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EVALUATION OF AND VARIABILITY IN YIELDS AND YIELD COMPONENTS OF WHEAT CULTIVARS IN NORTHERN SERBIA

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SUMMARY

The purpose of this research is to examine the variability in yields and yield components of wheat cultivars in Northern Serbia, examine and visualize their groupings and relationships, and determine the correlations between their traits using principal components analysis (PCA). A total of fifteen wheat genotypes (Triticum aestivum L.), developed in 10 different countries over a period exceeding 70 years, were analyzed during the growing seasons of 2018/2019 and 2019/2020 at Rimski šančevi, the experimental station of the Institute of Field and Vegetable Crops in Novi Sad. A phenotypic analysis was performed for the following wheat traits: spike weight, number of spikelets per spike, number of grains per spike, thousand grain weight, and grain yield. Data analysis was performed using descriptive statistics, an analysis of variance, a correlation analysis for interactions between the traits considered, and PCA. The results obtained indicate significant differences between the genotypes according to all the traits examined. The correlation analysis revealed significant positive correlations between the yields produced and nearly all yield components. The PCA confirmed the relationship between the traits examined, grouped the genotypes according to their performance, and highlighted the genotypes eligible for future breeding and research.

Key words: *genotype, variability, wheat, yield, yield components*

Abbreviations: CV - coefficient of variation; E - environment; G - genotype; G×E - genotype by environment interaction; GPS - number of grains per spike; PCA - principal component analysis; SPS - number of spikelets per spike; SW - spike weight; TGW - thousand-grain weight; Y - grain yield

INTRODUCTION

Cereals are of great economic and nutritional importance, and wheat (*Triticum aestivum* L.) is one of the most widely cultivated staple food crops in the world. Wheat is a good source of macronutrients such as carbohydrates, proteins, vitamins and minerals, and it is used to produce a broad variety of foods that include different types of bread, cakes, breakfast foods, biscuits and confections (Wani et al., 2011). With an average annual production of 750 million tons, wheat ranks third in the world's cereal production, after maize and rice. A total of 223 million ha are devoted to wheat, with an average yield of 3.5 t ha-1. In Serbia, wheat ranks second in the arable crop production, following maize. The average annual production of wheat in Serbia is about 2.5 million tons on an area of about 580,000 ha. Depending on the season, grain yields vary between 3.3 t ha-1 and 4.8 t ha-1 (FAOSTAT, 2020). Josipović et al. (2005) stated that the ideal wheat cultivar should express its full genetic potential for high grain yields and other desirable traits provided the variability in these traits were low in different environments. Winter, spring and facultative wheat types make wheat production possible in different environments, contributing to its wide distribution and use in the world.

The yield (Y) is a complex trait that consists of specific yield components. The expression of this quantitative trait largely depends on yield components and the effect of genotype (G), environmental factors (E), and genotype-by-environment interaction (G×E). Understanding the changes in yields, yield components and associated traits over time is an essential step for enhancing the knowledge about yield-limiting factors and forming future breeding strategies (Royo et al., 2006). Mladenov (2017) argued that the balance resulting from the effects of G, E, and G×E can be altered by changing one of the yield components, whereas Evans & Fisher (1999) claimed that the knowledge on genetic association between grain yields and its components would improve the efficiency of breeding programs by identifying the appropriate indices for selecting wheat varieties. In addition to the number of spikes per unit area, the basic components of yield include the number of grains per spike (GPS) and grain weight, and other important characteristics of the spike such as spike weight (SW) and the number of spikelets per spike (SPS) (Petrović, 2019). The success of plant breeding depends on the information on genetic and phenotypic variability in yields and yield components (Ullah et al., 2011). Therefore, an agromorphological analysis of these quantitative traits can provide an insight into the diversity of materials used in breeding programs. It is a challenging task for breeders to enhance the level of production as the growing population of the world will require more and more food (Arya et al., 2017). Arya et al. (2017) also stated that a major concern of a plant breeder is the constant improvement of the best available genotypes to increase their yield potential, either directly or indirectly through improving various factors that contribute to high yields. Accordingly, breeding methodology should focus on improving breeding material both through selection and hybridization of superior genotypes. The purpose of this study is to examine the variability and differences in yields and yield components of 10 winter wheat cultivars in Northern Serbia. A principal components analysis (PCA) was used to examine and visualize the groupings of and relationships between the wheat cultivars considered, and determine the correlations between their traits.

MATERIAL AND METHODS

Plant material

The genetic material analyzed included a total of 15 winter wheat cultivars from the collection used in the breeding program at the Small Grains Department of the Institute of Field and Vegetable Crops, Novi Sad, Serbia. The fifteen winter wheat genotypes used in this study were developed in 10 different countries over a period exceeding 70 years (Tab. 1). The genotypes were selected according to the following criteria: year of release, country of origin, historical importance, and recent high-yielding cultivars that have not been examined yet (GRIS, 2020).

Table 1. Year of recognition, country of origin and pedigree of the wheat cultivars analyzed

No.	Wheat cultivar	Year of release	Country of origin	Pedigree
1.	Bankut 1205	1931.	Hungary	Marquis/Bankuti-5
2.	Cheyenne	1933.	Nebraska, USA	(S)Crieman/(S)Turkey-Red
3.	Norin 10	1935.	Japan	Daruma/Fultz//Turkey-Red
4.	Capelle Desprez	1946.	France	Vilmorin-27/Hybride-Du-Jonquois
5.	Bezostaja 1	1959.	Russia	Lutescens-17 /Skorospelka-2
6.	NS Crvena	1967.	Serbia	U-1/Selkirk//San-Pastore/3/Mara
7.	Rusalka	1970.	Bulgaria	S-13/BAN-54
8.	Centurk	1971.	Nebraska, USA	Kenya-58/Newthatch//Hope/2*Turkey/3/Cheyenne/4/Parker
9.	Nova banatka	1973.	Serbia	Bezostaya-4/Argelato/Bezostaya-1
10.	PKB Krupna	1979.	Serbia	Avrora/Crvena-Zvezda
11.	Avalon	1980.	England	Maris-Ploughman/Bilbo
12.	Famulus	1982.	Austria	Kormoran/3/F-7736//F-7736/Probus
13.	Renesansa	1994.	Serbia	Yugoslavia/NS-55-25
14.	Malakhit	2000.	Russia	Albatros-Odesskii/Lutescens-1043-10-42
15.	Matrix	2007.	Germany	Hattrick/Tuerkis

Site location

A field experiment was conducted at Rimski šančevi, the experimental station of the Institute of Field and Vegetable Crops in Novi Sad (45°20’N, 19°51’E, 84 m a.s.l.) during the 2018/19 and 2019/20 growing seasons. The meteorological elements of the site were recorded at the nearest meteorological station and were obtained from the electronic publications "Meteorological Yearbook - Climatological Data" of the Republic Hydrometeorological Institute of Serbia (RHMZ, 2020). During the two growing seasons, the average temperatures recorded were 11.3 °C and 11.6 °C in 2018/19 and 2019/20, respectively. The total amounts of precipitation were 456.2 mm and 554.6 mm in 2018/19 and 2019/20, respectively (Fig. 1, 2).

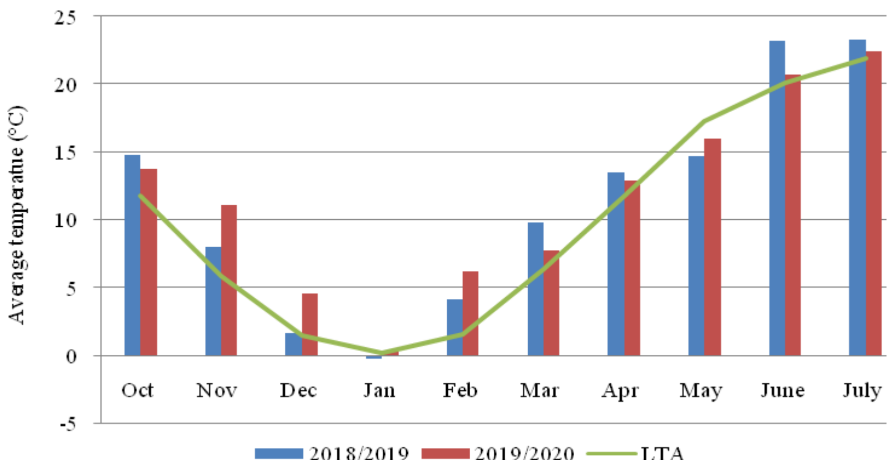

Figure 1. The average temperature values recorded in 2018/2019 and 2019/2020 compared to the long-term average (LTA) values

Temperatures higher than the long-term average (LTA) temperatures were recorded almost every month in both growing seasons. Temperatures corresponding to the LTA were recorded in the December of 2018 (1.7 °C), the January of 2019 (-0.2 °C), the January of 2020 (0.4 °C) and the June of 2020 (20.7 °C). The insufficient precipitation amounts during October and November are a common problem in Serbia as they slow down the emergence of wheat, suppress its growth and delay the qualitative stages of organogenesis (Kovačević et al., 2012). The months of February, March, June, July, October and November were extremely dry in 2018/19, with the total amount of precipitation considerably less than the LTA. The precipitation deficit was considerably less pronounced in 2019/20 than in 2018/19 compared to the LTA (Fig. 2). In 2019/2020, the precipitation rates recorded in January, April, May and October were below the LTA. Large amounts of precipitation were recorded in the May of 2019 (147.5 mm) and the June of 2020 (161.9 mm).

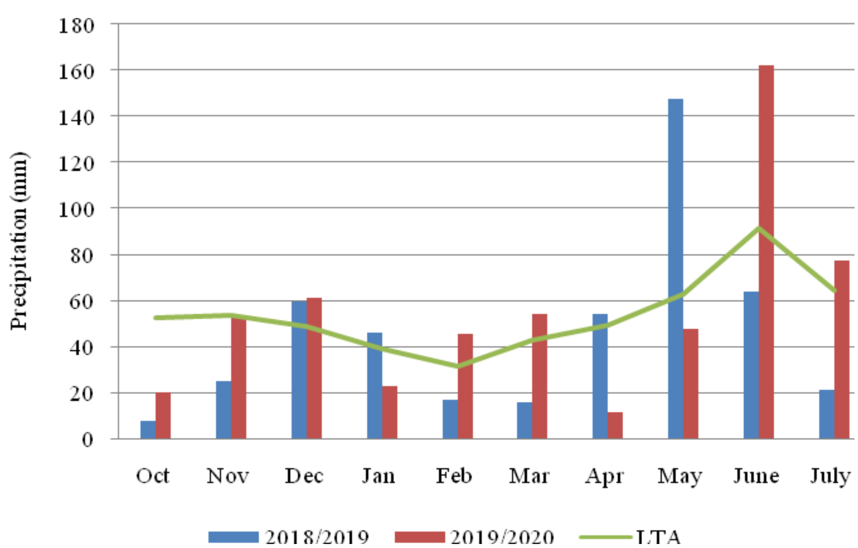

Figure 2. Total precipitation rates in the seasons of 2018/2019 and 2019/2020 compared to long-term average (LTA) values

Field experiment

The experiment conducted was set in a completely randomized design in three replications. The size of the demonstration plot was 2 m². The sowing of wheat cultivars selected was performed in the middle of October in 2018 and 2019, with a density of 550 germinating grains per square meter. The type of soil was chernozem, and soybeans were the previous crop. Mineral fertilizers were applied in doses of 50 kg N ha^{-1}, 60 kg P ha^{-1} and 60 kg K ha^{-1} prior to sowing. A soil analysis was performed using the N-min method in the February of each experimental year, and 50 kg N ha^{-1} of ammonium nitrate (33% N) was added in the form of top-dressing. In the April of 2018 and 2019, the experimental plot was treated with herbicides and insecticides. In the May of 2018 and 2019, the insecticide treatment was repeated with the addition of fungicides. Weeds were removed periodically either manually or by hoeing. The harvest was carried out when the crops were in the phase of physiological maturity, i.e. at the beginning of July in 2018 and 2019 when the grain moisture was below 13%. The following agronomic traits were analysed: grain yield, spike weight, number of spikelets per spike, number of grains per spike, and thousand grain weight (TGW).

Data analysis

Descriptive statistics and the analysis of variance (ANOVA) were performed using the XLSTAT software, an add-on of Microsoft Office Excel 2010. Tukey's multiple comparisons test of the means obtained (at a 5% significance level) was performed to test differences between the mean values. Further data analysis included PCA. Principal components analysis is a method of multivariate analysis that is applied in the case of a large number of variables.

The reduction of data dimensionality was done by reducing the number of source variables to a smaller number of indices that are a linear combination of source variables called principal components. Using the Pearson correlation coefficients, a correlation analysis was applied to assess the relationship between the analyzed traits. According to the scale proposed by Dawson & Trapp (2004), a correlation between two variables can be characterized as very weak (r = 0.00 to 0.25 and 0.00 to -0.25), weak (r = 0.25 to 0.50 and -0.25 to -0.50), moderate to strong (r = 0.50 to 0.75 and -0.50 to -0.75), and very strong (r = 0.75 to 1 and -0.75 to -1).

RESULTS AND DISCUSSION

Descriptive statistics

The winter wheat genotypes considered were found to have a relatively high level of phenotypic variation in all the traits analyzed (Tab. 2). The coefficient of variation ranged from 10.47% for SPS to 20.56% for Y. The yields recorded varied from 4.57 t ha^{-1} to 9.48 t ha^{-1}, with the mean for all the analyzed genotypes of 7.13 t ha^{-1}, revealing a large amount of phenotypic diversity among the cultivars. Despite a relatively small number of analyzed genotypes in this study, the coefficient of variation for Y indicates a higher genetic variability in the genotypes compared to previous studies (Ali et al., 2008; Baranwal et al., 2012; Fellahi et al., 2013; Kumar et al. 2013), which provides solid grounds for further investigation of the suitability of these genotypes in breeding for yield.

Table 2. Descriptive statistics of agronomic traits analysed

Agronomic traits	Mean	SE	Minimum	Maximum	CV (%)
Grain yield (t ha^{-1})	7.13	0.16	4.57	9.48	20.56
Spike weight (g)	2.26	0.06	1.28	4.20	20.44
Number of spikelets per spike	20.00	0.25	17.00	24.00	10.47
Number of grains per spike	48.73	0.11	32.00	68.00	20.08
Thousand-grain weight (g)	38.32	0.77	27.00	60.00	19.17

Legend: SE - standard error; CV - coefficient of variation

The SW and GPS show a considerable phenotypic diversity (with a coefficient of variation above 20%), followed by the TGW (with a slightly lower CV of 19.2%), suggesting a broad genetic variability of the genotypes relative to the traits examined. In other studies, the coefficients of variation for the analyzed yield components were usually lower. Guo et al. (2018), Mecha et al. (2017) and Bhushan et al. (2013) measured the CVs for SPS of 6.3%, 6.9% and 7.5%, respectively. However, the CV for SPS above 13% was recorded in the studies encompassing a larger number of varieties (Nukasani et al., 2013; Ali et al., 2008). For GPS, most of the previous research observed lower CV values than in this study, ranging from 10.7% in 30 wheat varieties (Kumar et al., 2013), 12.6% in 215 wheat genotypes (Guo et al., 2018), 14% in 36 varieties (Khodadadi et al., 2011), 16% in 64 wheat varieties (Mecha et al. ,2017), 19.8% in 114 wheat lines (Nukasani et al., 2013), or even up to 25.8% as reported by Ali et al., 2008. In like fashion, the CVs for TGW in previous findings were lower than in this report, generally increasing with the number of genotypes considered from 4.8% (Shamsi et al., 2011) to 15.7% (Nukasani et al., 2013). A greater variability in the analyzed traits observed in a relatively smaller number of genotypes than in previous studies could be due to a different geographic origin of the cultivars (Tab. 1) and various breeding parental materials used in different breeding programs, which was undoubtedly reflected in the varietal genetic backgrounds and lead to the diversification of phenotypic expression of the yield and yield components in the studied environments.

Analysis of variance

The analysis of variance for yield showed statistically significant differences between the genotypes, two seasons, and the genotype by season interactions (Tab. 3). The significant effects of the wheat genotype, the environment and the genotype by environment interaction were well reported in many studies (Al-Otayk, 2010; Riaz-ud-Din et al., 2010; El-Shafi et al., 2014). Grain yields are very variable and extremely susceptible to the influence of environmental factors (Đurić et al., 2020). The complexity of yield is reflected in the fact that, in addition to environmental factors, it can be influenced by morphological and physiological characteristics of plants such as the stem height and strength affecting the plant resistance to lodging, adaptability and stability to abiotic and biotic stress factors, vegetation period, harvest index, maturity time, development of the root system and the ability of the plant to absorb nutrients (Roksandić, 2010).

Table 3. Comparison of means and ANOVA

Genotypes/ wheat cultivars	Y (t ha-1)	SW (g)	SPS	GPS	TGW (g)
Renesansa	9.36^{a}	3.32^{a}	21.17^{abc}	59.00^{ab}	42.40^{bc}
Malakhit	9.20^{ab}	2.92^{abc}	18.17^{e}	48.00^{bcdef}	59.47^{a}
Avalon	8.51^{abc}	3.80^{ab}	23.50^{a}	66.83^{a}	37.67^{de}
Novosadska crvena	8.30^{abcd}	2.05^{d}	19.17^{bcde}	55.67^{abc}	32.28^{gh}
Nova banatka	8.23^{abcd}	2.71^{abcd}	21.00^{abcd}	50.67^{bcde}	40.62^{c}
Bezostaya 1	8.01^{bcd}	2.18^{bcd}	18.33^{de}	41.00^{ef}	43.80^{b}
Capelle Desprez	7.55^{cde}	2.15^{cd}	23.00^{a}	45.00^{cdef}	35.13^{ef}
Centurk	7.08^{def}	2.30^{bcd}	18.50^{cde}	41.17^{def}	36.67^{e}
Famulus	6.36^{efg}	2.35^{bcd}	21.17^{abc}	47.17^{bcdef}	32.43^{fg}
PKB Krupna	6.23^{fg}	2.18^{cd}	21.33^{ab}	40.17^{ef}	40.02^{cd}
Rusalka	6.03^{fg}	2.03^{d}	18.50^{cde}	37.17^{f}	42.40^{c}
Bankut 1205	5.96^{fg}	2.34^{bcd}	19.50^{bcde}	45.67^{def}	34.98^{efg}
Matrix	5.50^{g}	1.96^{d}	19.83^{bcde}	41.67^{cdef}	32.40^{fgh}
Norin 10	5.45^{g}	2.04^{d}	17.50^{e}	53.00^{bcd}	29.58^{h}
Cheyenne	5.24^{g}	1.96^{d}	19.50^{bcde}	40.17^{e}f	36.08^{e}
2019	6.96^{b}	2.22^{b}	20.07^{a}	46.89^{a}	38.95^{a}
2020	7.30^{a}	2.56^{a}	19.97^{a}	48.09^{a}	37.62^{b}
Genotype	**	**	**	**	**
Season	*	**	ns	ns	**
Genotype × Season	**	ns	**	**	**

Legend: Y - grain yield; SW - spike weight; SPS - number of spikelets per spike; GPS - number of grains per spike; TGW - thousand-grain weight; ****** - significant at a 0.01 probability level; ***** - significant at a 0.05 probability level; ns - not significant. Different letters indicate significant differences (p<0.05) between average values. The means followed by a common letter are not significantly different (p<0.05) within the genotypes/seasons.

Of the wheat cultivars considered, 'Renesansa', 'Malakhit' and 'Avalon' were the three best ranked wheat cultivars according to the average Y and SW values. Moreover, the high-yielding cultivars 'Renesansa' and 'Avalon' had the highest values of SPS and GPS, whereas 'Malakhit' had the highest TGW values. 'Malakhit' was placed in the group of cultivars with the lowest SPS and GPS values, whereas 'Avalon' was among the cultivars with lower TGW values. Considering grain yields, 'Novosadska crvena' and 'Nova banatka' were found to have nearly the same performance as the top three high-yielding cultivars. 'Novosadska crvena' also had the highest GPS, whereas 'Nova banatka' was among the cultivars with the highest SW and SPS values. The worst performing cultivars according to the Y, SW and SPS values were 'Matrix', 'Norin 10' and 'Cheyenne'. In addition, 'Matrix' and 'Cheyenne' had the lowest GPS, whereas 'Cheyenne' was among the genotypes with the lowest TGW values. The growing season (environment) effect was significant for all the traits, except for the SPS and GPS. The significant effect of the environment on the majority of traits analyzed was due to unfavourable meteorological conditions during the seasons of 2018/19 and 2019/20 (the former growing season was more unfavourable than the later compared to the LTA, especially in terms of precipitation distribution (Fig. 1, 2). Irrigation is not widely used in the crop production in

Serbia. Therefore, wheat yields largely depend on weather conditions (Jeločnik et al., 2019). The favourable annual precipitation distribution is a distribution that provides crops with the required amounts of water for their growth and development, particularly during the critical phenological stages such as flowering, seed setting and grain-filling. Reduced environmental effects on the SPS and GPS values obtained may be accounted for by a more prominent and significant influence of the wheat genotypes, which were less responsive to environmental changes (Fig. 1). Significant G×E interactions were recorded for all the traits analysed, except for the SW.

The ANOVA revealed highly significant differences in the genotypes and growing seasons for the SW values (Tab. 3), indicating significant effects of the wheat genotypes and environmental conditions. These results are consistent with the findings of Mollasadeghi & Shahryari (2011), Banjac (2015) and Zečević et al. (2016). Banjac (2015) stated that SW represented the total weight of the generative part of the wheat plant and that it was a quantitative trait inherited by the minor gene system, which allowed significant phenotypic variation under the influence of environmental factors, as well as the genotype by environment interaction, both under favourable growing conditions and abiotic stress conditions. It is a trait that depends on GPS, which is influenced by the number of fertile spikelets per spike, which, in turn, largely depends on environmental factors (Guo et al., 2016). A significant variability in the SW of the examined genotypes may be the result of unequal floret fertilization during flowering and grain-setting, since a large amount of precipitation was recorded in May 2018/19 (which could have affected the flowering and floret fertilization). Due to differences in the genetic makeup, vegetation length, growth and development rates of the genotypes with diverse origin, not all the cultivars considered entered phenological phases at the same time. Therefore, some cultivars might have been more susceptible to unfavourable meteorological condition in flowering and grain-setting than the other that were more tolerant to unfavourable weather conditions.

Significant effects of the genotype and G×E were found for SPS (Tab. 3). Favourable conditions such as sufficient moisture and optimal soil nitrogen and phosphorus supply are crucial for the development of a satisfactory number of fertile spikes (Milošević & Kobiljski., 2011). Rawson (1970) stated that SPS varied depending on the plant spacing, level of nitrogen nutrition, day length, temperature and light intensity. Significant differences between wheat genotypes were reported in the studies of Monpara & Kalariya (2009), Haq et al. (2010), Nukasani et al. (2013), and Roksandić (2010). Roksandić (2010) reported that this trait was not the basic component of yield, that it did not directly affect yield, but that it was important for breeding programs because it could affect the number of grains per spike as one of the main components of yield.

The GPS was significantly affected by the genotype and G×E (Tab. 3). The ANOVA showed significant differences in the genotypes for GPS, confirming differences between the cultivars considered according to this trait. The broad genetic variability in the GPS, as one of the main yield components, indicates the possibility of using the genotypes considered as a source of genetic variability in future breeding research to create more variable populations with superior genotypes (Roksandić, 2010). The number of grains per spike determines the productivity of the spike and the final grain yield. Breeding for improved yield could be achieved by breeding for higher GPS combined with other yield components (Marić et al., 1998). The maximum GPS depends on the number of fertile SPS, a trait that largely depends on environmental factors. This quantitative trait is also greatly influenced by environmental factors and crop management practices such as sowing density, in terms that a higher sowing density implies less GPS (Marić et al., 1998). A lack of soil moisture during spikelet formation may result in the shortening of spikelet lengths and reducing the number of fertile spikelets and GPS. The favourable environmental conditions are especially important for successful grain setting and good grain quality during the critical stages of grain formation, grain-filling and maturing. If the flow of grain filling is interrupted, forced ripening occurs due to the shortening of developmental phases and causing small and unfilled or partially filled grains, thus ultimately reducing yields.

The analysis of variance indicated that the TGW was affected by the genotype, environment and their interaction (Tab. 3), confirming the results of Farnia & Tork, 2015. Mollasadeghi & Shahryari (2011), Nukasani et al. (2013), Philipp et al. (2018), Singh et al. (2012) and Guo et al. (2018) reported significant differences in wheat genotypes. The meteorological conditions of growing seasons influenced the phenotypic expression of TGW. In the growing season of 2018/19, there was a lack of precipitation in June during the grain-filling period. If unfavourable conditions such as a lack of precipitation or high temperatures occur in this period, when the accumulation of dry matter is most intensive, TGW is decreased, and thus the overall yields decrease. TGW is a function of plant species and varieties, breeding, environmental conditions, applied management practices, seed composition and moisture, drying and processing (Mirić et al., 2007). It is used to determine the sowing rate and can be an indicator of the quality of some other traits (Mladenov, 2017). TGW depends on several factors such as abiotic and biotic factors, crop management practices, drying, and seed processing (Mirić et al., 2007). Higher TGW can be achieved with high fertility, quality tillage, higher fertilization doses, irrigation, appropriate pest management, early harvest before ripening, slow drying, correct purification, and proper calibration.

Correlation analysis

The correlation analysis revealed significant positive correlations between the yields and almost all yield components (Tab. 4). Significant positive values of correlation coefficients were recorded between the Y and SW (r = 0.807, p = 0.001), the Y and GPS (r = 0.580, p = 0.023), the Y and TGW (r = 0.591, p = 0.020), and the SW and GPS (r = 0.650, p = 0.009). Jocković (2015) stated that correlations between important agronomic traits could directly or indirectly facilitate the selection of desired traits. The yield and its components (SW, SPS, GPS and TGW) directly or indirectly affect the yield expression. The interrelationships between TGW, GPS, SW and Y showed significant positive correlations, which can be described as moderate to strong (Dawson & Trapp, 2004). Therefore, the focus of selection should be to improve the SW, GPS and TGW so to indirectly improve the Y. The positive values of Pearson's coefficients were also present among other traits, except between the SPS and TGW (r = -0.156) and he GPS and TGW (r = -0.05), but none of them were significant.

Table 4. Correlation analysis for the agronomic traits examined

Traits	SW	SPS	GPS	TGW	Y
SW	**1**	0.350	0.650**	0.565*	0.807**
SPS	0.201	**1**	0.418	-0.156	0.260
GPS	0.009	0.121	**1**	-0.052	0.580*
TGW	0.028	0.578	0.853	**1**	0.591*
Y	0.001	0.349	0.023	0.020	**1**

Legend: Y - yield; SW - spike weight; SPS - number of spikelets per spike; GPS - number of grains per spike; TGW – thousand-grain weight; ** - significant at a 0.01 probability level; * - significant at a 0.05 probability level

Singh et al. (2012) reported positive significant correlations between the Y and SW, and the Y and GPS by analyzing 44 wheat genotypes. Significant positive correlations between the Y and GPS, and the Y and TGW, as well as a negative correlation between the GPS and TGW, were confirmed by Jocković (2015), who analyzed the combination abilities of different parental wheat genotypes at two different locations. Desheva (2016) reported significant positive phenotypic and genotypic correlations between the GPS and SPS, the GPS and Y, and the TGW and Y of five wheat genotypes. Azimi et al. (2017) confirmed positive correlations between the Y and GPS, the Y and TGW, a positive correlation between the GPS and SPS, but also negative correlations between the TGW and SPS, the TGW and GPS, analyzing 35 genotypes at late sowing. Ayer et al. (2017) showed significant positive correlations between the Y and TGW, and the Y and GPS, as well as a negative correlation between the GPS and TGW, by analyzing 50 genotypes of wheat in sandy loam. Petrović et al. (2017) noted a positive correlation between the SW and GPS, analyzing seven wheat varieties in chernozem and solonetz soils, indicating that in better growing conditions of chernozem soils all varieties reached their phenotypic and genetic potentials, which further confirmed the dependence of the genotype on environmental factors. Accordingly, it is possible to conclude that the expression of yield directly depends on yield components and different growing conditions.

Principal components analysis

The principal components analysis showed that the first two principal components account for 82.9% of the total variance (Fig. 3). The first principal component, accounting for 55.6% of the variation, was mostly defined by the SW, Y and GPS, whereas the second principal component, accounting for 27.3% of the total variation, was mostly contributed to by the TGW and SPS. PCA tends to reduce the data dimension while retaining those data characteristics contributing the most to the overall variance (Filipović, 2018). Data interpretation offers a clear insight into data variability and, at the same time, indicates the interrelationships and correlations of the data obtained. According to Jolliffe (2005), the first few main components contain the majority share of the total variance in the original variables, so it is enough to select two or three components to summarize the multidimensional view without considerable data loss.

All the traits examined have long vectors directed in the same direction and certain genotypes grouped around them. The genotypes that are grouped on the left-hand side of the biplot around the trait vectors had higher average values of the analyzed agronomic traits than the genotypes found on the opposite side of the biplot. The angle that these vectors formed indicates an approximate correlation between the traits examined. 'Renesansa' was positioned close to the vectors for Y and SW, indicating that this variety had high values of these traits. 'Avalon' and 'Malakhit', which grouped around the vectors for GPS and TGW, were the nearest to 'Renesansa'. 'Nova banatka' was placed towards the vectors for Y and SW, indicating higher trait values than those in the genotypes on the right-hand side of the biplot, but not as high as in 'Renesansa', 'Avalon' and 'Malahkit'. In like fashion, 'Capelle Desprez' was placed close to the vector for SPS, implying that this variety has a high value of SPS (but being away from the vectors for Y, SW and TGW, it is less interesting for breeding). The biplot showed that the rest of the genotypes were positioned opposite to the direction of the trait vectors and thus had low values of yields and yield components.

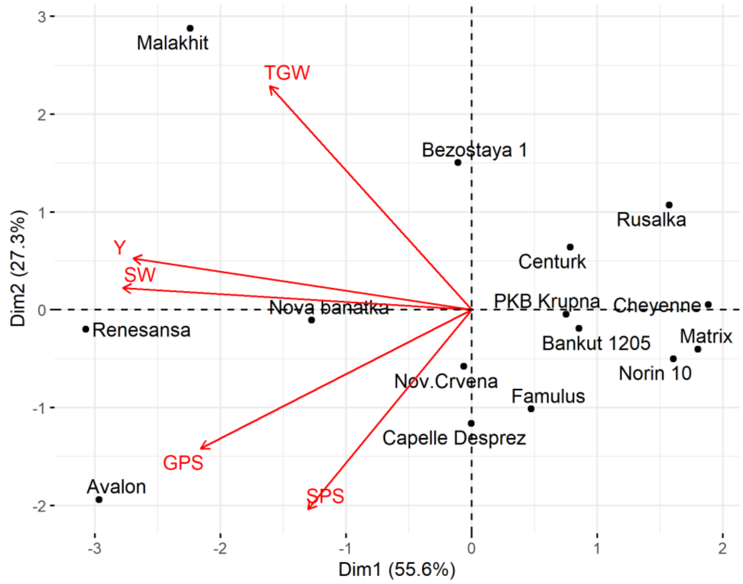

Figure 3. PCA biplot diagram of agronomic traits examined in the growing season of 2018/19. SW – spike weight, SPS - number of spikelets per spike, GPS - number of grains per spike, TGW - thousand-grain weight, Y – yield

CONCLUSION

The results obtained show a considerable variability in the traits analyzed and the diversity of wheat genotypes considered. The variability in most of the analyzed traits can be considered a result of the influence of genotype, season and genotype × season interaction. Significant positive correlations were recorded between the yield and spike weight, the yield and number of grains per spike, the yield and thousand-grain weight, and the spike weight and number of grains per spike. The correlations established indicate that the focus of selection should be placed on the improvement of spike weight, number of grains per spike and thousand-grain weight in order to indirectly improve the yield. The principal component analysis provided insight into the relationships between the wheat genotypes considered and the correlations between the analyzed agronomic traits. 'Matrix', 'Cheyenne' and 'Norin 10' were characterized by the lowest values of the traits examined. 'Renesansa', 'Malakhit' and 'Avalon' were the three best ranked wheat cultivars according to the average values of yields and yield components, thus being favourable for breeding programs aimed at improving yields.

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