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DUS TESTING CHARACTERISTICS RELATION WITH AGRO-MORPHOLOGICAL AND QUALITY TRAITS OF WINTER WHEAT

DUS SVOJSTVA RAZLIČITOSTI, UJEDNAČENOSTI I STABILNOSTI POVEZANIH S AGRO-MORFOLOŠKIM SVOJSTVIMA I PARAMETRIMA KVALITETE OZIME PŠENICE

Valentina Španić, Katarina Šunić, J. Duvnjak, Z. Lalić, L. Drenjančević, G. Jukić, I. Varnica

ABSTRACT

In a field trial, a database of qualitative traits associated with agro-morphological and quality traits of winter wheat (*Triticum aestivum* L.) has been collected. The present study aimed to determine the relationships between the winter wheat traits of productivity and quality with traits of Distinctness, Uniformity and Stability (DUS) testing. In addition, according to grain yield and significantly correlated traits, investigated genotypes will be clustered. Grain yield was significantly positively correlated with the number of days to heading, time of ear emergence, and plant growth habit. Based on the grouping of the winter wheat genotypes using the Euclidean distance algorithm, wheat genotypes were separated into five main clusters according to the similarity of those four traits. The grouping pattern was very origin homogeneous in each group, and the grouping pattern of genotypes appeared to be associated. The highest contributor to a grouping of genotypes was grain yield. The established result pertain to the potential for increasing the grain yield of winter wheat.

Keywords**:** DUS characteristics, genotypes, grain yield, quality, wheat

SAŽETAK

U poljskom pokusu prikupljena je baza podataka kvalitativnih svojstava povezanih s agromorfološkim i kvalitativnim svojstvima ozime pšenice (*Triticum aestivum* L.). Cilj ovog istraživanja bio je utvrditi odnose između svojstava produktivnosti i svojstava kakvoće ozime pšenice sa svojstvima različitosti, ujednačenosti i stabilnosti (DUS). Osim toga, prema urodu zrna i značajno koreliranim svojstvima, cilj je bio ispitivane genotipove grupirati. Urod zrna bio je u značajnoj pozitivnoj korelaciji s brojem dana do klasanja, s vremenom klasanja i tipom busanja. Natemelju grupiranja genotipova ozime pšenice na temelju algoritma Euklidske udaljenosti, genotipovi pšenice razdvojeni su u pet glavnih klastera prema sličnosti ta četiri svojstva. Uzorak grupiranja bio je vrlo ujednačens obzirom na podrijetlo u svakoj skupini ukazujući na povezanost grupiranja genotipova. Najveći utjecaj na grupiranje genotipova imao je urod zrna. Utvrđeni rezultati odnose se na mogućnosti povećanja uroda zrna ozime pšenice s pomoću specifičnih DUS svojstava.

Ključne riječi: DUS svojstva, genotipovi, urod zrna, kvaliteta, pšenica

1. INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is the most widely grown of all crops. The major target of breeding work is focused on the increase of winter wheat grain yield due to the predicted growth of the human population and decrease in the production area. In Croatia, winter wheat is also one of the dominant crops, with a cultivation area of approximately 164,000 hectares in 2023 (Croatian Bureau of Statistics, 2023).

Breeders need around ten years to develop and test homozygous wheat genotypes, after which the genotypes undergo the process of varietal recognition. Distinctness, Uniformity, and Stability (DUS) is a basis for an intellectual property system introduced in 1961 by the International Union for the Protection of New Varieties of Plants (UPOV, 2024) for breeders' investment protection and has been adopted by most countries. At the EU level, according to Council Regulation 2100/94, since April 1995, the Community Plant Variety Office (CPVO) has been created. It is a self-financed EU agency responsible for the management of the Community Plant Variety Rights System. DUS testing is also the requirement for a new wheat variety to obtain a release permit and recognizes both the plant 'breeder's right (PBR) and the plant variety right (PVR). DUS characteristics are evaluated in the field environment or greenhouse to ensure that a new variety is distinct from existing varieties, that its characteristics are uniform, and that the variety is stable in phenotypic characteristics from one generation to the next.

The latest guidelines for DUS testing were issued in 2019 and consisted of 27 characteristics (CPVO/TP-003/5). DUS testing can be used for identification and registration of varieties, plant variety protection (PVP), varietal information systems, and the grouping of different varieties (Bhim et al., 2015). Additionally, the measurement of the descriptors is used to assess diversity, though it can be relatively intensive due to the environmental effects, especially when differences are minimal between genotypes. The descriptors for DUS testing and varietal classification are morphological characteristics (Joshi et al., 2018). Further, DUS characteristics are qualitative traits that remain stable over environments and generations (Raut, 2003), thus being reliable for characterizing wheat genotypes. Conversely, environmental factors affect morphological traits, especially disease-resistant traits, or other quantitative traits, such as stress or tolerance resistance and flowering time (Achard et al., 2020). Wheat DUS testing involves a phenotypic evaluation of all 27 characteristics in Croatia. In addition to DUS testing, value for cultivation and use VCU testing is mandatory for certain crops in the EU and serves as evidence of the effectiveness of wheat genotypes and their ability to meet the end-users' requirements (Gilliland and Gensollen, 2010). VCU testing refers to grain yield, tolerance or resistance to biotic and abiotic stresses, grain quality traits, and factors in the physical condition. Grain yield is one of the most complex traits for wheat genetic improvement and is strongly influenced by wheat genotypes and numerous environmental factors. It would be beneficial to understand the correlation between quantitatively and qualitatively inherited characteristics and their influence on grain yield as a result of varietal response.

This study was carried out to assess the possible relationship between the traits used for determining DUS characteristics and the agro-morphological and quality traits of 34 winter wheat genotypes undergoing recognition. Additionally, wheat genotypes will be clustered based on grain yield and possible highly correlated traits with grain yield.

2. MATERIALS AND METHODS

2.1. Field trial

The evaluation trial of winter wheat lines was conducted at the station of the Croatian Agency for Agriculture and Food in Osijek (45°32′ N, 18°44′ E) in the 2022/2023 growing season. The experiment was laid out in two field blocks in a randomized complete block design, first adjusted for VCU testing (OG 7/2024) with standard agro-technics to observe the genetical yield potential along with quality traits, and the second following the CPVO protocol (CPVO/TP-003/5) for DUS testing which guarantees the optimized conditions for morphological scoring of varieties. The total amount of applied nitrogen (N), phosphorus (P), and potassium (K) was 136:90:135 kg ha^{-1} for the VCU block and 104:90: 135 kg ha^{-1} for DUS, respectively.

2.2. Plant material and investigated traits

The trial included 34 winter wheat genotypes that were subjected to DUS characterization for the 27 characters. Seed: color (A), seed coloration with phenol (B), and coleoptile: anthocyanin coloration (C) (Table 1) were DUS traits evaluated on the submitted seed. Eleven traits (labeled as D-L, XY and XYZ in Table 1) were measured in field plots during the growing season. The number of days to heading was counted from the sowing to heading stage. Plant height was measured from the base of the plant to the end of the spike (cm), prior to harvest. After harvest in July 2023, moisture content was adjusted at 14%, after which grain yield (t ha^{-1}), test weight (kg hl^{-1}), and quality traits were measured. Four quality traits (starch content, protein content, gluten content, and sedimentation value) were measured by Near Infrared (NIR) analysis. Thirteen traits (labeled as M-XX in Table 1) were evaluated on post-harvest samples from field-grown plots.

2.3. Statistical analysis

Quantitative traits (grain yield, test weight, starch content, protein content, sedimentation value, plant height, and number of days to heading) were calculated as a mean of two replications (I and II, and III and IV were merged from field), while qualitative traits were evaluated. Pearson pairwise correlation at $p<0.01$ was calculated for polymorphic traits (Tang et al., 2023). Cluster analysis of 34 investigated genotypes was performed based on Euclidean distances of average values of three highly positively correlated traits with grain yield (Tang et al., 2023). Contribution of traits was statistically analyzed using the Statistica software (version 14).

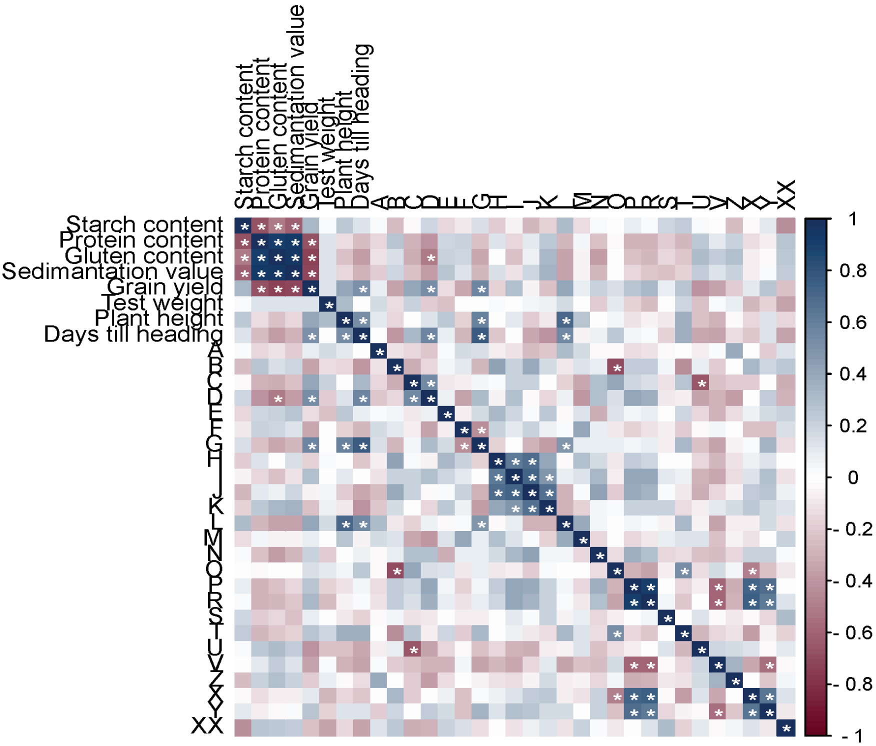
Table 1 DUS characteristics evaluated in 34 winter wheat genotypes

Tablica 1. DUS svojstva ocjenjena na 34 genotipova ozime pšenice

Label Oznaka	DUS characteristic DUS svojstvo	States of expression / Stupanj ekspresije
A	Seed: colour / Zrno: boja	1 white, 2 reddish, 3 purple, 4 bluish 1 bijelo, 2 crveno, 3 ljubičasto, 4 plavo
B	Seed: coloration with phenol Zrno: obojenost s fenolom	1 absent or very light, 3 light, 5 medium, 7 dark, 9 very dark / 1 izostaje ili vrlo svijetlo, 3 svijetlo, 5 srednje, 7 tamno, 9 vrlo tamno
C	Coleoptile: anthocyanin coloration / Koleoptila: obojenost antocijanom	1 absent or very weak, 3 weak, 5 medium, 7 strong, 9 very strong / 1 odsutno ili vrlo slabo, 3 slabo, 5 srednje, 7 jako, 9 vrlo jako
D	Plant: growth habit Biljka: tip busanja	1 erect, 3 semi-erect, 5 intermediate, 7, semi-prostrate, 9 prostrate / 1 uspravno, 3 polu-uspravno, 5 intermedijarno, 7 semi prostratum, 9 prostratum
E	Plants: frequency of plants with recurved flag leaves / Biljke: frekvencija biljaka sa povijenim listom zastavičarom	1 absent or very low, 3 low, 5, medium, 7 high, 9 very high / 1 odsutna ili vrlo niska, 3 niska, 5 srednja, 7 visoka, 9 vrlo visoka
F	Flag leaf: anthocyanin coloration of auricles List zastavičar: antocijansko obojenje aurikula	1 absent or very weak, 2 medium, 3 strong 1 odsutna ili vrlo slaba, 2 srednja, 3 jaka
G	Time of ear emergence (first spikelet visible on 50% of ears) Vrijeme klasanja (prvi klasić vidljiv na 50% klasova)	1 very early, 3 early, 5 medium, 7 late, 9 very late 1 vrlo rano, 3 rano, 5 srednje, 7 kasno, 9 vrlo kasno
H	Flag leaf: glaucosity of sheath List zastavičar: voštana prevlaka na rukavcu	1 absent or very weak, 3 weak, 5 medium, 7 strong, 9 very strong / 1 odsutno ili vrlo slabo, 3 slabo, 5 srednje, 7 jako, 9 vrlo jako
I	Fleg leaf: glaucosity of blade List zastavičar: voštanost plojke	1 absent or very weak, 3 weak, 5 medium, 7 strong, 9 very strong / 1 odsutno ili vrlo slabo, 3 slabo, 5 srednje, 7 jako, 9 vrlo jako
J	Ear: glaucosity Klas: voštanost	1 absent or very weak, 3 weak, 5 medium, 7 strong, 9 very strong / 1 odsutno ili vrlo slabo, 3 slabo, 5 srednje, 7 jako, 9 vrlo jako
K	Culm: glaucosity of neck Voštana prevlaka vrata	1 absent or very weak, 3 weak, 5 medium, 7 strong, 9 very strong / 1 odsutno ili vrlo slabo, 3 slabo, 5 srednje, 7 jako, 9 vrlo jako

L	Plant: length (stem,ears,awns and scurs) / Biljka: visina (stabljika, klasovi, osje i produžeci pljevica)	1 very short, 3 short, 5 medium, 7 long, 9 very long 1 vrlo kratka, 3 kratka, 5 srednja, 7 duga, 9 vrlo duga
M	Straw: pith in cross section Slama: debljina stjenke na presjeku	1 thin, 2 medium, 3 thick or filled 1 tanka, 2 srednja, 3 debela ili ispunjena
N	Ear: density / Klas: zbijenost	1 very lax, 3 lax, 5 medium, 7 dense, 9 very dense 1 vrlo rijedak, 3 rijedak, 5 srednji, 7 zbijen, 9 vrlo zbijen
O	Ear: length (excluding awns and scurs) / Klas: duljina (bez osja ili produžetka pljevica)	1 very short, 3 short, 5 medium, 7 long, 9 very long 1 vrlo kratak, 3 kratak, 5 srednji, 7 dug, 9 vrlo dug
P	Ear: scurs and awns / Klas (produžeci pljevica ili osje)	1 both absent, 2 scurs present, 3 awns present 1 oboje odsutni, 2 prisutni produžeci pljevica, 3 prisutno osje
R	Ear: length of scurs or awns Klas: dužina pljevica ili osja	1 very short, 3 short, 5 medium, 7 long, 9 very long 1 vrlo kratki, 3 kratki, 5 srednji, 7 dugi, 9 vrlo dugi
S	Ear: colour / Klas: boja	1 white, 2 coloured (red) / 1 bijeli, 2 obojeni (crveni)
T	Ear: shape in profile Klas: forma u profilu	1 tapering, 2 parallel sided, 3 slightly clavate, 4 strongly clavate, 5 fusiform 1 piramidalan, 2 paralelan, 3 slabo čunjast, 4 jako čunjast, 5 fusiforman
U	Apical rachis segment: area of hairness of convex surface Vršni segment rahise: dlakavost konveksne površine	1 absent or very small, 3 small, 5 medium, 7 large, 9 very large / 1 odsutna ili vrlo mala, 3 mala, 5 srednja, 7 velika, 9 vrlo velika
V	Lower glume: shoulder width Donja pljeva: širina ramena	1 very narrow, 3 narrow, 5 medium, 7 broad, 9 very broad 1 vrlo usko, 3 usko, 5 srednje, 7 široko, 9 vrlo široko
Z	Lower glume: shoulder shape Donja pljeva: oblik ramena	1 strongly sloping, 3 slightly sloping, 5 horizontal, 7 slightly elevated, 9 strongly elevated 1 jako nagnuto, 3 blago nagnuto, 5 vodoravno, 7 blago uzdignuto, 9 jako uzdignuto
X	Lower glume: length of beak Donja pljeva: dužina vrha	1 very short, 3 short, 5 medium,7 long, 9 very long 1 vrlo kratak, 3 kratak, 5 srednji, 7 dug, 9 vrlo dug
Y	Lower glume: shape of beak Donja pljeva: oblik vrha	1 straight, 3 slightly curved, 5 moderately curved, 7 strongly curved, 9 geniculate 1 ravan, 3 blago povijen, 5 umjereno povijen, 7 jako povijen, 9 koljenast

XX	Lower glume: area of hairiness on internal surface Donja pljeva: dlakavost unutarnje površine	1 very small, 3 medium, 5 very large 1 vrlo malo, 2 srednje, 5 vrlo jako
XY	Lower glume: hairiness of external surface / Donja pljeva: dlakavost vanjske površine	1 absent, 9 present 1 odsutna, 9 prisutna
XYZ	Seasonal type / Sezonalni tip	1 winter type, 2 alternative type, 3 spring type 1 ozimi tip, 2 prijelazni tip, 3 jari tip



Explanation of letters (A-XX) used in Figure 1. can be found in Table 1. (Material and Methods).
Objašnjenje slova (A-XX) na Slici 1 mogu se pronaći u Tablici 1 (Materijal i Metode).

Figure 1 Correlation analysis of agro-morphological traits, grain quality traits and DUS characteristics

Slika 1. Korelacijske analize agro-morfoloških svojstava, kvalitete zrna i DUS svojstava

3. RESULTS AND DISCUSSION

Based on the distinctiveness test using visual scoring, 27 DUS characteristics were observed. Variations between wheat genotypes were not found for lower glume hairiness of external surface and seasonal type, thus being monomorphic, and were omitted from further analysis. Other 25 DUS traits showed polymorphic variation and were included in correlation analysis. Together with DUS characteristics, agro-morphological and quality traits were calculated, thus reflecting the VCU value of tested genotypes. Both, grain yield and quality are the most important traits determining the economic value of bread wheat crop.

3.1. Correlations amongst investigated traits

Correlation analysis based on four-grain quality traits, grain yield, test weight, plant height, days to heading, and 25 DUS characteristics were performed to show relationships among them (Figure 1). Pearson's correlation coefficients were used to create a correlation matrix amongst the different traits under study, and it was found that there were 40 highly significant correlations. Sometimes, simple correlation studies may be insufficient to explain the associations that will enable breeders to know which traits to concentrate on during selection, but further phenotyping will give more accurate information.

Starch content negatively correlated with protein content, gluten content, and sedimentation value, while significant positive correlations were observed between protein content, gluten content, and sedimentation value. In previous research, grain protein was consistently positively correlated with gluten content, while no significant correlation was found with sedimentation value (Johnson et al., 2019). Further, three-grain quality traits (protein content, gluten content, and sedimentation value) showed significant negative correlation with the grain yield. The latter was expected, as similar results were obtained previously (Spanic et al., 2016). Plant growth habit was negatively correlated with gluten content, while plant growth habit positively correlated with grain yield, days to heading, and anthocyanin coloration of the coleoptile. Lozada et al. (2021) reported that the main genetic factors affecting grain yield in wheat are the major growth habit and adaptation genes, which include the vernalization, photoperiod, and reduced height genes. Further, in the current research, days to heading had a positive correlation with grain yield and plant height. Supporting this correlation, the time of ear emergence (first spikelet visible on 50% of ears) showed a significant positive correlation with grain yield, plant height, and days to heading. Also, a strong correlation of days to heading with ear length and the number of spikelets per ear was obtained that consequently influenced grain yields (Ullah et al., 2021). In environments that are under the influence of climatic changes, the main strategy is to develop early maturing wheat genotypes as an adaptive mechanism. For example, Croatia has also experienced terminal heat and drought stress during the last few years (Vuković et al., 2022), however, in 2022/2023, there was a huge amount of precipitation during the growing season, a more favorable season for genotypes that were later in maturity.

Ear length (excluding awns and scurs) showed a significant negative correlation with the seed coloration with phenol and anthocyanin coloration of coleoptile. Although ear length is a quantitative trait linked to the grain yield, the current research was qualitatively described. Previously, it was reported that the number and weight of seeds in the ear changed in proportion to the length of the ear (Lozhkin et al., 2020). Further, hard red wheat is typically darker in color than soft white, and usually, it has lower grain yield but better quality. A significantly positive significant correlation was observed between ear length (excluding awns and scurs) and ear shape in profile, while ear length (excluding awns and scurs) was negatively correlated with lower glume: length of beak. It was reported that forms of wheat ears that are usually longer are long low-density ears and, more rapidly could be dried after the rain, which reduces the susceptibility of plants to disease and the formation of large grains with good quality (Diordiieva et al., 2022). Furthermore, the anthocyanin coloration of the auricles of the flag leaf had a negative correlation with the time of ear emergence (the first spikelet was visible on 50% of the ears). Beside auricles, purple pigmentation caused by anthocyanins can appearon leaves, culm, glumes, grains, coleoptile, and anthers. Anthocyanins are flavonoid pigments that have a role in adaptation under biotic and abiotic stresses (Landi et al., 2015) by modulating the activity of various enzymes, hormones and antioxidants. Therefore, in the current research, the amount of anthocyanin could regulate the time of ear emergence in stress conditions in some wheat genotypes. Also, the purple color of coleoptile, culm and anthers was related to resistance to bunt (Shoeva and Khlestkina, 2015). Therefore, anthocyanin coloration of any wheat tissues is favorable not only because of its visibility but also because of its benefit in greater resistance to herbivory, fungal diseases, bacterial infections, heavy metals and other stresses (Khusnutdinov et al., 2021).

Ear scurs and awns, and ear length of scurs or awns were in significantly negative correlation with lower glume: shoulder width, and in positive correlation with lower glume: length of beak and lower glume: shape of beak. The research of Li et al. (2023) suggested that the glume and awn of ears play prominent roles during grain filling in wheat, especially under drought stress, and that the awn is more crucial than the glume. Further, our research showed a significantly negative correlation of lower glume: the shape of the beak with lower glume: shoulder width and also a significantly positive correlation with lower glume: length of beak. Glume is the closest organ to the grain and has a particular role in grain filling (Kohl et al., 2015). Interestingly. some research foundthat lower glume beak length varies in different environments (Tasnuva et al., 2010), making the trait difficult to characterize. However, the current research did not show a significant relation with grain yield. According to Takač et al. (2019), the traits that contributed the most to the genotype distinction were ear coloration, length of the beak of the lower glume, lower glume shape, ear length of awns at tip relative to ear length and color of awns. Also, all morphological traits might indicate the adaptation of the genotypes to the environment, and could synergistically influence grain yield.

3.2. Grouping of wheat genotypes according to grain yield and yield-correlated traits

The results indicated that the wheat materials have high genetic diversity in the evaluation of the phenotypic characteristics of DUS testing and grain yield. Morphological characterization of genotypes helps create a database on which these can be distinguished and the genetic diversity existing in them can be assessed.

The 34 winter wheat genotypes were divided into five main groups according to the dendrogram (unrooted) constructed from the grain yield, days to heading and qualitative traits (plant: growth habit and time of ear emergence (first spikelet visible on 50% of ears) that were highly positively correlated before (Figure 2). With principal component analysis, genotypes were also grouped according to the origin, as in the dendrogram in Figure 2. Table 2 shows that the greatest contribution to factor 3 was grain yield, to factors 1 and 4 days till heading, and to factor 3 plant: growth habit. This was expected as grain yield, the most important and complex trait, reflects the interaction of the environment with all growth processes that occur throughout the growing season.

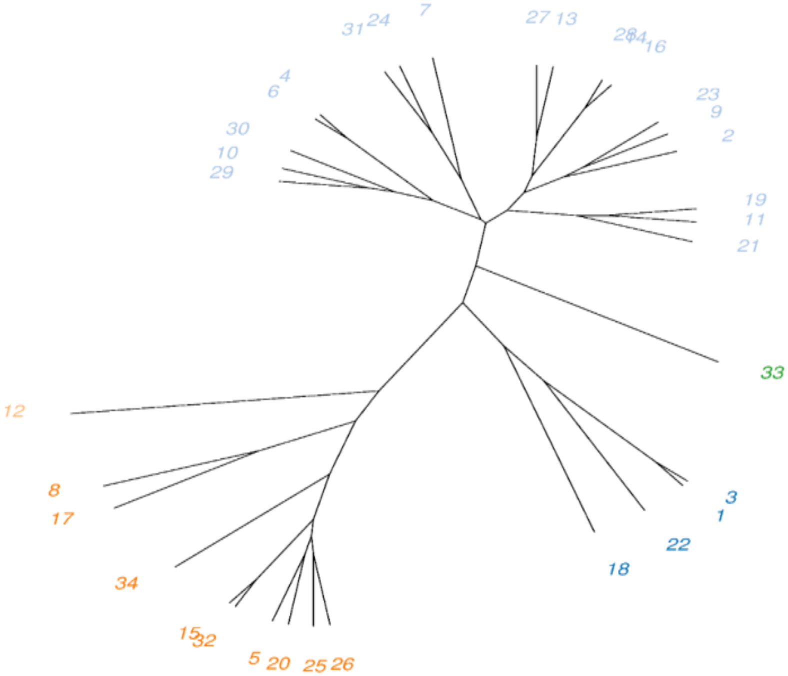


Figure 2 Dendrogram of 34 winter wheat genotypes based on grain yield, days to heading and qualitative traits (plant: growth habit and time of ear emergence (first spikelet visible on 50% of ears))

Slika 2. Dendrogram 34 genotipova ozime pšenice na temelju uroda zrna, dana do klasanja i kvalitativnih svojstava (biljka: tip busanja i vrijeme pojave klasa (prvi klasić vidljiv na 50% klasova))

Table 2 Contribution of four investigated traits

Tablica 2. Doprinos četiri istraživana svojstva

Trait Svojstvo	Factor 1 Faktor 1	Factor 2 Faktor 2	Factor 3 Faktor 4	Factor 4 Faktor 5
Grain yield / Urod zrna	0.227838	0.037563	0.697839	0.036760
Days till heading / Dani do klasanja	0.306641	0.050246	0.177286	0.465828
Plant: growth habit / Biljka: tip busanja	0.197575	0.568414	0.124594	0.109416
Time of ear emergence (first spiklet visible on 50% of ears) / Vrijeme pojave klasa (prvi klasić vidljiv na 50% klasova)	0.267946	0.343777	0.000282	0.387995

The first cluster had one genotype (12) that originated from France and was similar to the genotypes in the second cluster. The main difference between the first and second clusters was the number of days to heading, which was the lowest in genotype 12. All genotypes within the first and second clusters had similar grain yield. The second group consisted of nine genotypes with an average grain yield of 8 t ha^{-1} with 202 as the average number of days to heading. Plant growth habit and ear emergence were scored from 4 to 8 and from 4 to 7, respectively. These genotypes in the second cluster originated from France, with two exceptions from Croatia. Genotypes 8 and 17 had a score of 7 for the time of ear emergence, compared to other genotypes in the second cluster with a score of 4-5. Other genotypes in the second cluster were very similar to each other with respect to those four traits. As a major wheat exporter, 'France's crop prospects impact many countries, as they dedicate a lot of work to the creation of new wheat varieties. In French wheat, genetic variation in earliness was evident in previous research due to variability in the soil and climate conditions in different regions of France (Metakovsky and Branlard, 1998). However, in Croatia, these materials showed a tendency of medium to late ear emergence. In the year with high Fusarium head blight or other ear disease pressure during flowering, French genotypes are more likely to avoid ear diseases than genotypes with earlier ear emergence. The third cluster contained four genotypes (18, 22, 1 and 3). All genotypes originated from Croatia and, compared to the first and second clusters, had lower grain yield with an average value of 4 t ha^{-1} and a smaller number of days to heading (average 195). Plant growth habit and ear emergence were scored from 1 to 3. It seems that those genotypes were earlier in ear emergence compared to the first two clusters. The date of ear emergence and grain yield are traits that are reliably influenced by growing conditions, and in the more favorable growing seasons, relationship between these two traits will be weaker, and vice versa (Tsenov et al., 2021). According to that, we conclude that the growing season 2022/2023 was not favorable for wheat grain yield due to disease occurrence, and later genotypes in ear emergence or genotypes planted in later sowing dates obtained higher grain yield (Spanic et al., 2023).

The fourth cluster contained only one genotype (33) with a similar grain yield of genotypes from the third cluster, but this genotype had a larger number of days to heading (the average number was 198), plant growth habit with a score of 1 and time of emergence with a score of 4. The fifth cluster was the largest, including 19 genotypes (21, 11, 19, 2, 9, 38, 16, 14, 28, 13, 27, 7, 24, 31, 4, 6, 30, 10 and 29). These genotypes mostly originated from the Pannonian region except three genotypes that originated in France.

The average grain yield of genotypes in the fifth cluster was 7 t ha^{-1}, counting 197 days to heading on average. Plant growth habit and ear emergence were scored from 2 to 5. It was reported that in the Pannonian Plain, wheat grain yield has more than doubled in the last few decades due to improvements in both plant breeding and crop production management (Jocković et al., 2022). As mentioned before, FHB disease could have affected genotypes in the fifth cluster due to earliness in ear emergence.

4. CONCLUSION

In the present study, all DUS characteristics showed polymorphism except lower glume hairiness of the external surface and seasonal type. The results of the study showed a highly significant positive correlation of grain yield with the number of days to heading, time of ear emergence, and plant growth habit. It remains to be seen whether highly correlated traits are potentially useful for the detection of phenotypes with increased grain yield. As those traits are under the influence of the environment another year of study is needed to confirm our observations. In addition, dendrogram analysis revealed a diversity pattern of the germplasm with respect to the country of origin of genotypes. The most discriminative trait that provided the best differentiation among winter wheat germplasm was grain yield, among the other three highly correlated traits.

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Adresa autora - Author's address:
Valentina Spanic, PhD,
Corresponding author e-mail:
valentina.spanic@poljinos.hr
Katarina Sunic, mag.biol.,
Jurica Duvnjak, mag.agron.
Agricultural Institute Osijek,
Juzno predgradje 17, 31000 Osijek

Zvonimir Lalic, mag. agron.,
Luka Drenjancevic, PhD,
Goran Jukic, PhD,
Ivan Varnica, PhD
Croatian Agency for Agriculture and Food,
Vinkovacka cesta 63c, 31000 Osijek

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