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Value of *Hordeum vulgare* L. genotypes in terms of yield and its stability

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Our purpose was to determine the value of spring barley (*Hordeum vulgare* L.) cultivars and lines in terms of yield and its stability. The GGE biplot analysis of competitive cultivar trial data was used. Due to the GGE biplot, the relationships between the barley cultivars and lines under investigation with the environment (years of their cultivation) were visualised. The mega-environment of 2018 and 2020 was the most optimal one for yields from the cultivars, especially Grace, Amil, Troian and Talisman Myronivskyi, while the 2019 environment for Avhur, Margret and Khors. The GGE biplot ranking graphically described the genotypes by average yield and its stability over the three years: Grace, Margret, Amil, Troian, Datcha, Avhur, Khors, Ahrarii, Talisman Myronivskyi and Herkules were high-yielding cultivars; naked cultivars Merlin, Gatunok and Akhiles gave the lowest yields; Grace, Gladys, Gatunok, Yavir, Kontrast and Khors were highly stable cultivars; Amil, Avhur, KWS Bambina and Rezerv were low stable. Of the high-yielding cultivars, Grace and Khors were the most stable ones. The GGE biplot also visualised the comparison of the genotypes with the hypothetical 'ideal' genotype by the highest 'breeding value': Grace was the best (5.43 t ha^{-1}), Troian was the second best (5.31 t ha^{-1}), followed by Margret (5.27 t ha^{-1}), Avhur, Ahrarii, Krechet and Herkules (5.00–5.22 t ha^{-1}). As a conclusion of the identified patterns, we established the practical and breeding value of the high-yielding and stable cultivars, Grace (5.43 t ha^{-1}) and Khors (5.22 t ha^{-1}), for conditions of different years, as well as the high-yielding and highly responsive cultivars, Amil (5.37 t ha^{-1}) and Avhur (5.22 t ha^{-1}), for the most optimal growing conditions.

Keywords: spring barley (*Hordeum vulgare* L.), cultivar, line, yield, stability, GGE biplot analysis, genotype value

INTRODUCTION

First of all, spring barley cultivars should give high yields and top-quality products and be resistant to unfavourable biotic and abiotic factors. In addition, they must be environmentally stable, i.e. adapted to various growing conditions. The availability of starting material with a high adaptability and stability of traits, in particular of yield, is an important problem in breeding (Al-Abdallat et al., 2017; Dahlin et al., 2020; Demydov et al., 2017).

Trait expression depends on many bio- and abiotic factors. These issues are covered in numerous experimental studies (Hakala et al., 2012; Zeynu, Asfaw 2019; Sturite et al., 2019; Al-Abdallat et al., 2017; Dahlin et al., 2020). Barley traits and their stability are significantly influenced both by genotype and by growing conditions (Sturite et al., 2019; Al-Abdallat et al., 2017; Dahlin et al., 2020).

Selections at all stages of the breeding process are conducted according to a phenotypic expression of quantitative traits, the expression of which depends on growing conditions (Muhleisen et al., 2014; Vasylkivskyi et al., 2017). The efficiency of selection by traits is determined by the strength of a genotype's response to hydrothermal conditions – the stronger the genotype's response is, the lower the efficiency of selection is (Vasylkivskyi et al., 2017).

Yield and its stability under the influence of growing conditions are important characteristics of cultivars. Along with different parametric methods of their evaluation (Eberhart, Rassel, 1966; Marukhnyak, 2018), more modern methods are now widely used – AMMI and GGE biplot (Gudzenko et al., 2017; Hudzenko, 2018; Vaezi et al., 2017; Khanzadeh et al., 2018) or GGE biplot alone (Kendal, 2016; Demydov et al., 2017).

Since the yield depends not only on the genotype, but also on the environment and the genotype-environment interaction, it is important to assess the adaptability of barley cultivars to a particular growing area.

Our purpose was to determine the value of spring barley (*Hordeum vulgare* L.) cultivars and lines in terms of yield and its stability upon the genotype–environment interaction and to select, on this basis, cultivars that would be valuable for practice and breeding.

MATERIALS AND METHODS

Twenty-two spring barley cultivars were taken as the test material: awny chaffy cultivars belonging to *submedicum* Orl. variety – Vzirets; to *nutans* Schubl. Variety – Avhur, Ahrarii, Khors, Troian, Rezerv, Sviatomykhailivskyi, Talisman Myronivskyi, KWS Bambina, Datcha, Gladys Grace, Quench and Margret; to *rikotense* R. Red variety – Amil; naked cultivars belonging to *nudum* L. variety – Merlin, Gatunok, Akhiles and Yavir; awnless cultivars belonging to *inerme* Coern. Variety – Kontrast, Krasen and Modern; and three lines – two awny chaffy lines, 14–561 and 15–139, and one awnless naked line belonging to *duplialbum* variety, 15–1246.

The research was carried out in 2018–2020 at the Plant Production Institute named after V. Ya. Yuriev located in the forest-steppe zone in the east of Ukraine. The soil of the field is ordinary chernozem. The humus content in the arable layer is 5.8%. The soil has the following agrochemical indicators: pH 5.8, hydrolytic acidity 3.29 mg equivalent per 100 g, easily hydrolyzed nitrogen 134 mg kg^{-1}, mobile phosphorus 97 mg kg^{-1} and exchangeable potassium 133 mg kg^{-1}.

Both temperature and precipitation were various in 2018–2020, affecting the yields from spring barley cultivars and lines and allowing for a comprehensive evaluation of the experimental material. The weather in 2018–2019–2020 was not quite favourable for the growth and development of barley. Barley was sown under the optimal conditions. During emergence, the air temperature was close to the 30-year average for the zone, and sprouts were even. During tillering, the air temperature was higher than the average; however, the precipitation favoured a good tillering of barley plants.

The 2018 vegetation period was hot and dry; the average daily temperature exceeded the monthly average by 2.3–4.4°C, reaching the maximum of 22.9–24.7°C in June and July. This occurred on insufficient precipitation; only during some 10-day periods, the precipitation amount exceeded the average, but even then the rains were torrential, i.e. ineffective.

The 2019 vegetation period was also hot and dry. Barley used the April and May precipitation very well, but there was a drought in June and July combined with high temperatures. The average daily temperature exceeded the monthly average by 1.5–4.6°C, reaching the maximum of 33.2–35.2°C in June. Such weather was unfavourable for the development of barley plants, led to the formation of short spikes and small numbers of lateral stems, while the summer droughts were a cause of shrivelled grain.

On the contrary, the 2020 vegetation period had an excessively humid and cool spring. The temperature in April–May was lower than the 30-year average by 0.8–2.6°C, and the precipitation amount in May was 64 mm (147% related to the average). Such weather favoured the barley growth, as it boosted productive tillering and formation of long spikes. As early as in June, droughts began, and the air temperature elevated (by 0.8–1.7°C than the average). Only during the second 10 days of July, there was a lot of precipitation (by 67 mm more than the average, or 368%), but the rains were torrential, it often hailed, hence, the precipitation was ineffective.

Thus, 2018 and 2019 were unfavourable for the growth and development of barley, while 2020 can be considered as quite favourable, but some cultivars lodged considerably.

The experiments were conducted by the plant cultivar qualification examination method (Plant Cultivar Qualification Examination Method). Sowing was carried out at the optimal time – in the first decade of April, harvesting in the phase of full grain ripening, in the first decade of August. The predecessor crop was pea. The plot area was 10 m^2, in four replications. The farming techniques were conventional for barley cultivation. No chemical protection of crops against diseases or against lodging was used and no fertilizer was used before sowing.

The experimental variants were compared with the check cultivar, Vzirets, and with the average across the experiments. Significance of differences between the variants was assessed by ANOVA in STATISTICA 10. Evaluation of the genotypes–environment (year conditions) interaction, genotype ranking by average yield and its stability, and assessments of closeness of the genotypes to the hypothetical 'ideal' genotype were performed by GGE biplot analysis. For visualisation, graphs were constructed from the principal components (genotype–genotype–environment interaction) as matrix multiplication-based graph algorithms (Yan, Tinker, 2006) in GENSTAT 17. For graphical analysis, the R-based software was used (Frutes et al., 2014). Statistical parameters were calculated in STATISTICA 10.

RESULTS AND DISCUSSION

The yields from the studied cultivars and lines depended both on the genotype and on the growing conditions. In 2018, the yield was 4.17–5.55 t ha^{-1}; in 2019 it was 3.29–4.91 t ha^{-1}; in 2020 the yield was 3.69–5.43 t ha^{-1} (Table 1). That is, the highest level was achieved in 2020, which was waterlogged

Table 1. **Yields from the spring barley cultivars and lines**

Cultivar/line	Code	Yield, t ha^{-1}			
		2018	2019	2020	Mean
Vzirets – check cultivar	*G1*	4.69	3.91	5.66	4.75
Amil	*G2*	5.16	4.26	6.69*	5.37*
Avhur	*G3*	5.08	4.91*	5.72	5.26*
Ahrarii	*G4*	5.06	4.20	6.18	5.15*
Khors	*G5*	5.24	4.51*	5.91	5.22*
Troian	*G6*	5.34	4.42	6.16	5.31*
Rezerv	*G7*	4.46	4.68*	5.26	4.80
Sviatomykhailivskyi	*G8*	5.02	4.36	5.46	4.95
Talisman Myronivskyi	*G9*	5.25	4.25	5.96	5.15*
KWS Bambina	*G10*	5.26	3.50	6.18	4.98
Datcha	*G11*	5.53*	4.32	6.01	5.29*
Gladys	*G12*	5.15	3.90	5.30	4.78
Grace	*G13*	5.44*	4.60*	6.25*	5.43*
Quench	*G14*	5.03	4.38	5.38	4.93
Margret	*G15*	5.55*	4.59*	5.66	5.27*
Merlin	*G16*	4.14	2.79*	4.15*	3.69*
Gatunok	*G17*	3.56*	3.64	4.72*	3.97*
Akhiles	*G18*	4.17	3.29*	4.76*	4.07*
Yavir	*G19*	4.46	3.75	4.92*	4.38
15–1246	*G20*	4.37	3.54	4.89*	4.27*

Table 1. **(continued)**

Cultivar/line	Code	Yield, t ha^{-1}			
		2018	2019	2020	Mean
Herkules (14–561)	*G21*	5.47*	4.51*	5.62	5.20*
15–139	*G22*	5.36	3.90	4.75*	4.67
Konsrast	*G23*	5.09	4.14	5.64	4.96
Krechet	*G24*	5.14	4.10	6.35*	5.20*
Modern	*G25*	4.92	3.92	5.18	4.67
Average	–	4.95	4.09	5.55	X = 4.86
LSD_{05}	–	0.73	0.60	0.57	0.39

Note. * Significant difference compared to the check cultivar, Vzirets, $p \leq 0.05$.

had low temperatures during the tillering phase of barley. Such weather favoured the growth and development of barley.

GGE biplot analysis. Several researchers (Hudzenko et al., 2017; Hudzenko, 2018; Vaezi et al., 2017; Khanzadeh et al., 2018) reported that the environment made the greatest contribution to the variability of traits, while the contributions of the genotype and the genotype–environment interaction were insignificant. In particular, Hudzenko (2018) showed that their contributions were 82.05%, 12.51% and 5.45%, respectively, i.e. the genotype effect was 6.56–fold as weak as the environment effect, which was seen in lower levels of genotypic traits.

ANOVA for the AMMI model (Table 2) revealed significant effects of the genotype, environment and genotype–environment interaction on the yield variability, allowing for GGE biplot analysis. The environment made the greatest contribution to the variance – 49.27%. The genotype also made a quite significant contribution to the variance – 27.95%. The contribution of the genotype–environment interaction was much weaker (8.73%). The total contribution of these three sources of variance was 85.95%. The first two principal components (PC1 and PC2) accounted for 90.45% of the variability caused by the genotype–environment interaction, namely: PC1 = 78.32%, PC2 = 12.13%.

Thus, we obtained results for modern spring barley cultivars and selection lines, where the genotype significantly influenced the yield variability (its effect was only by 1.76 times weaker than the environment effect), and observed considerable differences in the yield.

Visualisation of the genotype–environment (years) interaction, genotype ranking by average yield and its stability over the years and the genotypes closeness to the hypothetical 'ideal' genotype by 'breeding value' was performed by GGE biplot analysis. The graphs were constructed from the principal components PC1 and PC2 obtained through the singular value decomposition. In such

Table 2. **ANOVA table for the AMMI model**

Source	Df	SS	MS	F	F prob
Total	299	222.5576	0.7443	*	*
Treatments	74	191.2979	2.5851	26.53	0.00000
Genotypes	24	62.2066	2.5919	26.60	0.00000
Environments	2	109.6554	54.8277	48.33	0.00000
Block	9	10.2108	1.1345	11.64	0.00000
Interactions	48	19.4359	0.4049	4.16	0.00000
IPCA 1	25	11.5260	0.4610	4.73	0.00000
IPCA 2	23	7.9099	0.3439	3.53	0.00000
Residuals	0	0	*	*	*
Error	216	21.0489	0.0974	*	*

a model, PC1 and PC can be displayed on a two-dimensional biplot to visualise the interaction between each genotype and each environment.

The which-won-where scatter biplot illustrates the relationships between genotypes and the environment as a polygon (Fig. 1). Its vertices are genotypes located as far as possible from the biplot center. Hypothetical environments are separated by lines into sectors. Sector 1 comprises environments E18 (2018) and E20 (2020), where the average yields from the genotypes under investigation were the highest ones (4.95–5.55 t ha^{-1}). Therefore, these environments form a mega-environment. Cultivar Grace (G13) is in this mega-environment, which had optimal conditions (2018 and 2020) for this cultivar (yield 5.44–6.25 t ha^{-1}). Cultivars Troian (G6), Amil (G2) and Talisman Myronivskyi (G9) also gave high yields in 2020. Environment E19 (2019) was optimal for cultivars Avhur (G3), Khors (G5) and Margret (G15). The cultivars in the empty sectors (without environments) gave lower yields than the above-mentioned ones.

The GGE biplot ranking characterises genotypes by average yield and its stability in different environments (Fig. 2). The yield line (average environment coordinate (AEC) X-axis) horizontally passes through the biplot origin and ranks cultivars by average yield. The AEC abscissa has one direction, with the arrow pointing to the greater yield. It is clearly shown that the highest 3-year average yield was produced by Grace (G13). Amil (G2), Avhur (G3), Ahrarii (G4), Khors (G5), Troian (G6), Talisman Myronivskyi (G9), Datcha (G11) and Herkules (G24) also gave high yields. Naked cultivars Merlin (G16), Gatunok (G17) and Akhiles (G18), which are located on the left at the beginning of the X axis, gave the smallest yields.

The stability line, or the Y axis, passes through the biplot origin perpendicular to the X axis. The distance between a cultivar and the abscissa axis along the ordinate axis in both directions characterises the year-to-year variability of yields, which determines their stability. Cultivars positioned farther from the X axis are more variable, and, therefore, unstable. Amil (G2), Avhur (G3), KWS Bambina (G10) and Rezerv (G7) were the most unstable cultivars. Grace (G13), Gladys (G12), Gatunok (G17), Yavir (G19), Kontrast (G20) and Khors (G5) were the most stable cultivars, as they were in the closest positions to the X axis. Of the high-yielding cultivars, Grace (G13) and Khors (G5) were stable.

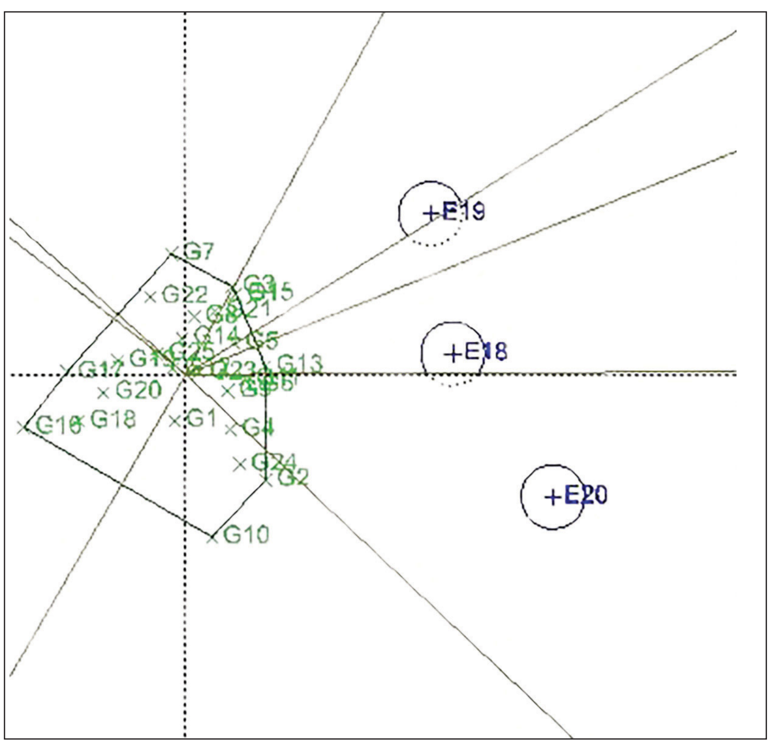

Fig. 1. The polygon view of GGE biplot – the genotype–environment interaction

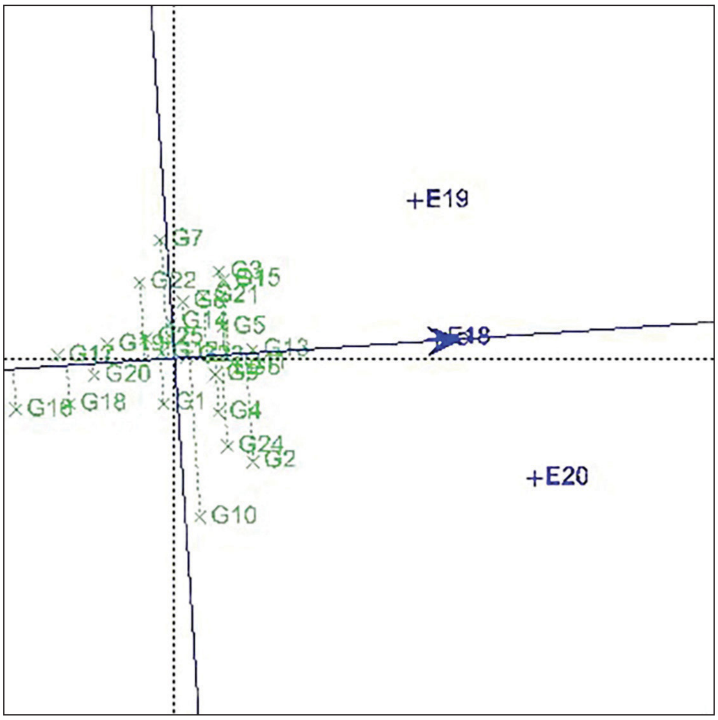

Fig. 2. Genotype ranking by average yield and its stability

The GGE biplot comparison ranks genotypes in relation to the hypothetical ('ideal') genotype, i.e. by their 'breeding value'. The 'ideal' genotype is the center of concentric circles. The closer to the center the genotype is positioned, the more valuable it is.

Figure 3 clearly shows that Grace (G13) was closest to the circle center, as it was located on the central circle border. It was the most productive cultivar (5.43 t ha^{-1}) and stable to the growing conditions. Troian (G6), which is in the second circle, was also better than the others. Margret

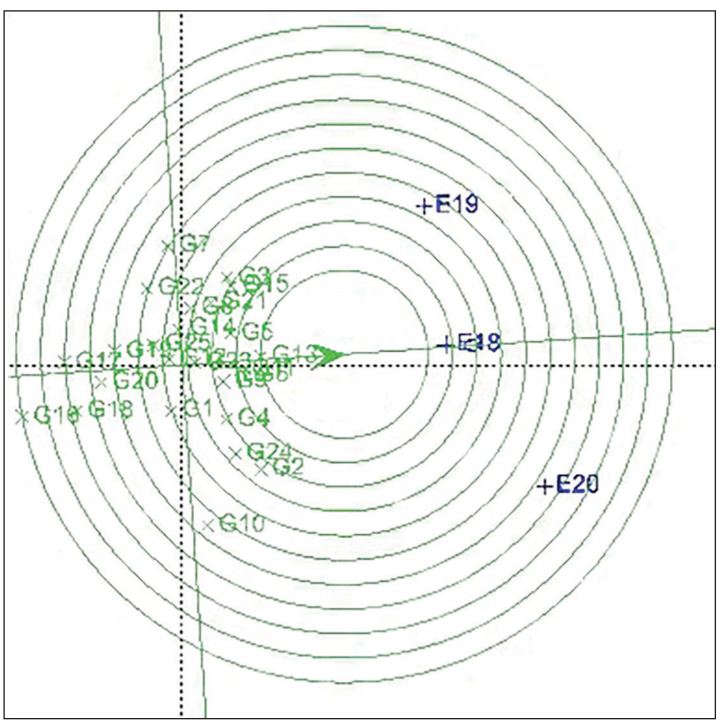

Fig. 3. Comparison of the genotypes with the 'ideal' genotype

(G15), Khors (G5) and Talisman Myronivskyi (G9), which were located in the third circle, were good (5.31 t ha^{-1} and 5.27 t ha^{-1}, respectively). Herkules (G24), Ahrariin (G4), Crechet (G21), Avhur (G3) and Amil (G2) were a little farther (in the fourth circle), and their average yields were higher than those from cultivars in more remote circles and amounted to 5.00–5.37 t ha^{-1}.

CONCLUSIONS

GGE biplot analysis of data on spring barley cultivars and lines studied under the contrast conditions of 2018–2020 showed that high average yields were given by cultivars Grace, Amil, Troian and Talisman Myronivskyi, for which the 2018/2020 mega-environment was the most optimal one. The 2019 environment was optimal for Margret, Avhur and Khors, which also gave high yields. We established the practical and breeding values of high-yielding and stable cultivars Grace (5.43 t ha^{-1}) and Khors (5.22 t ha^{-1}) for years with various conditions as well as of high-yielding and highly responsive cultivars Amil (5.37 t ha^{-1}) and Avhur (5.22 t ha^{-1}) for the most optimal growing conditions.

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VASARINIŲ MIEŽIŲ (*HORDEUM VULGARE* L.) GENOTIPŲ DERLIAUS STABILUMAS

Santrauka

Tyrimų tikslas buvo nustatyti vasarinių miežių (*Hordeum vulgare* L.) veislių ir linijų vertę derlingumo ir jo stabilumo požiūriu. Naudota konkurencinių veislių tyrimų duomenų GGE biplotinė analizė. 2018 ir 2020 metų aplinkos sąlygos buvo optimaliausios miežiams augti, ypač 'Grace', 'Amil', 'Troian' ir 'Talisman Myronivskyi' veislėms, o 2019 metais – 'Avhur', 'Margret' ir 'Khors' veislėms. Sugrupavus genotipus pagal vidutinį derlių ir jo stabilumą per trejus metus, 'Grace', 'Margret', 'Amil', 'Troian', 'Datcha', 'Avhur', 'Khors', 'Ahrarii', 'Talisman Myronivskyi' ir 'Herkules' buvo didelio derlingumo veislės; grynosios veislės 'Merlin', 'Gatunok' ir 'Akhiles' davė mažiausią derlių; 'Grace', 'Gladys', 'Gatunok', 'Yavir', 'Kontrast' ir 'Khors' veislių derlius buvo stabilus; 'Amilas', 'Avhuras', 'KWS Bambina' ir 'Rezervas' – derlius kito. Iš derlingų veislių 'Grace' ir 'Khors' buvo stabiliausios.

Raktažodžiai: vasariniai miežiai (*Hordeum vulgare* L.), veislė, linija, derlius, stabilumas, GGE biplotinė analizė, genotipas