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EVALUATION OF GENETIC GAIN IN NEWLY DEVELOPED WINTER BARLEY VARIETIES FOR GRAIN YIELD AND RELATED TRAITS

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ABSTRACT

As a result of multi-year trial (2012/13-2016/17) there have been proved statistically significant breeding and genetic improvement of yield, its stability and level of manifestation yield-related traits in new winter barley varieties Paladin Myronivskyi, MIP Yason, MIP Oskar, and MIP Hladiator compared to the old Myronivka variety Bemir 2. The winter barley varieties MIP Yason and Paladin Myronivskyi were characterized with optimal combination of yield and its stability according to the AMMI model. When using statistical and graphical analysis, the winter barley varieties MIP Hladiator and MIP Oskar were revealed to have the highest genetic gain for kernel number per spike, Paladin Myronivskyi for number of productive tillers and MIP Yason number of productive tillers and thousand kernel weight. Thus, the newly developed winter barley varieties differed from each other with their combination of yield and its components. According to the GYT biplot model the winter barley variety MIP Yason was the nearest to the "ideal" genotype by yield*traits combination.

Keywords: *Hordeum vulgare* L., yield-related trait, genetic gain, AMMI and GYT biplot models.

INTRODUCTION

The recent studies which have been conducted in different countries revealed a significant increasing of barley (*Hordeum vulgare* L.) yield due to breeding improvement of modern varieties (Grausgruber et al., 2002; Ortiz et al., 2002; Lillemo et al., 2009; Rajala et al. 2017; Laidig et al., 2017). In turn, barley yield is a complex trait which appears as a result of combination a set of lower-order yield-related traits, such as number of productive tillers per plant, kernel number per spike, thousand kernel weight, etc. (Shaaf et al., 2019; Herziga et al., 2019; Wang et al., 2021). Thus, cultivars yield increasing depends on genetic improvement and the optimal combination of these structural components (Swati et al., 2018; Hu et al., 2018; Sharma et al., 2018; Rodrigues et al., 2020). Thereby the level of manifestation and interrelation between individual yield-related traits has received considerable attention in the numerous of breeding and genetic studies (Doğan et al., 2016; Mikołajczak et al., 2016; Wang et al., 2016; Vitrakoti et al., 2016; Xu et al., 2018; Matin et al., 2019). The main challenge for breeders in this aspect is that phenotypic performance of the yield structural elements, as well as, the others quantitative traits, is largely influenced by environmental factors (Tamm et al., 2015; Wiegmann et al., 2019). That is why it is important for a breeder to have information about the genetically determined part in the total phenotypic variability of yield and its structural components. 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 ones (Fekadu et al., 2011; Mirosavljević et al., 2016).

Thus, the purpose of our research was to identify patterns for genetic gain in newly

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developed Myronivka winter barley varieties in terms of yield and yield-related traits when using different statistical and graphical methods.

MATERIAL AND METHODS

The study was conducted in 2012/13-2016/17 at the V.M. Remeslo Myronivka Institute of Wheat of NAAS of Ukraine. Natural zone is Ukrainian Forest-Steppe (latitude - 49°64', longitude - 31°08', altitude - 153 m). Soils are deep, little humus, slightly leached black. The soil was characterized by humus content of 3.8%, alkaline hydrolyzed nitrogen - 59 mg/kg, P_2O_5 - 221 mg/kg, K_2O - 96 mg/kg, and pH of 5.8.

Four newly developed winter barley varieties Paladin Myronivskyi, MIP Yason, MIP Oskar, and MIP Hladiator (registered in Ukraine during 2014-2017) were studied. These varieties were compared with the old one Myronivka variety Bemir 2 (released in 1987).

The contrasting weather conditions during 2012-2017 period made it possible to comprehensively explore the yield performance and level of manifestation its structural elements. In particular, the period of trial covered the dry 2012/13, more humid 2013/14, 2014/15, and 2015/16 (as a result in these years there were observed high level of lodging and wide spreading pathogens) and very unfavorable in winter, spring and summer periods 2016/17 (data not presented). The trial was laid out with complete randomized blocks in three replications. The individual plot size was 10 m^2.

In order to determine the achieved or expected breeding improvement for different traits are widely used different statistical parameters of phenotypic and genotypic variation, heritability coefficient, and genetic gain (Ahmadi et al., 2016; Hailu et al., 2016; Dinsa et al., 2018; Kumari et al., 2019; Katiyar al., 2020; Rasaily et al., 2020; Dyulgerov and Dyulgerova, 2020; Iannucci et al., 2021). Genetic gain was calculated for number of productive tillers, kernel number per spike, and thousand kernel weight.

Statistical analysis of genetic gain 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 first Myronivka variety Bemir 2. The heritability coefficient was calculated with the formula: $H^2 = \sigma_g / \sigma_{ph}$, where σ_g is the genotypic variance, σ_{ph} is the phenotypic variance.

For processing genotype by environment data from multi-environment or multi-year trials to interpret interaction between genotypes and environments (conditions of the years of the research) and genetic gain in terms of yield*structural elements two biplot models [*AMMI* - additive main effects and multiplicative interaction (Mirosavljević et al., 2014; Abtew et al., 2015; Solonechnyi et al., 2018; Kendal et al., 2019; Verma et al., 2019; Bocianowski et al., 2019; Hudzenko et al., 2020) and *GYT* - genotype by yield*trait (Yan and Frégeau-Reid, 2018; Yan et al., 2019)] were used.

Graphical analysis was performed using non-commercial software *GEA-R* version 4.1.

RESULTS AND DISCUSSION

As a result of multi-year (2012/13-2016/17 growing seasons) trial we revealed that the winter barley varieties Paladin Myronivskyi, MIP Yason, MIP Hladiator, MIP Oskar had significantly higher yield performance (1.27-1.72 t ha^{-1}) compared to the first Myronivka variety Bemir 2 (Table 1). At the same time, we found significant variation in yield of the studied varieties in different growing seasons.

Table 1. Grain yield of newly developed winter barley varieties compared to the old registered Myronivka variety Bemir 2, (t ha^{-1})

Code	Variety	Years of trial, code					Mean
		2012/13	2013/14	2014/15	2015/16	2016/17	
		E13	E14	E15	E16	E17	
G1	Bemir 2	3.30	3.57	5.44	4.70	2.73	3.95
G2	Paladin Myronivskyi	5.15	5.20	6.96	6.52	3.77	5.52
G3	MIP Yason	5.21	5.29	7.21	6.90	3.75	5.67
G4	MIP Oscar	5.41	5.46	6.95	6.60	3.32	5.55
G5	MIP Hladiator	5.22	4.53	7.15	6.85	3.42	5.43
LSD_{05}		0.33	0.35	0.39	0.33	0.21	0.32

The AMMI1 biplot contains the variation of the principal additive effects of genotypes and environments. This is shown in the horizontal axis (YLD), while the variation of multiplicative effects of the genotype by environment interaction is shown in the vertical axis (Factor 1) (Fig. 1). It is evident that the varieties formed the maximum productivity in 2014/15 and the minimum one in 2012/13. All newly developed varieties significantly predominated over the variety Bemir 2 (G1) both in yield and in its combination with stability. The varieties Paladin Myronivskyi (G2) and MIP Yason (G3) had higher stability compared to others.

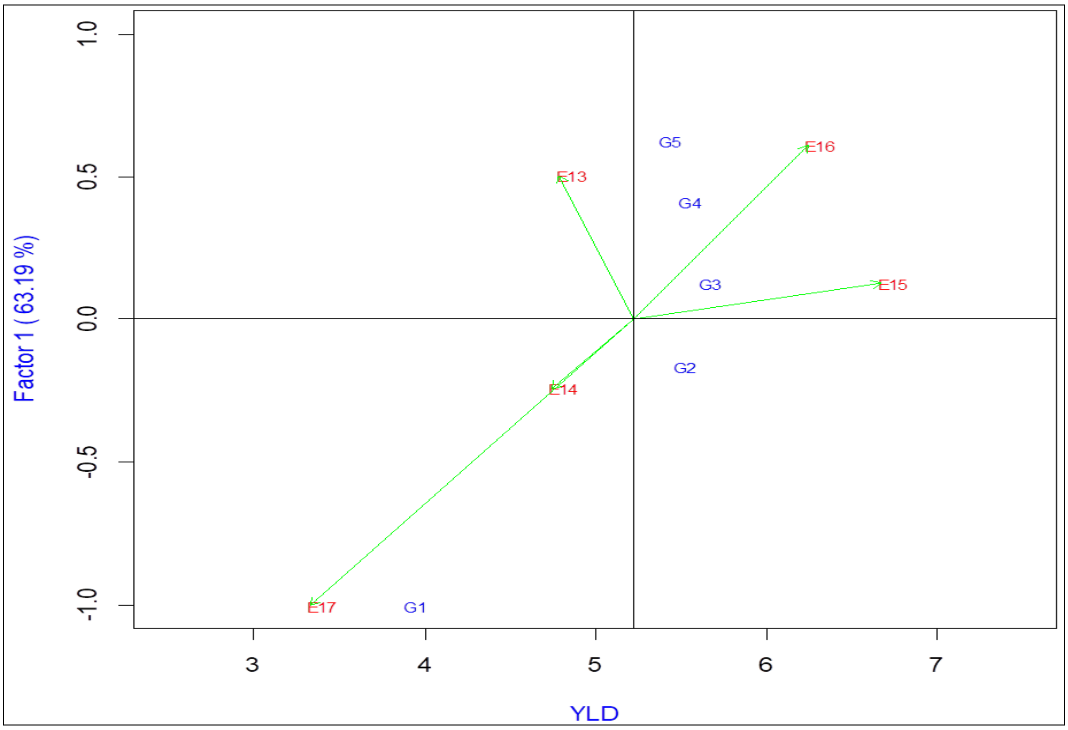

Figure 1. The AMMI1 biplot distribution of winter barley varieties and growing seasons in coordinates: mean yield (YLD) vs. first principal component (Factor 1)

This is also confirmed with the pattern of varieties scattering in the coordinates of two first principal components (Factor 1, Factor 2) AMMI2 biplot (Figure 2). It is noticeable that the variety MIP Hladiator (G5) had a stronger positive response to the conditions in 2014/15 and 2015/16, and the variety MIP Oskar (G4) was characterized by better adaptation to the conditions in 2012/13 and 2013/14. More favorable for variety Bemir 2 (G1) there were conditions in 2016/17, when the yield difference between it and new varieties was the least in the years of the research.

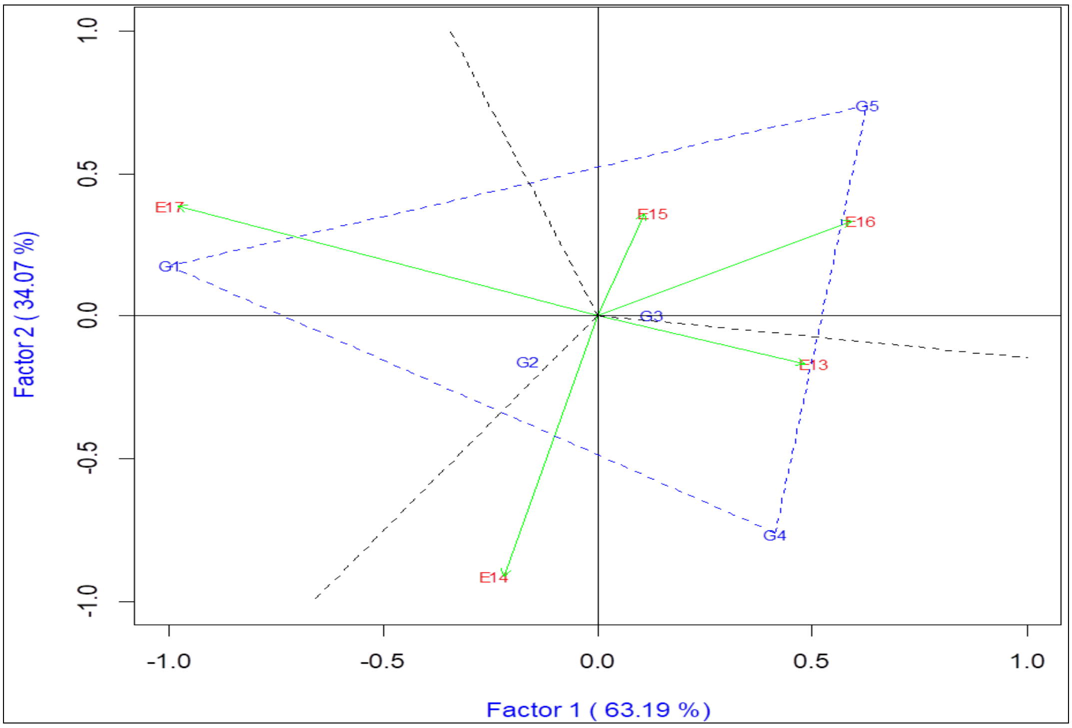

Figure 2. The AMMI2 biplot distribution of winter barley varieties and growing seasons in coordinates of the first and second principal components

According to the results of the structural analysis, it was revealed that the winter barley varieties Paladin Myronivskyi, MIP Yason, MIP Oskar, and MIP Hladiator were significant superior to the variety Bemir 2 for the number of productive tillers in the most years (Table 2). As an exception, it should be noted the variety MIP Hladiator in 2013/14 and the variety MIP Oskar in 2014/15, when they had unreliable predominance over the variety Bemir 2. Across five years, we observed the highest value of number of productive tillers in the variety MIP Yason (2.51 tillers/plant) as well as in the variety Paladin Myronivskyi (2.47 tillers/plant).

In our study the selection differential for number of productive tillers (NPT) varied from 0.50 tillers/plant (variety MIP Oskar) to 0.90 tillers/plant (variety MIP Yason). The heritability coefficient (H^2) was 0.87. Thus, the genetic gain (ΔG) for this trait varied from 0.44 tillers/plant in the variety MIP Oskar to 0.78 in the variety MIP Yason (Table 2).

Table 2. Phenotypic manifestation and genetic gain for yield-related traits in newly developed winter 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	1.27	1.58	2.35	1.80	1.03	1.61	-	0.87	-
G2	2.23	2.58	3.08	2.97	1.48	2.47	0.86		0.75
G3	2.25	2.53	3.18	3.13	1.44	2.51	0.90		0.78
G4	2.03	2.12	2.63	2.65	1.12	2.11	0.50		0.44
G5	2.05	1.83	2.80	2.83	1.23	2.15	0.54		0.47
LSD_{05}	0.23	0.28	0.31	0.23	0.13	0.24	-	-	-
Kernel number per spike (KPS)									
G1	40.92	41.70	43.47	45.20	41.13	42.48	-	0.88	-
G2	46.20	50.17	50.00	50.90	45.57	48.57	6.08		5.35
G3	46.60	50.23	50.77	51.87	46.13	49.12	6.64		5.84
G4	50.67	52.37	54.00	55.47	50.97	52.69	10.21		8.98
G5	49.63	50.90	53.63	58.00	48.87	52.21	9.72		8.56
LSD_{05}	2.78	3.03	2.94	2.37	2.50	2.72	-	-	-
Thousand kernel weight (TKW)									
G1	40.13	39.05	40.77	40.28	36.10	39.27	-	0.98	-
G2	41.15	41.03	42.90	42.17	40.30	41.51	2.24		2.20
G3	42.17	41.23	43.12	43.88	42.03	42.49	3.22		3.16
G4	43.05	42.50	42.13	42.45	39.02	41.83	2.56		2.51
G5	41.48	41.22	43.18	42.23	39.07	41.44	2.17		2.13
LSD_{05}	0.28	0.29	0.55	0.25	0.17	0.31	-	-	-

Notes: SD - selection differential, H^2 - heritability coefficient, ΔG - genetic gain.

All new varieties had the advantage over the variety Bemir 2 in kernel number per spike through all years of the trial. The maximal number of kernels per spike was noted in the varieties MIP Oskar (52.69 kernels) and MIP Hladiator (52.21 kernels). The selection differential for this trait varied from 6.08 to 10.21 kernels, and heritability coefficient was 0.88. The maximal genetic gain for this trait was observed in the varieties MIP Oskar (ΔG = 8.98 kernels) and MIP Hladiator (ΔG = 8.56 kernels) (Table 2).

The varieties Paladin Myronivskyi, MIP Yason, MIP Oskar, and MIP Hladiator significantly dominated over the Bemir 2 in thousand kernel weight. However, as comparing new varieties to each other, it should be noted that in different years the highest thousand kernel weight was noted in various ones. In particular, in 2012/13 and 2013/14, the variety MIP Oskar had the maximal 1000 kernel weight, in 2014/15 it was the variety MIP Hladiator, but in 2015/16 and 2016/17 the variety MIP Yason. An average for five years, the highest thousand kernel weight was noted in the variety MIP Yason (42.49 g). The breeding differential for the thousand kernel weight varied from 2.17 g in the variety MIP Hladiator to 3.22 g in the variety MIP Yason. This trait was characterized with the highest heritability coefficient (0.98). Thereby the genetic gain ranged from 2.13 g for the variety MIP Hladiator to 3.16 g for the variety MIP Yason (Tabel 2).

In general, in new winter barley varieties compared to the variety Bemir 2 there was detected statistically confirmed genetic gain for all studied traits. However, the varieties Paladin Myronivskyi and MIP Yason had a stronger genetic gain for number of productive tillers, and the varieties MIP Oskar and MIP Hladiator had for kernel number per spike. The most improved thousand kernel weight was noticed in the variety MIP Yason.

As it was mentioned, yield is the main integral trait characterizing economic value of any commercial variety. Therefore, information about the combination of yield and other parameters is of significant practical importance. For genotypes selection based on yield and trait complex combination a novel approach was proposed (Yan and Frégeau-Reid, 2018; Yan et al., 2019). It consists in modifying the experimental data of trials with multiplying yield performance and other economically valuable traits. A several authors used this method to assess the genotypes on a complex of economically important traits (Mohammadi, 2019; Boureima and Yaou, 2019; Kendal, 2020; Faheem et al., 2021). In our study, we applied this statistical and graphical model to estimate genetic gain in terms of yield*structural elements combination. In the first stage genotype traits data were converted to GYT (genotype by yield*trait) (Table 3). 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 in the variety MIP Yason (G3), the lowest its value was in the variety Bemir 2 (G1).

Table 3. Characteristics of winter barley varieties with genotypes by yield*trait combination, 2012/13-2016/17

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	0.06	-1.66	1.68	-1.76	1.55	-1.76	-1.73
G2	0.14	0.68	2.68	0.20	2.29	0.36	0.41
G3	0.14	0.87	2.79	0.40	2.41	0.70	0.66
G4	0.12	0.06	2.92	0.67	2.32	0.45	0.39
G5	0.12	0.05	2.84	0.50	2.25	0.25	0.26
Mean	0.12	-	2.58	-	2.16	-	-
σ	0.03	-	0.51	-	0.35	-	-

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

The GYT biplot (Figures 3, 4) graphically displays the standardized GYT data. The procedure for constructing a GYT biplot are the same as constructing the known GGE biplot (Yan and Tinker, 2006) except the term “environment” are replaced with “yield*trait” combination (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) GYT biplot explained 99.92% variation of the genotype for yield*trait combination. GYT biplot “which-won-where” shows that yield*trait combination and varieties distributed in two sectors (Figure 3). The first sector contained the combinations YLD_NPT and YLD_TKW, as well as the varieties MIP Yason (G3) and Paladin Myronivskyi (G2). Thus, these two varieties combined yield performance with higher level of manifestation for number of productive tillers and thousand kernel weight.

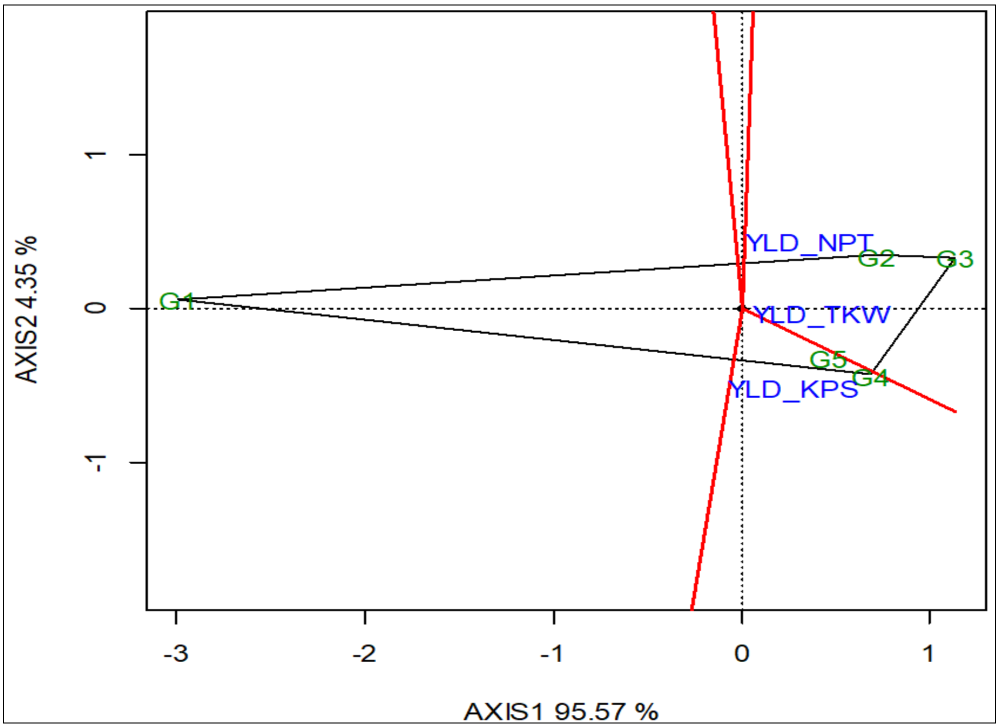

Figure 3. GYT biplot “which-won-where” polygon view, 2012/13-2016/17

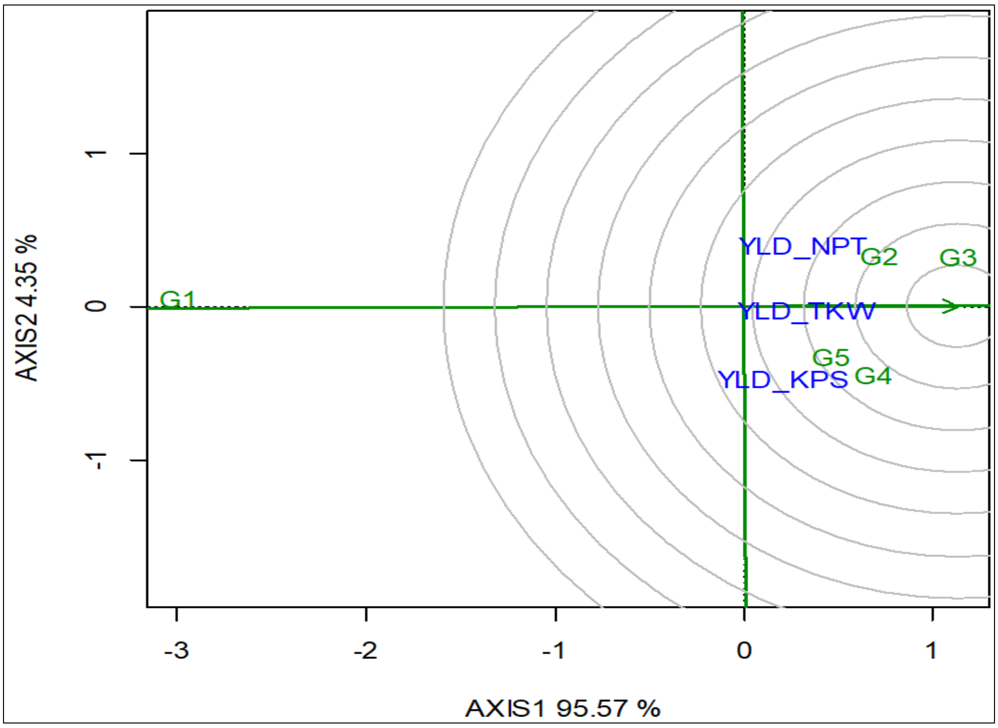

Figure 4. GYT biplot ranking varieties respectively to the “ideal” genotype, 2012/13-2016/17

The second sector contained YLD_KPS and the varieties MIP Oskar (G4) and MIP Hladiator (G5). That is, these two varieties were characterized by combination of yield and kernels number per spike. The variety Bemir 2 (G1) is located in the sector with no yield*trait combination. It indicates that this variety had poorer performance than new genotypes both in yield and in its combination with individual structural elements. GYT biplot genotypes ranking relative to the "ideal" is shown in Figure 4. It is noticeable that the new varieties (G2…G5) had significant advantage over the variety Bemir 2 (G1). The variety MIP Yason (G3) had the optimal combination of yield and its three main structural elements. The variety Paladin Myronivskyi (G2) was more displaced towards to yield*number of productive tillers combination (YLD_NPT). The varieties MIP Oskar (G4) and MIP Hladiator (G5) were located nearer to yield*kernels per spike combination (YLD_KPS). Thus, the GYT biplot confirms the above-stated patterns for breeding and genetic improvement revealed using statistical parameters for yield-related traits in the new winter barley varieties. 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, its stability and level of manifestation yield-related traits in the new winter barley varieties Paladin Myronivskyi, MIP Yason, MIP Oskar, and MIP Hladiator compared to the old Myronivka variety Bemir 2. However, using statistical and graphical analysis we revealed that the winter barley varieties MIP Hladiator and MIP Oskar had the highest genetic gain for kernel number per spike, Paladin Myronivskyi for number of productive tillers, and MIP Yason for number of productive tillers and thousand kernel weight. According to GYT biplot model the winter barley variety MIP Yason was the nearest to the "ideal" genotype by yield*traits combination. Thus, the newly developed winter barley varieties differed from each other with their combination of yield and its structural elements. The practical worth of the identified patterns is that the new varieties, due to the relatively different mechanisms of yield formation, will complement each other under unfavorable environmental conditions for the barley production.

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