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INTRODUCTION OF NEW STRESS-RESISTANT AND HIGH-YIELDING WINTER WHEAT VARIETIES BASED ON CHROMOSOME ENGINEERING AND MARKER-ASSISTED SELECTION

The results of research conducted in 2013 at the Institute of Plant Physiology and Genetics of NASU have been showed. The status of soft winter wheat breeding, seed production, and varietal resources of strategic culture has been identified. The examples of how the crop areas of innovative varieties significantly expanded within the territory of Ukraine and how the innovative varieties started being produced in nearby countries have been described.

Key words: winter wheat, variety, genetic potential, selection, seed production, rye-wheat translocation, and innovation.

Today, Ukraine faces a challenge of entering the international food market and meeting the needs of domestic grain producers in varietal resources and seeds. The global climate change and the associated adverse global trends in the crop production certainly affect it. Every year, the winter wheat crops are exposed to extremely low or high temperatures, suffer from diseases and pests. As a result, the wheat yield is unstable, with some farms incurring significant economic losses.

The soft winter wheat being the most important food crop in the world, the creation of its new varieties that are highly resistant to environmental stressors is a promising and cost-effective way out of this situation. The soft winter wheat ensures about 75% of the calories and 50% of the vegetable protein in the structure of human nutrition. A large share of domestic- and foreign-bred wheat varieties is not adapted to the new conditions of global warming and droughts that occur during the growing season in the last five years in the climatic zones of Ukraine.

The state-of-the-art world and domestic developments in genetics and breeding associated with the creation of new varieties of plants are characterized by wide use of classical methods (hybridization, experimental mutagenesis, chromosome engineering) and cutting-edge molecular genetic research in this area. This is just the combination of various new genetic and molecular technologies with conventional breeding, which allows the researchers to obtain new high-yielding varieties of crops that are resistant to climate change.

According to *Plant Breeding & Genetics Newsletter,* in the upcoming decades, the main global trends in the development of new high-yielding genotypes of crop plants that are resistant to extreme environmental factors will be aimed at improving the methods of genetics, cell and molecular biology as well as at identifying new molecular genetic markers for marker-assisted selection

(MAS). Today, there is no doubt that DNA genotyping and marker-assisted selection make it possible to speed the transfer of useful genes to the required genotypes and to ensure the creation of new varieties with a whole set of valuable attributes. Therefore, for creating and supporting the production of new competitive high-yielding winter wheat varieties bred in Ukraine it is very important to conduct research aimed at using the latest methods of genetics and breeding in combination with molecular marking of genes that determine the useful properties.

STATUS OF BREEDING AND SEED PRODUCTION IN UKRAINE

In the last decades, the Department for Genetic Improvement of Plants of the Institute of Plant Physiology and Genetics (IPPG) of NASU has been focusing its efforts on breeding high-yielding varieties of wheat having a premium quality in term of baking and other important agronomic characteristics.

While implementing its programs, the Institute uses the newest methods of genetics, marker-assisted selection, chromosome engineering, and classical breeding techniques. This allows the researchers to create, in a short time, new varieties of winter wheat suitable for the mass production in Ukraine and abroad. The economic effect of the development is approximately USD 2.2 billion annually due to an increase in yield of 0.6-1 tons/ha as compared with the varieties that are currently in production and with the national standards. It should be noted that the energy consumption per unit of area is equivalent in both cases.

Grain farming in Ukraine is a strategic industry and the most effective sector of the national economy. The *Grain of Ukraine* sectoral program presets to reach a gross grain output of 80 million tons annually.

During 2013, the Institute's expert team implemented an innovative project of NASU on the introduction of high-yielding winter wheat varieties resistant to stress factors using chromosomal genetic engineering and marker-assisted selection. The objectives of the innovative project were as follows:

- To accelerate the reproduction of original seeds of new winter wheat varieties adapted to the climatic conditions of Ukraine;
- To start the production of a new generation of varieties and to form a network of seed stocks in Ukraine and abroad;
- To conduct a research on molecular genetic labeling of varieties and lines of winter wheat;
- To conduct a market research and to provide information and advisory support to the innovative project.

In 2013, in Ukraine, for the first time, the total production of grain exceeded 63.5 million tons, with the average yield reaching 40 cwt/ha. The yield of winter wheat accounted for 33.9 cwt/ha over an area 6.5 million ha; the harvest of corn exceeded 64 cwt/ha over an area of 4.8 million ha; and the gather of barley (winter and spring) made up 23.4 cwt/ha over an area of 3153,000 ha.

In 2013, in Ukraine, the grain production per capita exceeded 1380 kg versus 360 kg in the world, with the export capacity reaching more than 30 million tons (Table 1).

In Ukraine, 11 research institutions of the National Academy of Agrarian Sciences of Ukraine (NAASU) and NASU, universities, and 6 private breeding companies are involved in soft winter wheat breeding. As of 2013, about 60 varieties from the Register of Plant Varieties of Ukraine were bred by Institute for Breeding and Genetics (Odesa), 58 varieties were reared by the Institute of Plant Physiology and Genetics of NASU; the Myronivka Institute of Wheat raised 22 varieties; and V.Ya. Yuriev Institute for Crop Research and Plant Breeding cultivated 11 varieties, etc.

Totally, as of today, the Register of Plant Varieties of Ukraine has included 389 varieties of winter grain crops, including 283 varieties of winter wheat, with 264 of them being soft or bread wheat varieties. Two hundred and eleven varieties of them (80% of the total) were reared by Ukrainian breeders.

The results of field studies have showed that potential productivity of varieties listed in the

State Register of Plant Varieties of Ukraine is 7.2–12.4 tons/ha (Table 2).

Among the foreign-bred varieties listed in the Register of Plant Varieties of Ukraine there are 17 varieties cultivated in the Russian Federation, 12 varieties from Germany, as well as varieties originated from France, Austria, Serbia, Cyprus, Poland, the Netherlands, and from other countries. However, every year, the foreign varieties cover only 10–15% of the total area under winter wheat in Ukraine.

An important task of plant breeding is to create winter wheat varieties with high environment flexibility. It should be noted that, in general, the winter wheat varieties registered in Ukraine proportionally represent the different climatic zones (Fig. 1).

The study of new varieties in different soil and climatic conditions has showed that newly registered varieties able to produce stable high yields possess the highest environmental adaptability in different subzones, micro-areas, and geographic locations of Ukraine. The winter wheat varieties bred by IPPG of NASU represent the woodlands (44 varieties or 36%), the wood steppe (47 varieties or 39%), and the steppe (31 varieties or 25%). In 2013, the winter wheat varieties bred by the Institute covered about 1,746,000 ha or 25.6%. The largest areas occupied by these varieties are as follows: 195 thousand ha in Vinnytsia Oblast; 168 thousand ha in Kharkiv Oblast, 149 thousand ha in Dnipropetrovsk Oblast, 120 thousand ha in Poltava Oblast, and 110 thousand ha in Cherkasy Oblast.

Table 1

Ukraine's Share in the World Grain Production and Export, million tons

	Grain production, 2013, tons		Export, 2013
	Total	Including per capita	
Worldwide	2491.8	0.36	329.8
Ukraine	63.5	1.38	31.0

Table 2

Number of Winter Wheat Varieties in the State Register of Varieties of Plants in 2013

Cropper	Total varieties	Including		
		Ukrainian Breeding	Foreign Breeding	Ukrainian breeding, %
Winter wheat, total including	389	307	82	79
Wheat, including	283	230	53	81
Soft (bread) wheat	264	211	53	80
Hard (macaroni) wheat	19	19	—	100

In 2013, the area occupied by winter wheat varieties cultivated by the Institute was structured by climatic zones as follows: more than 1.046 million ha of the wooded steppe; 525 thousand ha of the steppe; and 182 thousand ha of the woodlands (Fig. 2).

The newly registered winter wheat varieties can be classified by yield capacity into the high-value crops and the economic crops. The high-value crops have a high yield capacity and a quite wide norm of reaction to optimization of growing conditions. Among this group, there are varieties bred by IPPG NASU. The most noteworthy of them are *Niva Kyivschyny*, *Slavna*, *Chorniava*, *Spasivka*, *Darunok Podillia*, *Sotnytsia*, etc. Under favorable conditions, they can produce a record-breaking high yield. The varieties of this group effectively utilize their yield capacity on the area with good soil fertility and agricultural background, under favorable climatic conditions (Table 3).

Unfortunately, the majority of the farmers is not able to provide this type of varieties with required agricultural technologies and material resources. In addition, the climate change and global warming require breeding the varieties that have natural adaptability to adverse conditions. Therefore, the availability of varieties of different groups with different requirements for growing conditions is a prerequisite for successful production.

The economic crops are characterized with a better environmental flexibility and resistance to drought and frost. Among the registered varieties in this group, there are winter wheat varieties

Podolianka,Bohdana,Vinnychanka,Novokyyivska, Lazurna, Lymarivna, Natalka, Snihurka, Sonechko, etc. These varieties are characterized by high frost, drought, and heat resistance, bushiness, enhanced competitiveness with respect to weeds; they better tolerate unfavorable growing conditions and adverse effects of stressors. Therefore, they occupy large areas (Table 4).

One of the main objectives of the innovation project was to ensure rapid seed multiplication at primary levels of production of seeds of new winter wheat varieties and to organize their production.

Last year, the Institute cultivated seeds of 38 winter wheat varieties. Despite the adverse conditions (asphyxiation and snow mold) more than 150 tons of primary seeds were grown (the first-year stock seeds).

In 2013, the Institute produced the second-year and the super-quality stock seeds. The area used for seed production totaled 203.6 ha. Over 550 tons of seeds (the second year and the super-quality stock seeds) of 30 new winter wheat varieties were gathered, prepared for sowing and sold. Among them there were as follows: *Natalka, Sonechko, Solokha, Zolotovolosa, Horevytsia, Sotnytsia, Lymarivna, Smuhlianka, Kalancha, Khurtovyna, Lazurna, Oriika, Volodarka, Pereiaslavka, Novokyivska, Prydniprovska, Zymoiarka, Nyva Kyivschyny,Dostatok,Snihurka,Chorniava,Spasivka, Podolianka, Favorytka, Darunok Podillia, Chyhyrynka, Bohdana*, and *Vynnychanka*.

Thanks to the innovative project, positive dynamics of increase in acreage for the varieties bred by IPPG of NASU. For the harvest of 2014, the acreage under primary stock seeds increased almost 2.5 times, as compared with 2013. For the first time, the best foundation seed stocks of Vinnytsia and Kyiv Oblasts have been used (Table 5).

Nowadays, the primary seed acreage totals 500 ha; the projected seed production (the second-year stock seeds) is 1750 tons. In several years, the acreage under the winter wheat reared at the IPPG is expected to increase up to 2 million ha (30% of acreage), in Ukraine, and up to 250–300 thousand ha, abroad.

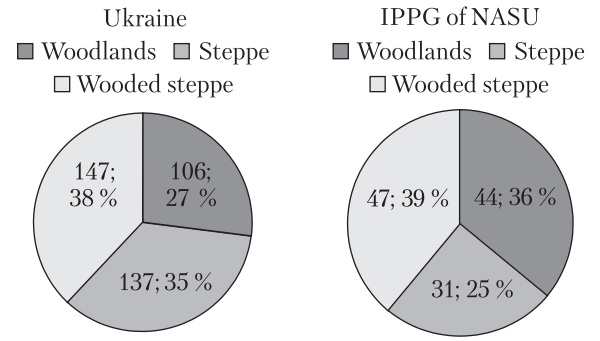

Fig. 1. Regional Assignment of Winter Wheat by Climatic Zones of Ukraine (2013)

Fig. 2. Climatic Structure of Area Planted with Winter Wheat Bred by IPPG NASU in 2013

Table 3

New High-Effective Soft Winter Wheat Varieties Bred by IPPG of NASU

Variety	Year of registration	Regional assignment	Maximum yield, tons/ha
Spasivka	2012	S WS WL	11.2
Oriika	2013	S WS WL	11.4
Darunok Podillia	2013	S WS WL	10.9
Sotnytsia	2013	S WS WL	11.0
Kalancha	2013	WS WL	10.7
Polianka	2013	S WS WL	10.8
Hileia	2014	S WS WL	10.8
Boria	2014	S WS WL	10.1
Prydnistrovska	2014	WS WL	10.4
Astarte	2014	S WS WL	11.7
Malynivka	2014	S WS WL	11.1

Note. *S — steppe, WS — wooded steppe, WL — woodlands.

As part of the innovative project, a research on the molecular and genetic labeling of varieties and lines of winter wheat has been conducted. Today, many winter wheat varieties with rye-wheat translocation (1RS.1BL or 1RS. 1AL) are produced. These translocations have a high breeding value insofar as they positively influence the grain productivity; they are highly adaptable to external environmental factors and resistant to pathogens.

According to many researchers, these translocations have not only the favorable, but also the adverse effects, as they can worsen the baking quality of flour and impair the grain value. In the world practice of wheat breeding, the rye-wheat translocation have been used for more than 35 years, however, to separate the positive and the negative breeding effects is extremely difficult. In this context, the effective control of translocation chromosomes both during the breeding and primary seed production. For this purpose, the appropriate biochemical and molecular genetic tests have been developed.

During the project implementation, a test polymerase chain reaction (PCR) with the use of specific primers has been studied; temperature conditions of reaction have been chosen; and the results of identification marker loci for the shoulder (1 RS) of rye chromosome (X rems and Sec-1) have been obtained. The PCR laboratory procedures for controlling Glu-Bl A1 locus that has an extra positive effect on baking quality of flour and requires a regular control during the selection and primary stock seed production have been elaborated.

The data obtained show that the optimized PCR procedure for Glu-B1 Al locus control makes it possible to reveal the homogeneous samples of wheat depending on the presence/absence of Glu-B1 Al locus.

This means that in the case of heterogeneity, the respective laboratory procedure allows the researchers to divide the heterogeneous samples of wheat (during the breeding or primary stock seed production) by separate biotypes, to achieve homogeneity of the variety sample, and to improve greatly its quality and flexibility.

In the course of project implementation, special attention is paid to information and advisory support of innovation created. In 2013, the inno-

Table 4

New Economic Soft Winter Wheat Varieties Bred by IPPG of NASU

Variety	Year of registration	Regional assignment	Maximum yield, tons/ha
Natalka	2010	S WS WL	10.2
Sonechko	2010	S WS WL	10.6
Novokyivska	2010	S WS WL	10.2
Khorevytsia	2011	S WS WL	10.5
Lymarivna	2012	S WS WL	10.2
Chyhyrynka	2012	S WS WL	11.2
Lazurna	2012	S WS WL	10.3
Zluka	2012	S WS WL	11.5

Table 5

Planting of Primary Seeds by Research Farm Production of IPPG of NASU and on the Training Plots in 2014

No.	Company	Acreage, ha	Number of varieties	Expected production of primary stock seeds (PP2), tons
1	IPPG of NASU	75	40	300
2	Research Farm Production of IPPG of NASU	230	20	600
3	*L. Pohorilyi* UkrNDIPVT	50	5	200
4	*Agrobud*, LLC	60	21	300
5	*Olhopil*, AF	85	21	350
	Total	500	—	1 750

vative project team and other leading researchers of the Institute held 12 *Day of the Field* regional conferences (Table 6) and *Day of the Field 2013* international research conference at *Olhopil,* AF, in Vinnytsia Oblast.

More than 2.3 thousand specialists of breeding units, farms, and agricultural holdings, as well as representatives of regional authorities, the Ministry of Agrarian Policy and Food of Ukraine, agricultural research and educational institutions of Ukraine, and international partners took part in the events widely covered in the media (newspapers, radio, and television).

The ranges for testing the innovative varieties adapted to the environmental conditions in different climatic zones of Ukraine and the state-of-of-the-art technologies for production of high-quality seeds and food grains are an extremely effective measure for the promotion and implementation of research results.

In 2013, the authors of innovative project supervised the foundation of testing ranges at 12

Table 6

***Day of the Field* Research and Practical Conferences Held in 2013**

Institution	Date	Content/exhibit	Number of participants
Olhopil, AF, Chechelnytskyi Raion, Vinnytsia Oblast	June 2013	Winter wheat varieties bred by IPPG of NASU and techniques for cultivating of seeds and commercial grain	400
Slavutych, AF, LLC, Pokrovskyi Raion, Dnipropetrovsk Oblast	June 2013	Winter wheat seed and grain production in the central steppe region of Ukraine	75
Obolon-Agro, LLC, Chemerivetskyi Raion, Khmelnytskyi Oblast	June 2013	Winter wheat varietal resources and high-quality seeds as guarantee of success	200
Dovzhanska, AF, PC, Sverdlovskyi Raion, Luhansk Oblast	June 2013	Winter wheat seed and commercial grain production in the eastern steppe region of Ukraine	100
L. Pohorilyi UkrNDIPVG, Kyiv Oblast	June 2013	Specific features of grain and seed production in the wooded steppe of Ukraine	200
Archi, LLC, Koziatynskyi Raion, Vinnytsia Oblast	June 2013	Techniques for seed and commercial grain production of Kyiv winter wheat in Vinnytsia Oblast	150
Mria, FG NVO, Hustynskyi Raion, Ternopil Oblast	June 2013	New varieties and techniques for planting high-quality grain and seeds of winter wheat bred by IPPG of NASU	150
Pischyanska, AF, LLC, Krasnogvardiiskyi Raion, Kharkiv Oblast	June 2013	Specific features of new winter wheat varieties and elements of technique for seed and commercial grain production in Kharkiv Oblast	100
Rise Maxymko, PrJSC Chervonozavodske, Lokhvytsia, Poltava Oblast	June 2013	New varieties of Kyiv wheat in seed and commercial grain production in the central wooded steppe zone of Ukraine	200
Nasinprom, MNZ, LLC, Poligon, Zhovtnevyi Raion, Mykolaiv oblast	June 2013	Techniques for production of new high-quality varieties of winter wheat	400
Askon, PP, Yakymivka, Yakymivskyi Raion, Zaporizhia Oblast	June 2013	Specific features of production of high-quality seeds on dry-land and irrigated fields	150
January 9, DPDG, Khorolskyi Raion, Poltava Oblast	June 2013	Specific features of new varieties of winter wheat and elements of technique for seed and commercial grain production in Poltava Oblast	200

seed production companies and at 5 agricultural farms of Russia, Transdniestrian Republic, and Moldova (Table 7).

Together with the Department for Genetic Improvement of Plants, the authors of innovative project made efforts to record the varieties bred by the Institute in neighboring countries. Today, in the Register of Plant Varieties of the Russian Federation, there have been two Ukrainian varieties of winter wheat; 3 varieties are tested and for 3 ones the applications for tests have been submitted in 2014.

The Register of Varieties of the Transdniestrian Republic has included seven varieties of winter t; the Register of Moldova has listed one variety; for six varieties the applications for tests have been filed. The applications for testing four varieties of winter wheat have been filed in Belarus; in the future, the varieties (hybrids) can be tested in the Baltic states.

Table 7

Testing Ranges, 2013

No.	Name of Company	Number of varieties	Region/Oblast
	Russia		
1	*Pavlovaskaia Niva*	8	Voronezh Oblast
2	*Belmiaso-Prom*, AF	10	Belgorod Oblast
3	*Eco-Niva*, AF	6	Kursk Oblast
	Moldova		
4	Moldova	6	Chisinau
	Transdniestrian Republic		
5	Tiraspol Raion	6	Transdniestrian Republic
	Ukraine		
6	Research Farm Production of IPPG of NASU	40	Kyiv Oblast
7	*Olhopil*, AF	35	Vinnytsia Oblast
8	*Agrobud*, LLC	35	Vinnytsia Oblast
9	*Nasinprom*, MNZ	16	Mykolaiv
10	*Korsun*, AF	28	Cherkasy Oblast
11	*Cherkaske*, DPDG	17	Cherkasy Oblast
12	*Svarog West Group*	28	Khmelnytskyi Oblast
13	*Obolon-Agro*, LLC	28	Khmelnytskyi Oblast
14	*Mria*, NVO	28	Ternopil Oblast
15	*Zelenyi Hai*	31	Poltava Oblast
16	*January 9*, DPDG	14	Poltava Oblast
17	*TsSENSM*, DP	24	Dnipropetrovsk Oblast

The project team has published ten articles, made five appearances on television and radio and two articles in printed newspapers. The recommendations on the production of certified winter wheat seeds have been prepared.

The NASU pays great attention to the innovation and the investments into the development of Ukraine's science. The greatest effect has been established to be achieved by joint efforts of research and engineering and the business sectors through the development of effective innovation infrastructure. Given the international experience, the effective knowledge-based structure of the domestic market should be determined by technological, scientific and industrial parks, innovation centers for technology transfer, innovation and investment business incubators, information and consultancy networks of engineering firms, as well as by public and private investors, which, unfortunately, show a very slow development in Ukraine.

CONCLUSIONS

The R&D on new wheat varieties and their large-scale production are a significant contribution to the development of agricultural economy and food security of Ukraine. The IPPG of NASU has a significant research capacity for the further development and application of new innovative varieties for enhancing the grain export potential of Ukraine.

New high-yield varieties have won the recognition as an achievement of breeding.

The acreage used for planting new varieties of winter wheat increases regularly. In the past 5 years, the number of license agreements for the use of varieties reared by the Institute grew from 1860 to 2785. As a result, the wheat varieties raised by IPPG of NASU occupy more than 1.75

million ha, with the yield being capable of meeting the needs of Ukraine in food grains almost entirely. The annual economic effect from new varieties exceeds USD 2.2 billion.

However, today, the material and resource facilities of the Institute do not meet the current requirements for research and application of innovations. It should be modernized and needs financial support from the state. The Institute lands are also very limited and located only in the woodlands. Insofar as breeding and seed production imply conducting research in different zonal climatic conditions of Ukraine, there is a need to expand the Institute's lands to the steppes and the woodlands for intensifying the innovative activities.

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ВНЕДРЕНИЕ В ПРОИЗВОДСТВО НОВЫХ, СТОЙКИХ К СТРЕССОВЫМ ФАКТОРАМ, ВЫСОКОПРОИЗВОДИТЕЛЬНЫХ СОРТОВ ОЗИМОЙ ПШЕНИЦЫ, СОЗДАННЫХ НА ОСНОВЕ ИСПОЛЬЗОВАНИЯ ХРОМОСОМНОЙ ИНЖЕНЕРИИ

Приведены результаты исследований, проведенных в Институте физиологии растений и генетики НАН Украины в 2013 г. Охарактеризовано современное состояние селекции, семеноводства и сортовых ресурсов стратегической для нашего государства культуры — озимой мягкой пшеницы. Приведены конкретные примеры, с помощью которых существенно расширены посевные площади сортов-инноваций на территории Украины и впервые начата работа по внедрению их в производство стран ближнего зарубежья.

Ключевые слова: озимая пшеница, сорт, генетический потенциал, селекция, семеноводство, ржано-пшеничная транслокация, инновация.

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ВПРОВАДЖЕННЯ У ВИРОБНИЦТВО НОВИХ, СТІЙКИХ ДО СТРЕСОВИХ ФАКТОРІВ, ВИСОКОПРОДУКТИВНИХ СОРТІВ ОЗИМОЇ ПШЕНИЦІ, СТВОРЕНИХ НА ОСНОВІ ВИКОРИСТАННЯ ХРОМОСОМНОЇ ІНЖЕНЕРІЇ ТА МАРКЕР-ДОПОМІЖНОЇ СЕЛЕКЦІЇ

Наведено результати досліджень, проведених в Інституті фізіології рослин і генетики НАН України в 2013 р. Охарактеризовано сучасний стан селекції, насінництва та сортових ресурсів стратегічної для нашої держави культури — озимої м'якої пшениці. Наведено конкретні приклади, за допомогою яких суттєво розширено посівні площі сортів-інновацій на території України та вперше розпочато роботу по впровадженню їх у виробництво країн ближнього зарубіжжя.

Ключові слова: озима пшениця, сорт, генетичний потенціал, селекція, насінництво, житньо-пшенична транслокація, інновація.

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