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WINTER BARLEY SELECTION IN STEADY GRAIN PRODUCTION PROVISION IN THE CENTRAL FOREST-STEPPE OF UKRAINE

Ідентифікація генетичної стабільності та адаптації сортів рослин, у тому числі й ячменю озимого, дуже важливі для селекційних програм. Наведено результати багаторічних (2003/2004 – 2015/2016 рр.) досліджень ячменю озимого у Миронівському інституті пшениці імені В.М. Ремесла НААН. Встановлено рівень прояву врожайності ячменю озимого залежно від варіюючих погодних умов вегетації у Лісостепу України. Доведено, що використання AMMI та GGE biplot моделей дає можливість здійснювати поглиблену оцінку взаємодії генотип-середовище урожайності генотипів ячменю озимого за різних строків сівби та відбирати кращі за врожайністю і стабільністю селекційні лінії.

Ключові слова: ячмінь озимий, генотип × середовище AMMI, GGE biplot, стабільність.

Introduction. Food security is one of the main indicators of national security provided by the national seed breeding which plays an outstanding role in food provision and provides a basis for sustainable development of agriculture.

Analysis of recent research and publications. Food disasters have accompanied mankind since the beginning of a sedentary lifestyle and cultivating wild species, which coincides with the incipience of selection and agriculture as an industry, and they persist today. XXI century challenges were outlined in the materials of FAO international symposium (2014, Rome) in Agroecology Section "Ensuring food security and nutrition" [1-4]. The priority task is to overcome hunger and to feed the world population that will have made nine billion by 2050 while preserving the environment in terms of global climate change. In other words, it is to provide sustainable development of agriculture covering the modern demands without compromising the ability of future generations to meet their needs, which makes us to reconsider agricultural systems and redirect them in accordance with new demands.

Sustainable agriculture must be cost effective and protect the environment as well as be socially acceptable [5, 6].

Crops breeding is an essential platform of sustainable agriculture [7]. The need to introduce new crop varieties adapted to the environmental conditions will never disappear due to constant new challenges caused by new races of pathogens, fluctuations in weather conditions, changing market needs and others. Therefore, the contribution of crops breeding is increasingly recognized as one of the key factors in solving global problems of food security and sustainable development [8-10].

A variety is a unique means of production which ensures better performance, quality and environmental safety for a long time with practically no additional costs of energy and other resources due to its inherent genetic properties. It is the creation of new generations of these varieties that has initiated "green revolutions" contributing to the significant increase in grain production in the world [11].

Resistance to the limiting environmental factors that can reduce formation of potential productivity inherent in a genotype is one of the principal requirements set up to crop varieties in the global climate change environment. Against the background of the global warming the frequency of anomalous phenomena (long ground-ice crust, late spring frosts, the sharp increase in average air temperature in early spring vegetation, lack of moisture in the spring or autumn months, etc.) increases in Ukraine. This creates a number of problems in implementing genetic potential of varieties, and, ultimately, in winter barley production. To avoid the effects of climate change, crops breeding needs development of a set of measures with a significant component of further genetic breeding correction programs.

The paper **aims** at determining winter barley yield variation manifestation level in the "genotype-environment" interaction depending on the vegetation conditions in the Central Forest-Steppe of Ukraine and at selecting genotypes with optimal combination of yield and stability.

Material and methods. Field research was conducted in 2003/2004-2015/2016 vegetation years in the breeding crop rotation in Myronivka Institute of Wheat named after V.M. Remeslo, NAAS of Ukraine according to the conventional methods. [12] Invariable collection of 22 varieties of winter barley of Ukrainian (Myronivska, Odessa) and foreign (Russian, Czech) selection was studied every year.

14 lines of competitive test Myronivska breeding varieties were studied experimentally on sowing time in 2012/2013 – 2014/2015. The lines were compared with Gerard national standard variety. The research areas were set yearly for four sowing times: September 27 (1st term), October 4 (2nd term), October 11 (3rd term) and October 18 (4th term).

The sum of effective temperatures (over +5 ºC), average daily temperature and precipitation for individual interphase vegetation periods of winter barley was calculated according to the actual data of Myronivska meteorological station. Vegetation cessation and renewal was defined according to the date when the average daily temperature exceeded +5 ºC.

Statistical analysis of the experimental data was performed using Excel 2010 and Statistica 8.0 software. Assessment of the genotype-environment interaction was performed using AMMI and GGE biplot analysis. For this purpose, R-programming based application programs were used [13].

Results and discussion. The value of adaptive capacity is considered as the main criteria in varieties assessment. It is determined by various breeding traits with the yield among the most important ones. Plant growth and their ability to shift from vegetative to generative development takes place provided the temperature conditions are appropriate to each crop [14, 15]. Average values of air temperature and amount of rainfall in the interphase periods of growth and development, as well as for the entire period of the growing season of winter barley, varied (Table. 1).

Table 1 – **Hydrothermal conditions in the interphase periods of winter barley vegetation in the Central Forest-Steppe of Ukraine**

Vegetation period	Average daily temperature, ºC					Precipitation total, mm				
	SS	SC	SR	RE	ER	SS	SC	SR	RE	ER
2003/2004	14.5	6.9	-1.3	9.8	16.8	0.8	112.0	146.1	67.3	98.3
2004/2005	7.6	8.9	-1.8	12.7	18.1	17.3	22.1	182.4	93.2	69.6
2005/2006	8.2	5.4	-3.0	11.4	18.1	47.0	11.2	238.8	74.7	196.3
2006/2007	8.7	4.2	-0.1	9.9	21.9	27.2	38.1	80.8	13.0	103.9
2007/2008	9.4	7.9	0.0	12.2	18.0	8.9	13.2	165.4	131.3	76.7
2008/2009	12.1	9.1	-0.6	11.3	19.0	6.4	8.4	227.1	6.1	112.3
2009/2010	10.0	5.7	-4.5	12.0	20.2	31.2	42.7	211.8	61.2	95.5
2010/2011	14.7	8.1	-2.8	11.2	20.8	0.0	60.4	151.4	35.3	79.5
2011/2012	11.7	4.3	-2.1	14.9	19.9	70.4	5.8	152.7	71.6	63.2
2012/2013	16.7	9.2	-1.5	15.8	20.2	0.8	68.1	344.9	18.0	96.0
2013/2014	8.8	9.1	-1.3	10.1	18.8	0.0	13.2	54.3	91.2	142.0
2014/2015	9.2	6.4	0.1	12.2	19.5	0.0	35.6	183.6	43.7	123.9
2015/2016	7.2	4.3	-0.3	12.7	17.9	0.5	88.9	159.8	72.6	136.9
X	**10.7**	**6.9**	**-1.5**	**12.0**	**19.2**	**16.2**	**40.0**	**176.8**	**59.9**	**107.2**
Min	*7.2*	*4.2*	*-4.5*	*9.8*	*16.8*	*0.0*	*5.8*	*54.3*	*6.1*	*63.2*
Max	*16.7*	*9.2*	*0.1*	*15.8*	*21.9*	*70.4*	*112.0*	*344.9*	*131.3*	*196.3*
R(max–min)	9.5	5	4.6	6	5.1	70.4	106.2	290.6	125.2	133.1
V, %	28.2	28.5	-	14.9	7.3	136.9	84.1	40.9	59.9	33.8

Note: hereafter: SS – sowing-coming-up; SC – sowing-vegetation cessation, CR – vegetation cessation-renewal; RE – vegetation renewal – earing, ER – earing-ripening; X, min, max – average, minimum, maximum values, correspondingly; R(max–min) – range of deviation; V – variation coefficient.

In over 13 years term of research, a significant variation of the average daily air temperature (V = 28.2 %) was observed in the period of sowing-coming-up and coming-up – vegetation cessation (V = 28.2 %), the range of deviation (min – max) 7.2 – 16.7 ºC and 4.2 – 9.2 ºC respectively. Average variation (V = 14.9 %) was observed during the vegetation cessation – earring and minor one (V = 7.3 %) – during the earing-ripening stages.

The sums of effective temperatures (above 5 ºC) varied similarly in interphse periods of growth and development as well as during the entire period of winter barley growing season. The lowest variation (V = 1.0 %) magnitude (R = 166 °C) in this indicator was observed during the period from earing to ripening. On the average for 13 years, a very strong variation in the sum of effective temperatures (V = 56.5 %) was observed from coming-up to the crops fall vegetation cessation phases.

Moisture supply is one of the main limiting factors affecting crop plants growth and development [16, 17]. The average long-term (2003/2004 – 2015/2016) amount of precipitation during the growing season of winter barley crops was 400.2 mm and ranged from 262.9 mm (2006-2007) to 568.0 mm (2005-2006). Of these, 176 mm (44.2 %) fell during the crops winter dormancy. The largest amount of precipitation during the active growing season was observed in the earing – ripening interphase period – 107.2 mm (26.8 %). Precipitation amount varied both in certain periods (V = 33.8-136.9; R = 70.4-290.6 mm) and during the growing season as a whole (V = 21.4 %; R = 305.1 mm). This variability in precipitation influenced the growth and development of crops significantly as well as the yield formation.

Being the main characteristics of a variety productive potential, yield is formed under the influence of numerous environmental factors on the crop organism. The degree of manifestation of the genetic potential is the result of interaction between the environmental conditions and variety genotype. Crops live in constantly varying environmental conditions, and even in the same geographical site these conditions are so changing that the foreground it is not a high genetic potential productivity of a variety but the genotype ability to withstand the adverse effects of the environmental factors. Therefore, it is crucial to select the best varieties from a large number of newly bred ones adapted to the conditions of a particular area.

Extreme changes in meteorological parameters and other abiotic factors require adequate functional reactions from a crop organism, which may or may not be realized due to cellular mechanisms of adaptation to adverse environmental conditions a crop faces during the growing season. [18]

All physiological processes, in their ontogenesis, consist of specific biological events, chemical and biophysical reactions chains that occur under the control of genes. A new epigenetic phenomenon has been found out [19, 20]: if an environmental factor limiting a crop growth changes, the range and the number of genes determining the same quantitative trait change as well. As M.I. Dzubenko [21] points out two basic aspects stand out in the regulation of crop adaptive potential: genetic (change in adaptive properties by genetic plant breeding methods) and epigenetic (which includes a package of agro-environmental measures including the environmental conditions optimizing appropriate for varieties adaptive features, agrocenosis design *etc.*), whose ultimate goal is to ensure stable growth of the crop yield and quality.

Long-term (2003/2004–2015/2016) analysis of 22 varieties of winter barley yield reveals a credible contribution of genotype, vegetation year weather conditions and their interaction in the productivity level. However, the conditions of growth contribute 86.14 % to its overall dispersion (Table 2).

The yield varieties in the experiment ranged from 7.5 t/ha in 2003–2004 to 3.1 t/ha in 2010–2011. This indicates that crops growing, including barley, is impossible without taking into account the climatic characteristics of the zone and the crops biological requirements. Successful incorporation and use of these two factors enables to fully develop the crop genetic potential and implement the existing productive properties of the variety genotype.

Table 2 – **Results of two-factor dispersion analysis of winter barley yield, 2003/2004–2015/2016**

Factors	SS	df	MS	F	F_{05}	Factors contribution into total dispersion, %
Genotype	84.76	21	4.04	138.40	1.57	4.96
Year	1472.64	12	122.72	4207.88	1.77	86.14
Genotype-year	135.59	252	0.54	18.45	1.19	7.93
Error	16.68	572	0.03	–	–	0.98
Total	1709.67	857	–	–	–	–

Note: SS – sum of squares, df – degree of freedom number, MS – mean square, F – Fisher criterion value, F_{05} –Fisher criterion critical value.

It is the environment that conditions assessing the breeding material at all stages of the selection process from the very beginning to obtaining generated new varieties, aiming at identifying genotypes adapted to the adverse effects of biotic and abiotic environmental factors. Therefore, evaluation of breeding material at different seeding time, in terms of global climate change, is one of the important methodological approaches and ecological genetics and adaptive selection.

The maximum average yield (5.18 t/ha), in 2012-2013 experiment year was obtained under the first sowing term, slightly lower one – 4.98 t/ha, was obtained in the second term. A significantly lower yield was received in the third and fourth sowing term plots – 4.37 and 4.13 t/ha, respectively.

Heavy lodging of plants, especially in the first two crops sowing terms, was observed in 2013-2014 vegetation year, which affected significantly the yield level. As a result, the maximum average yield on all lines was obtained under the third sowing term – 4.83 t/ha, the minimum – under the first one (3.93 t/ha). Maximum yield was obtained in 2014-2015 under the second sowing term – 6,33 t/ha, and the lowest one – in the fourth (5.08 t/ha).

The data clearly show a significant variation in the conditions of the growing season in different years in the central steppes of Ukraine, which is manifested through different levels of breeding lines yield. Varied sowing terms increase this variation significantly. Each biotype is characterized through a certain response to environmental conditions in which its reaction norm is manifested. It is important for the breeder to know the value of genotypic variability of productivity quantitative traits, i.e. its genotypic variance, to select successfully the best genotypes for adaptability. Some approaches which, along with the calculation of mathematical and statistical indicators, enable to visualize the distribution of genotypes and media in 2D or 3D space have been widely used lately to analyze the genotype-environment interaction [22, 23, 24, 25]. Dispersion analysis of AMMI model showed the most significant contribution of the environmental conditions to the dispersion (66.5 %) (Table 3).

Table 3 – **Results of dispersion analysis of AMMI model of winter barley breeding lines yields**, 2012/2013 – 2014/2015

Factors	SS	PORCENT	DF	MS	F
ENV	260.521	66.457	11	23.684	667.239*
GEN	62.119	15.846	14	4.437	125.005*
ENV*GEN	69.375	17.697	154	0.450	12.692*
PC1	34.719	50.046	24	1.447	92.321*
PC2	16.710	24.087	22	0.759	48.473*
PC3	7.537	10.864	20	0.377	24.048*
PC4	3.815	5.499	18	0.212	13.525*
PC5	3.075	4.432	16	0.192	12.264*
PC6	1.902	2.742	14	0.136	8.671*
PC7	0.987	1.423	12	0.083	5.251
PC8	0.289	0.418	10	0.029	1.849
PC9	0.227	0.328	8	0.028	1.814
PC10	0.065	0.093	6	0.011	0.688
PC11	0.047	0.068	4	0.012	0.753
PC12	0	0	2	0	0
Residuals	12.778	0	360	0.035	-

Note: ENV – environment, GEN – genotype, ENV*GEN – genotype-environment interaction, SS – sum of squares, PORCENT – share of contribution into the variation, %; DF – degree of freedom number, MS – mean square, F – criterion, PC1…PC12 – principal components, *reliable for 0.01 % sampling significance.

Genotype and the genotype-environment interaction had a much lower effect – 15.8 and 17.7 % respectively. The first two principal components (PC1, PC2) make 74.1% of genotype-environment interaction. AMMI1 biplot (Fig. 1) represents the variance of the main additive effects of genotype and the environment (average yield), which make the horizontal axis and the variance of multiplicative effects of the genotype-environment interaction located on the vertical axis (the first basic component). It allows to analyze graphically the dispersion of genotypes, environments (experiment years) and the interaction between them.

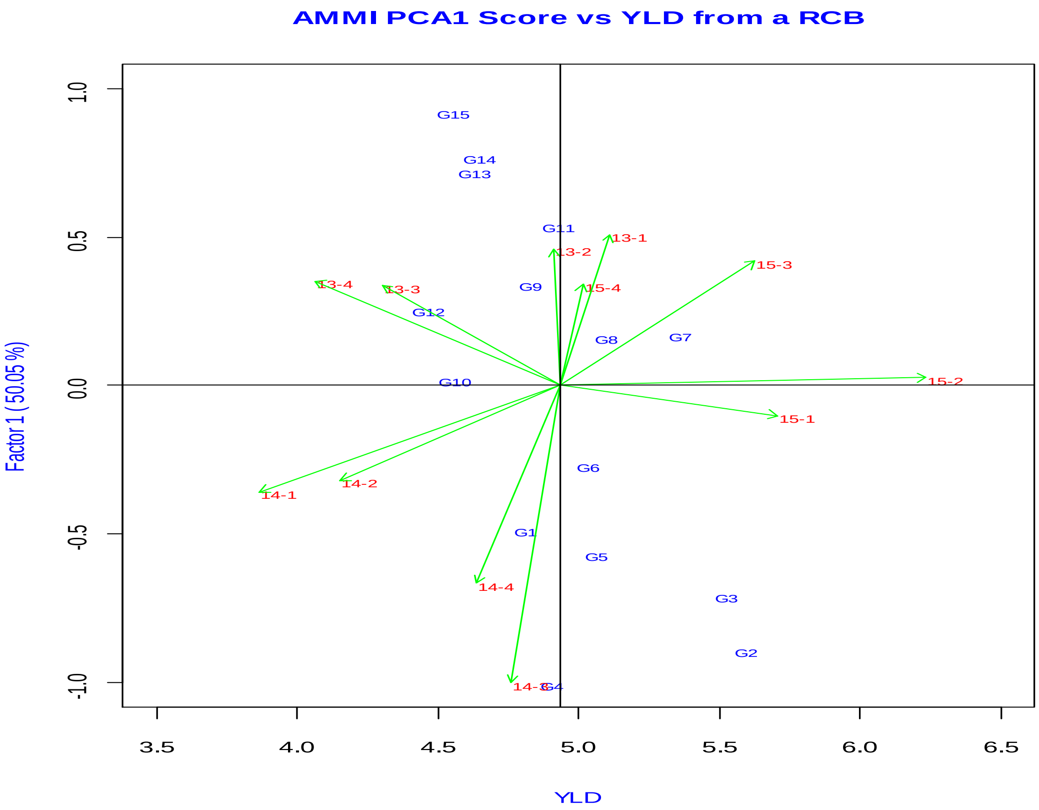

Fig. 1. **AMMI1 biplot – distribution of genotypes and environments in coordinates: principal component 1 (Factor 1) and the average yield of genotypes and environments (YLD),** 2012/2013 – 2014/2015.

Figure 2 presents AMMI2 biplot of multiplicative interaction genotype-environment effects in the coordinates of the first (PC1) and second (PC2) principal components. It is possible to visualize the clustering of samples and environments and to assess which of the environment was the best for a specific genotype, i.e. the conditions under which the genotype formed the highest productivity.

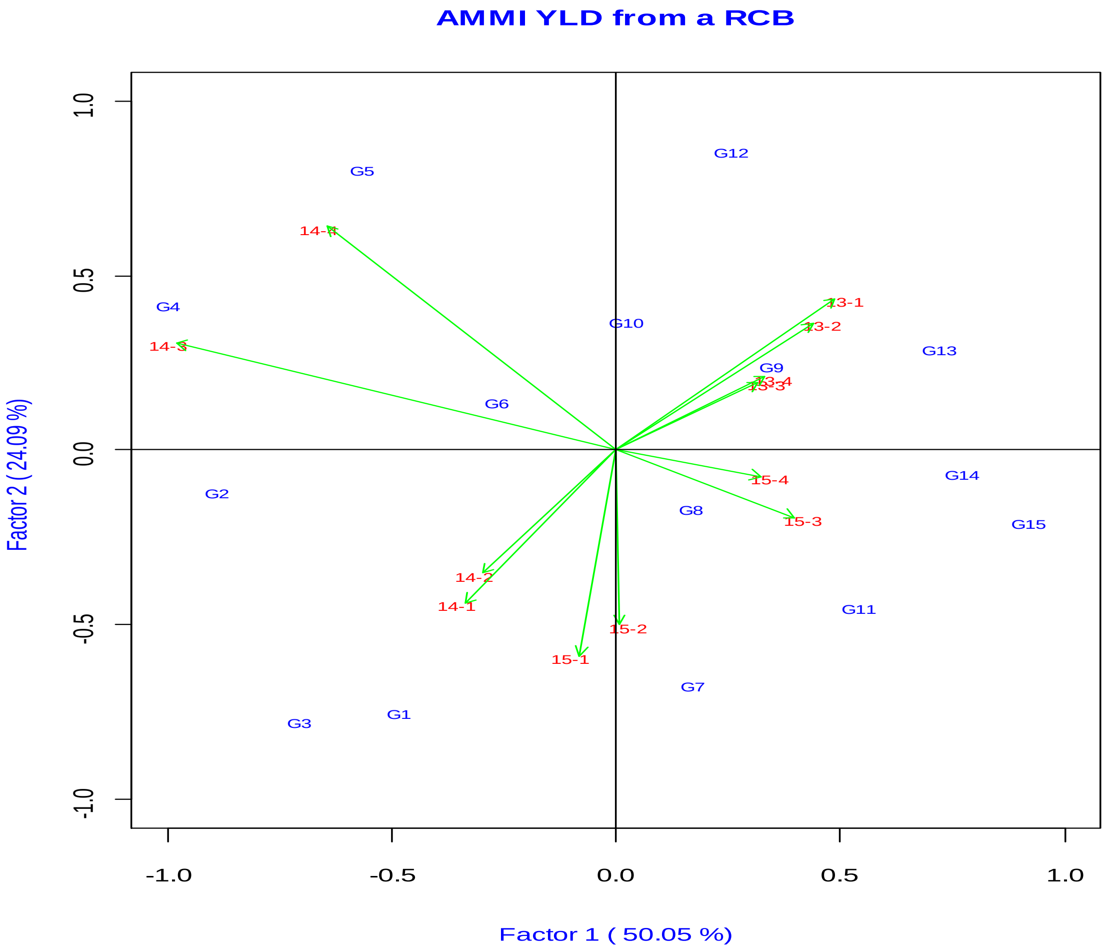

Fig. 2. **AMMI2 biplot – distribution of genotypes and environments in the coordinates of the first two principal components,** 2012/2013 – 2014/2015.

Natural selection, as part of the selection process is based on organisms competition, i.e. on the individual elimination. The creative role of natural selection is displayed in the interaction of organisms and varying environmental factors. That is, evolutionary patterns make the basis of the selection process and are that are implemented through natural selection. Natural selection keeps most adapted forms while human artificial selection is oriented towards selecting the most economically valuable genotypes on certain breeding programs. Therefore, individual selection of adaptive forms is carried on the results of natural selection.

The first two principal components (Axis 1, Axis 2) of GGE biplot analysis explain 80.98 % of the genotype-environment interaction. Genotypes GGE biplot ranking in relation to the so-called "ideal" genotype, which is a middle of centric circles (Fig. 3), demonstrates the superiority of G 2 breeding lines (Pallidum 4857), G3 (Pallidum 4816) and G7 (Pallidum 4659). The remaining genotypes were significantly inferior to the abovementioned in terms of productivity level manifestation and its stability.

The interaction of environmental and physiological systems is based on the fact that any physiological object is part of the environmental one. Each physiological object functions within the spatial and temporal heterogeneity defined by a higher rank object, thereby energy and substances flow is carried in the body that calls for its viability.

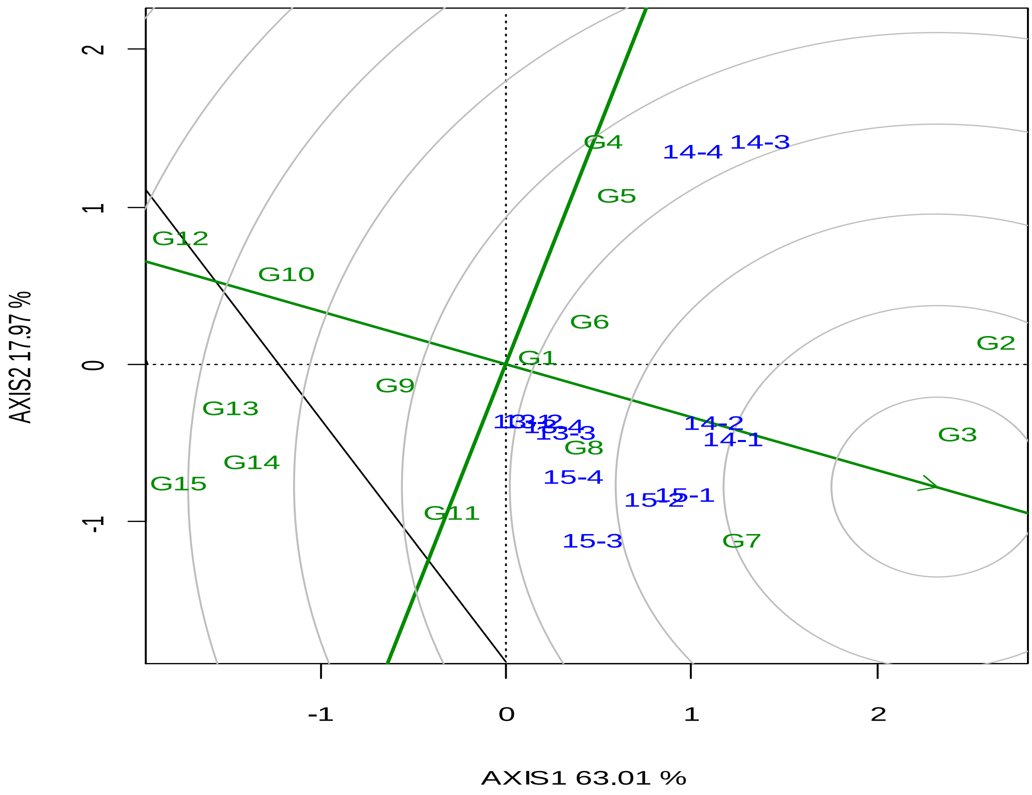

Fig. 3. **Breeding lines ranking with respect to a hypothetical "ideal" genotype**, 2012/2013 – 2014/2015.

Therefore, as a result of the analysis of 14 breeding lines the following three lines were selected: Pallidum 4857 (Osnova/Mironovskiy 87) Pallidum 4816 (Luxor/Mironovskiy 87) and Pallidum 4659 (Erfa/Radical//Kromoz), which significantly exceeded the others in terms of yield and stability. The received data indicate good homeostasis of their genotypes under varying conditions of vegetation. Each plant cell has a complete set of genes required for ontogeny, but only the genes required for the organism growth and development are active in a particular time. The existence of genes activity epigenetic regulation mechanisms causes basic adaptive reactions, which are stages in the chain of genotype hereditary implementation and, consequently, are displayed in quantitative and qualitative features specific to a particular genotype. Barley selection can be carried out on any trait and characteristics of the crop: morphological, physiological, biochemical, ontogenetic, resistance to environmental stressors, adaptive and other characteristics. Growth, development and morphogenesis are so closely related to each other that they should be considered only in the complex. Growth as an integral process is one of the leading processes in the implementation of an organism genetic program that provides its morphogenesis and ontogenetic development.

The regulatory system consists of plant genetic apparatus, biological rhythms, cell membranes, enzyme systems, ions and phytohormones. It is characterized by high sensitivity to various physical and chemical factors. All physiological processes consist of specific biological events, chemical and biophysical chain reactions that occur under the control of genes. All features and properties of crops can be found at the morphological, physiological, genetic, biochemical, environmental, etc. levels. Due to the integrity of living systems, their structural and functional levels are interconnected that enables to assess one system through the others. However, insufficient study of these connections at the ultimate stage of the traits manifestation, especially at the level of their determination (genetic and epigenetic) and formation hinder the fullest use of the detected patterns in the selection.

Conclusions. 1. The combination of different sowing terms and AMMI and GGE Biplot analysis in the final stages of the selection process enables to characterize in detail and differentiate breeding lines not only by the average yield, but by reacting to changing growing conditions as well.

2. Three promising lines, Pallidum 4857, Pallidum 4816 and Pallidum 4659, with the best combination of yield and stability were selected.

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Селекция ячменя озимого для обеспечения стабильного производства зерна в Центральной Лесостепи Украины

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Идентификация генетической стабильности и адаптации сортов растений, в том числе и ячменя озимого, очень важны для селекционных программ. Приведены результаты многолетних (2003/2004 – 2015/2016 гг.) исследований ячменя озимого в Мироновском институте пшеницы имени В.М. Ремесла НААН. Установлен уровень проявления урожайности ячменя озимого в зависимости от варьирующих погодных условий вегетации в Лесостепи Украины. Доказано, что использование AMMI и GGE biplot моделей дает возможность осуществлять углубленную оценку взаимодействия генотип-среда урожайности генотипов ячменя озимого при разных сроках сева и отбирать лучшие по урожайности и стабильности селекционные линии.

Ключевые слова: ячмень озимый, генотип × среда AMMI, GGE biplot, стабильность.

Winter barley selection in steady grain production provision in the Central Forest-Steppe of Ukraine

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Identification of genetic stability and adaptation of crops varieties, including winter barley is rather important for breeding programs. The paper reveals the results of long-term (2003/2004 – 2015/2016) winter barley studies conducted in Myronivka Institute of Wheat named after V.M. Remeslo, NAAS of Ukraine.

The level of winter barley yields manifestation depending on the varying weather conditions of vegetation in the Forest-Steppes of Ukraine was determined. It was proved that the use of AMMI and GGE biplot models made it possible to carry out profound estimation of genotype-environment yield interaction for winter barley genotypes under different seeding time and select the best ones in terms of yield and breeding lines stability.

Key words: winter barley, genotype × environment interaction, AMMI, GGE biplot, stability.

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