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EVALUATION OF BREEDING IMPROVEMENT FOR SPRING BARLEY VARIETIES IN TERMS OF YIELD AND YIELD-RELATED TRAITS

SUMMARY

As a result of multi-year trial (2013–2017) there have been proved statistically significant breeding and genetic improvement of yield, its stability and level of manifestation of yield-related traits in the newly developed spring barley varieties Virazh, Talisman Myronivskyi, MIP Myrnyi, MIP Saliut, MIP Sotnyk, MIP Azart, and MIP Bohun. The spring barley varieties MIP Bohun and MIP Myrnyi were characterized with the optimal combination of yield and its stability according to the GGE biplot model. It was revealed that the spring barley varieties Virazh, MIP Saliut, and MIP Sotnyk had the highest genetic gain for thousand kernel weight, the variety Talisman Myronivskyi for number of productive tillers, and MIP Myrnyi for kernel number per spike and thousand kernel weight. The variety MIP Azart was differed from the other varieties in the ratio of main yield structural elements. Thus, the newly developed spring barley varieties had differences from each other in pattern of yield and yield-related traits manifestation. According to the GYT biplot model the spring barley variety MIP Bohun was the nearest to the "ideal genotype" in terms of yield*traits combination. The practical worth of the identified patterns is that the new varieties, due to the relatively different pathways of yield formation, will complement each other under unfavorable environmental factors in the production conditions. On the whole, it was shown effectiveness of combining statistical and graphical approaches to comprehensive evaluation the breeding improvement for yield and yield-related traits in new varieties compared to ones created in the previous period.

Key words: *Hordeum vulgare* L., genetic gain, GGE biplot, GYT biplot

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the major crops in world agriculture. Therefore, increasing barley grain yield production is an important

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aspect of human food security. The recent studies in different countries based on both statistical data and the results of comparative trials of barley varieties revealed a significant yield increasing due to breeding improvement (Laidig *et al*., 2017).

Grain yield is formed depend on influence of numerous different environmental factors. It rarely happens that the ranges of vital factors of growing conditions coincide with optimal for plants. At least one factor is limiting. Its effect on genes products (proteins–enzimes) leads to the epigenetic regulation and modifies the phenotypic manifestation of quantitative traits. The presence of the epigenetic regulation of genes expression leads to elementary adaptive reactions, which are stages in the path of the genotype hereditary realization and are ultimately expressed in quantitative and qualitative traits which specific to it (Vasylkivskyi and Gudzenko, 2017). Moreover, yield is a complex trait. It is a result of combination a number of quantitative yield-related traits – its structural components. Thereby yield increasing depends on genetic improvement and the optimal combination of these individual traits (Sharma *et al*., 2018; Hu *et al*., 2018). That is why the level of manifestation and interrelation between yield and its structural components has received considerable attention in breeding and genetic studies (Abdullah *et al*., 2018; Matin *et al*., 2019). The information about already achieved level of manifestation of yield-related traits in previously developed varieties has the practical worth for the purpose of consistent improvement of new varieties (Mirosavljević *et al*., 2016). The problem is that phenotypic manifestation of yield structural elements is largely determined by environmental conditions (Tamm *et al*., 2015). It is important for the breeder to have information about the genetically determined proportion in the overall phenotypic variability of yield structural components. In order to determine the breeding improvement for economically important traits there are widely used different statistical parameters of phenotypic and genotypic variation, heritability coefficient, and genetic gain (Tahar *et al*., 2015; Addisu and Shumet, 2015; Ahmadi *et al*., 2016; Hailu *et al*., 2016).

The aim of our research was to identify main patterns of breeding improvement in newly developed Myronivka spring barley varieties in terms of yield and yield-related traits when using statistical and graphical methods.

MATERIAL AND METHODS

The study was conducted in 2013–2017 growing seasons at the V.M. Remeslo Myronivka Institute of Wheat of NAAS. The objects of study were seven spring barley varieties Virazh, Talisman Myronivskyi, MIP Myrnyi, MIP Saliut, MIP Sotnyk, MIP Azart, and MIP Bohun, which have been registered in Ukraine since 2016. These varieties were compared with the first Myronivka variety Myronivskyi 86 (registered in Ukraine in 1994). The trial was laid out with complete randomized blocks in three replications. The individual plot size was 10 m^2. Genetic gain was calculated for number of productive tillers, kernel number per spike, and thousand kernel weight. Statistical analysis was performed using the breeding equation:

$$\Delta G = SD \times H^2,$$

where ΔG is genetic gain, SD is selection differential, H^2 is heritability coefficient.

The selection differential was calculated with the formula:

$$SD = X_c - X_в,$$

where X_c is the individual trait level of manifestation/ in new variety, $X_в$ is the individual trait level of manifestation in the variety Myronivskyi 86.

The heritability coefficient was calculated with the formula:

$$H^2 = \sigma_q / \sigma_{ph},$$

where σ_q is the genotypic variance, σ_{ph} is the phenotypic variance.

Graphical analysis (GGE biplot, GYT biplot) was performed with accordance to Yan and Tinker (2006) and Yan and Frégeau-Reid (2018) using non-commercial software *GEA-R* version 4.1.

Meteorological conditions through the years of the trial were characterized with significant variability of hydrothermal parameters (Table 1). These meteorological fluctuations made it possible to comprehensive explore spring barley varieties for yield performance, its stability, and the level of manifestation of main yield-related traits.

Table 1. Meteorological conditions during the spring barley growing season

Year	Code	Monthly air temperature, °C				Monthly precipitation, mm			
		April	May	June	July	April	May	June	July
2013	E13	10.5	19.0	21.4	20.6	35.0	61.0	57.0	52.0
2014	E14	10.1	17.3	18.0	21.7	60.7	158.3	47.5	107.0
2015	E15	9.3	16.3	19.4	21.5	34.0	55.0	101.0	99.0
2016	E16	12.4	15.2	20.1	22.2	55.4	91.7	68.6	19.1
2017	E17	10.4	15.4	20.6	21.0	42.7	23.6	20.1	101.8
Long-term		8.8	15.0	18.0	19.7	42.1	51.2	85.2	86.5

RESULTS AND DISCUSSION

Grain yield and genotype plus genotype by environment interaction

According to multi-year trial data there was revealed that the spring barley varieties Virazh (G2), Talisman Myronivskyi (G3), MIP Myrnyi (G4), MIP Saliut (G5), MIP Sotnyk (G6), MIP Azart (G7), and MIP Bohun (G8) had reliable higher yield (1.09–1.60 t/ha) compared to the first Myronivka variety Myronivskyi 86 (Table 2). In general, there is a noticeable significant variability in the yield of genotypes through the years. Several other researchers also have reported about high year-to-year, or site-to-site grain yield variation in Eastern European countries (Pržulj and Momčilović, 2012; Mirosavljević *et al*., 2014; Pržulj *et al*., 2015; Solonechnyi *et al*., 2018). For accurate interpretation of the genotype by environment data it is necessary to use the most appropriate statistical models (van Eeuwijk *et al*., 2016). The genotype main effects plus genotype by environment interaction (GGE biplot) model has been the most widely used for this purpose in different countries (Kendal and Doğan, 2015;

Meng *et al.*, 2016; Bilgin *et al.*, 2018; Kendal *et al.*, 2019; Hudzenko *et al.*, 2019).

Table 2. Grain yield of newly developed spring barley varieties compared to the first registered Myronivka variety Myronivskyi 86, t ha^{-1}

Code	Variety	Years of trial (code)					Mean
		2013	2014	2015	2016	2017	
		E13	E14	E15	E16	E17	
G1	Myronivskyi 86	3.21	4.17	6.27	4.57	3.98	4.44
G2	Virazh	3.83	5.01	7.50	7.13	5.08	5.71
G3	Talisman Myronivskyi	3.52	4.95	7.17	7.05	4.97	5.53
G4	MIP Myrnyi	4.12	5.35	7.81	7.41	5.23	5.98
G5	MIP Saliut	3.67	5.32	7.27	7.16	5.01	5.69
G6	MIP Sotnyk	3.62	5.12	7.24	7.22	4.83	5.61
G7	MIP Azart	3.82	5.45	7.39	7.38	5.19	5.85
G8	MIP Bohun	4.70	5.48	7.34	7.21	5.45	6.04
LSD_{05}		0.18	0.35	0.26	0.28	0.17	0.25

The first two principal components of the GGE biplot explained 97.57 % of genotype by environment interaction (Fig. 1). The environment E16 was characterized by the greatest discriminating ability. The environment E14 was the most representative, whereas E13 was the least representative. The environments E13 and E16 were the most distant from each other. The environments E14 and E17 were similar among themselves. GGE biplot "which-won-where" polygon view is effective to visualize the interaction patterns between genotypes and environments (Fig. 2). In our case, the first mega-environment is formed by the environments E13, E17, and E14. The variety MIP Bohun (G8) had advantage in it. The second mega-environment is formed by the environments E15 and E16. The varieties MIP Azart (G7), Virazh (G2), and MIP Saliut (G5) were more adapted to it. The variety MIP Myrnyi (G4) was located on the line which separated these two mega-environments. It is indicating that the variety MIP Saliut (G5) showed high performance in both of them. The varieties Myronivskyi 86 (G1), Talisman Myronivskyi (G3), and MIP Sotnyk (G7) had no advantages in the formed mega-environments. The variety MIP Bohun (G8) was characterized the maximal mean yield according to "mean yield against stability" view (Fig. 3). The poorest performance of both yield and stability was noted in the variety Mironovsky 86 (G1). Ranking the spring barley varieties relative to a hypothetical "ideal genotype", which conventionally is represented as the center of centric circles, shows that the varieties MIP Bohun (G8) and MIP Myrnyi (G4) were the nearest to it (Fig. 4)

In general, it should be noted that the new spring barley varieties Virazh (G2), Talisman Myronivskyi (G3), MIP Myrnyi (G4), MIP Saliut (G5), MIP Sotnyk (G6), MIP Azart (G7), and MIP Bohun (G8) significantly exceeded over the variety Myronivskyi 86 in both yield performance and adaptive reaction to changeable conditions through different years of trial.

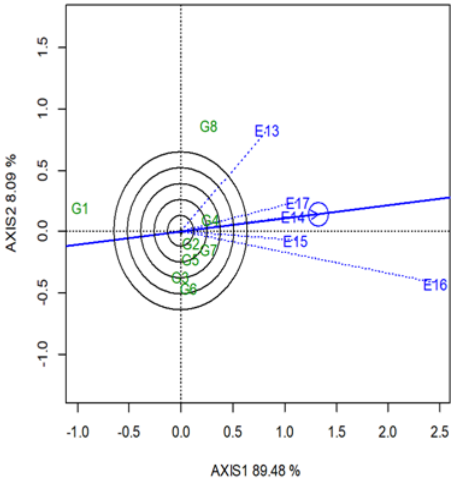

Figure 1. GGE biplot of discriminating ability and representativeness of test environments, 2013–2017

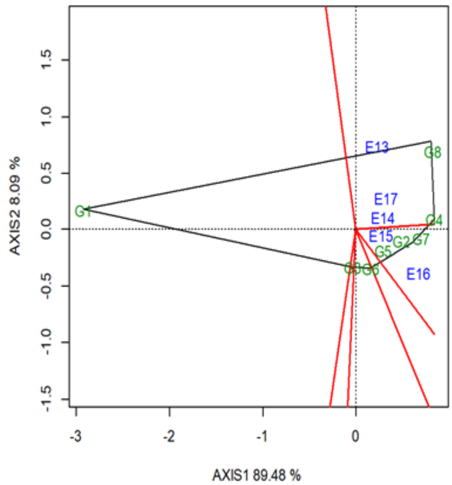

Figure 2. GGE biplot “which-won-where” polygon view for spring barley varieties and test environments, 2013–2017

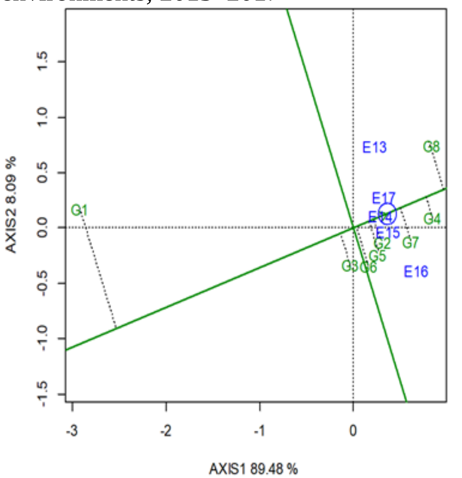

Figure 3. GGE biplot average environment coordination view of spring barley varieties for mean yield against stability, 2013–2017

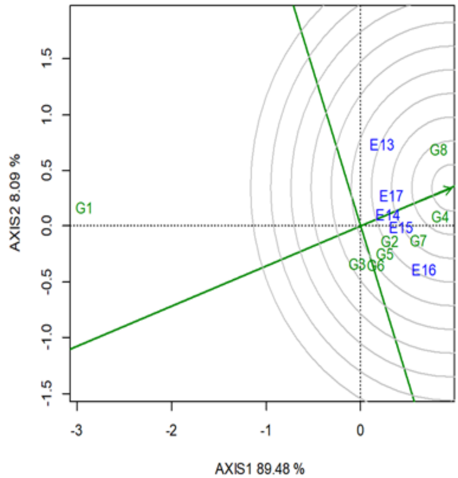

Figure 4. GGE biplot ranking spring barley varieties relative to an “ideal genotype”, 2013–2017

Yield-related traits manifestation and genetic gain

All newly developed varieties predominated over the variety Myronivskyi 86 (G1) in number of productive tillers, despite the significant variability of this trait during years of trial (Table 3).

Table 3. Phenotypic manifestation and genetic gain for yield-related traits in newly developed spring barley varieties

Code	Years of trial, code					Mean	Statistical indices		
	E13	E14	E15	E16	E17		SD	H^2	ΔG
Number of productive tillers per plant (NPT)									
G1	1.40	1.59	2.11	2.02	1.60	1.74	-	0.80	-
G2	1.70	2.23	2.68	2.80	2.08	2.30	0.56		0.44
G3	1.97	2.89	3.38	3.42	2.67	2.87	1.12		0.90
G4	1.68	2.12	2.66	2.52	2.10	2.22	0.47		0.38
G5	1.64	2.11	2.63	2.51	2.05	2.19	0.45		0.36
G6	1.57	2.32	2.83	2.74	2.15	2.32	0.58		0.46
G7	1.91	2.41	3.17	2.95	2.35	2.56	0.81		0.65
G8	1.73	2.17	2.69	2.60	2.13	2.27	0.52		0.42
LSD_{05}	0.23	0.34	0.31	0.26	0.18	0.26	-	-	-
Kernel number per spike (KPS)									
G1	19.57	19.47	20.33	20.50	19.33	19.84	-	0.86	-
G2	22.03	23.80	24.43	23.57	22.50	23.27	3.43		2.95
G3	19.43	19.27	20.23	20.63	19.77	19.87	0.03		0.02
G4	26.37	29.60	28.47	27.37	26.60	27.68	7.84		6.74
G5	22.43	24.33	23.13	24.43	23.17	23.50	3.66		3.15
G6	22.65	24.13	22.63	22.63	22.20	22.85	3.01		2.59
G7	22.50	24.17	23.50	22.03	21.60	22.76	2.92		2.51
G8	23.47	26.37	23.57	23.57	24.47	24.29	4.45		3.82
LSD_{05}	1.95	1.99	1.73	1.48	1.30	1.69	-	-	-
Thousand kernel weight (TKW)									
G1	44.67	44.50	47.27	47.47	40.27	44.83	-	0.98	-
G2	51.00	51.00	52.90	51.73	44.67	50.26	5.43		5.32
G3	45.20	47.73	48.43	48.07	41.23	46.13	1.30		1.27
G4	50.37	49.57	51.37	50.13	46.13	49.51	5.29		5.19
G5	51.33	50.23	53.37	52.63	46.20	50.75	5.92		5.80
G6	47.97	47.40	49.33	48.73	42.10	47.11	2.27		2.23
G7	47.60	47.90	49.30	50.23	45.57	48.12	3.29		3.22
G8	48.18	47.67	49.13	51.83	46.33	48.63	4.25		4.17
LSD_{05}	0.45	0.36	0.56	0.46	0.43	0.45	-	-	-

It was observed the highest value of number of productive tillers in the variety Talisman Myronivskyi (G3) (2.87 tillers/plant). The selection differential for number of productive tillers varied from SD = 0.45 tillers/plant in the variety MIP Saliut to SD = 1.12 tillers/plant in the variety Talisman Myronivskyi (G3). The heritability coefficient was H^2 = 0.80. Thus, the genetic gain for this trait varied from ΔG = 0.36 tillers/plant in the variety MIP Saliut (G5) to ΔG = 0.90 in the variety Talisman Myronivskyi (G3). The varieties Virazh (G2), MIP Myrnyi (G4), MIP Saliut (G5), MIP Sotnyk (G6), MIP Azart (G7), and MIP Bohun (G8) had the advantage over the variety Myronivskyi 86 (G1) in kernel number per spike through all years of the trial. It was observed the highest value of kernel number per spike in the variety MIP Myrnyi (G4) (27.68 kernels). The same variety was characterized with the highest selection differential. The heritability coefficient for kernel number per spike was $H^2 = 0.86$. Accordingly, the genetic gain for this trait varied from $\Delta G = 6.74$ kernels in the variety MIP Myrnyi (G4) to $\Delta G = 0.03$ kernels in the variety Talisman Myronivskyi (G3). All new varieties had the advantage over the variety Myronivskyi 86 (G1) in thousand kernel weight. The maximal its value was noted in the varieties MIP Saliut (G5) (50.57 g) and Virazh (G2) (50.26 g). Thousand kernel weight had the highest heritability coefficient among the studied traits ($H^2 = 0.98$). The lowest genetic gain for this trait was in the variety Talisman Myronivskyi (G3) ($\Delta G = 1.27$ g). Its high value was noted in the varieties MIP Saliut (G5) ($\Delta G = 5.80$ g), Virazh (G2) ($\Delta G = 5.32$ g), and MIP Myrnyi (G4) ($\Delta G = 5.19$ g).

In general, in new spring barley varieties compared to the variety Myronivskyi 86 (G1) there was detected statistically confirmed genetic gain for studied traits. As an exception, it should be noted the variety Talisman Myronivskyi (G3), which had no genetic gain for kernel number per spike, and minimal its value in thousand kernel weight. Meanwhile, the Talisman Myronivskyi (G3) was characterized by the highest genetic gain in number of productive tillers. The most improved thousand kernel weight was noticed in the varieties MIP Salyut (G5) and Virazh (G2). The variety MIP Myrnyi (G4) combined the highest genetic gain in kernel number per spike with high its value in thousand kernel weight.

Genotype by yield*trait combination

To visualize the level of manifestation for a number of traits in genotypes some researchers used GT (genotype by trait) biplot (Al-Sayaydeh *et al*., 2019). However, as it was mentioned, yield is the main integral trait which characterizes economic value of any commercial variety. Therefore, information about the combination of yield and other parameters is of significant practical importance. For genotype selection based on yield and trait complex combination a novel approach was proposed by Yan,and Frégeau-Reid (2018). It consists in modifying the experimental data of trials with multiplying yield performance and other economically important traits. For the first time in Eastern European conditions we have used this method for study of genetic gain in terms of yield*structural elements combination. In the first stage genotype and traits data were converted to GYT (genotype by yield*trait) table (Table 4). In this table the raw column is for yield by trait multiplication, the index column is for standardized GYT data. This is done by subtracting the mean and dividing the centered value by the standard deviation within the yield*trait combination. Mean GYT index is calculated from these standardized yield*traits data for each genotype.

The highest Mean GYT index was noted in the variety MIP Myrnyi (G4), the variety Myronivskyi 86 (G1) had the lowest one. The GYT biplot (Fig. 5, 6) graphically displays the standardized GYT data. The procedure for constructing GYT biplot are the same as for constructing GGE biplot except the term "environment" is replaced with "yield*trait" combination. In our case they are yield*number of productive tillers (YLD_NPT), yield*kernels per spike

(YLD_KPS), yield*thousand kernel weight (YLD_TKW). The first two principal components (AXIS1, AXIS2) of the GYT biplot explained 98.14 % variation of the genotype for yield*trait combination. The GYT biplot “which-won-where” shows that only two sectors contain both genotypes and yield*traits combinations (Fig. 5). The first sector contains the combinations YLD_KPS and YLD_TKW, as well as the varieties MIP Myrnyi (G4), MIP Bohun (G8), Virazh (G2), and MIP Saliut (G5).

Thus, these varieties combined yield performance with higher level of manifestation in kernel number per spike and thousand kernel weight. The second sector includes YLD_NPT and the variety Talisman Myronivskyi (G3). That is, this variety was characterized by combination of yield and number of productive tillers. The variety MIP Azart (G7) was in a narrow sector, which lies between two sectors mentioned above.

Table 4 Characteristics of spring barley varieties with genotype by yield*trait combination, 2013–2017

Code	Raw and index (standardized) value of genotype by yield*trait						
	YLD_NPT		YLD_KPS		YLD_TKW		Mean GYT index
	raw	index	raw	index	raw	index	
G1	0.08	-2.19	0.88	-1.80	1.99	-2.22	-2.07
G2	0.13	0.05	1.33	0.13	2.87	0.50	0.23
G3	0.16	1.18	1.10	-0.86	2.55	-0.48	-0.05
G4	0.13	0.11	1.66	1.55	2.96	0.79	0.81
G5	0.12	-0.23	1.34	0.17	2.89	0.56	0.17
G6	0.13	0.00	1.28	-0.07	2.64	-0.20	-0.09
G7	0.15	0.81	1.33	0.15	2.82	0.33	0.43
G8	0.14	0.29	1.47	0.73	2.94	0.71	0.58
Mean	0.13	0.00	1.30	0.00	2.71	0.00	-
σ	0.02	-	0.23	-	0.32	-	-

Notes: σ – standard deviation, YLD_NPT – yield*number of productive tillers, YLD_KPS – yield*kernel per spike, YLD_TKW – yield*thousand kernel weight, Mean GYT index – superiority index.

Thus, the variety MIP Azart (G7) differed from the varieties from the first and second sectors in the pattern of manifestation of yield*structural elements combination. The varieties Myronivskyi 86 (G1) and MIP Sotnyk (G6) are located in the sector with no yield*trait combination. It is indicating that these varieties had poorer performance than characterized above genotypes in yield and its combination with individual structural elements. Accordingly, to the GYT biplot ranking relative to the “ideal genotype” it is noticeable that the new varieties (G2…G8) had significant advantage over the variety Myronivskyi 86 (G1) (Fig. 6).

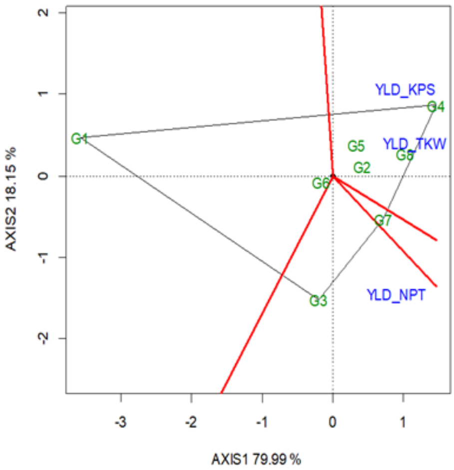

Figure 5. The “which-won-where” polygon view of the genotype by yield*trait (GYT) biplot

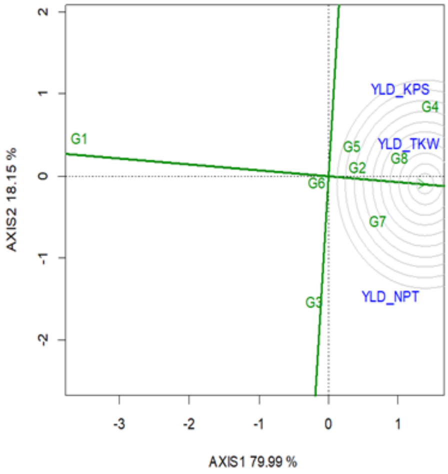

Figure 6. GYT biplot ranking spring barley varieties relative to an “ideal” genotype

The variety MIP Bohun (G8) was characterized the optimal combination of yield and its three main structural elements. The variety MIP Myrnyi (G4) was more displaced towards to YLD_KPS marker. The variety Talisman Myronivskyi (G3) was significantly displaced in the direction of YLD_NPT combination.

Thereby, the GYT biplot confirms the above-stated patterns for breeding and genetic improvement in the new spring barley varieties revealed when using statistical parameters for yield-related traits. In addition, it complements statistical indices with visual ability to analyze combination of yield and its structural elements.

CONCLUSIONS

As a result, our study proved statistically significant breeding and genetic improvement for yield and level of manifestation of yield-related traits in the newly developed spring barley varieties Virazh, Talisman Myronivskyi, MIP Myrnyi, MIP Saliut, MIP Sotnyk, MIP Azart, and MIP Bohun compared to the first Myronivka variety Myronivskyi 86. The spring barley varieties MIP Bohun and MIP Myrnyi were characterized with optimal combination of yield and its stability according to the GGE biplot model. However, using statistical and graphical analysis we revealed that the spring barley varieties Virazh, MIP Saliut and MIP Sotnyk had the highest genetic gain for thousand kernel weight, the variety Talisman Myronivskyi for number of productive tillers, and the variety MIP Myrnyi for kernel number per spike and thousand kernel weight. The variety MIP Azart was differed from the other varieties in the ratio of main yield structural elements. Thus, the newly developed spring barley varieties significantly differed from each other with their combination of yield and its structural elements. According to GYT biplot model the spring barley variety MIP Bohun was the nearest to the "ideal genotype" in terms of yield*traits combination. The practical worth of the identified patterns is that the new varieties, due to the relatively different pathways of yield formation, will complement each other under unfavorable environmental factors under production conditions.

On the whole, it is shown effectiveness of combining statistical (breeding equation) and graphical (GGE biplot, GYT biplot) approaches to comprehensive evaluation the breeding improvement for yield and yield-related traits in new genotypes compared to varieties created in the previous period.

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