all cultivars, regardless of their origin. At the end of the vegetative growth, mass lodging was observed in the genotypes which had formed the highest number of productive tillers and which were with higher number of seeds in spike. The lowest scores of resistance were registered in the Bulgarian, Austrian and Serbian breeding. In the following vegetative growth season (2016-2017), the combination of conditions was rather different. In such years, the formation of a good plant stand and the normal crop density was decisive for the end yield. The lower number of productive tillers is difficult to compensate for, especially if there are conditions for the mass occurrence of diseases. Under conditions of drought (2017-2018), the formation of a higher number of tillers was related to a decrease of yield, especially if the drought was longer and co-occurred with the periods of formation of reproductive organs and vegetative mass.

In 2018-2019, the highest productivity was obtained from the genotypes with a balanced combination of the traits. Since the entire phenological development occurred under the effect of different types of abiotic and biotic stress, the plants could not realize their potential in practice. The comparison between the weight coefficients of the yield's structural elements by year shows that it is desirable to search for balanced combinations ensuring better adaptability. This allows avoiding yield compromises because the negative effect of the conditions by phenophases is difficult to compensate for. Some compromise is possible if the breeding purpose is to develop varieties suitable for a specific region, with a high frequency of certain risk factors. A disadvantage of Bulgarian breeding is the low number of productive tillers. The new investigated accessions allow developing genetic diversity and cultivars with a higher coefficient of tillering, as well as involving of suitable genes for short stem against lodging.

Conclusions

Sixty-six accessions from different ecological and geographic origin were evaluated; they had specific combinations of economically important traits. The cultivars from France were with the highest coefficient of tillering, followed by those from Croatia and Germany. The variability with regard to 1000 kernel weight was considerable. The Bulgarian and Serbian accessions were with the highest absolute weight, and with the lowest – the French ones. The differences with regard to number of grains in spike were significant at low level, but in the respective groups, Athlon (DE), Moison (F), Fani (BG), Fidelius (AT), Iveta (BG) Korona (BG) and Simonida (RS) were with high values of the trait. Within the investigated period, the Bulgarian cultivars, which realized the highest yield, were Rada and Dragana, while the European ones were Andalou, Basmati, NS 407, and Sofru. The comparison by years of the weight coefficients of the structural components of yield on its formation showed that it is desirable to search for balanced combinations ensuring better adaptability.

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