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Barley Genetic Resources from the Global Vavilov Seed Bank to Use in Plant Breeding

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Abstract

Presents the results of a long-term study of spring barley collection samples from the gene pool of VIR. Field experiments were carried out on conventional agricultural techniques. Collection samples seeds were sown in optimal time (I decade of may) on plots of 2 m2. Shoots are obtained on the 10-15th day in different years. The vegetation period of the standard in different years was from 81 to 92 days depending on weather conditions, and collection samples from 65 to 93 days. The harvest was harvested in the III decade of August. Barley collections were evaluated according to VIR guidelines and other original methods. Biochemical analysis of barley samples was carried out in the spectrometer Spectra Star 2400, the protein content is found through the determination of nitrogen by Kieldalmetod and the conversion factor N x 5, 7 and N x 6,25 for malting barley, filminess – according to the method of antispyware crops.

Key words: barley, VIR gene pool, productivity, stability

Introduction

Barley is one of the most important cereal crops, second in Russia behind wheat in terms of sown area, and fourth in the world behind wheat, rice, and corn. Barley kernels are used as a high-quality concentrated feed due to its high protein and starch contents; in the brewing industry for malt and beer production; and also for making pearl barley and groats. At the end of 2018, the gross grain harvest of this crop amounted to 16.99 million tons.

Advances in barley breeding worldwide are associated with its phenotypic plasticity and high adaptability to local conditions. Despite certain achievements, the generic protection for domestic high-yielding varieties of barley and other crops from dangerous diseases, such as Fusarium head blight (FHB), loose and covered smut, root rot, and enzyme-mycotic depletion of kernels, is insufficient. This issue halts the industry's progress. In 2019, 229 varieties of spring barley (17 new ones, eleven of which are foreign and only six represent domestic breeding efforts), and three of winter barley were released to production.

In 2014, FAO experts noted, following international experience, that technogenic crop production intensification cannot solve the problem of further increasing yields, reducing energy costs, and maintaining the ecological balance in nature. The global agricultural crisis of the 21st century requires a new strategy for the biologization of crop production; that is, the creation of new varieties, hybrids, and species of agricultural plants resistant to abiotic and biotic environmental factors. Domestic developments in breeding, genetics, and biotechnology, along with their promotion, are indissolubly related to the effective use of the gene pool from the Vavilov Collection of Worldwide Crop Genetic Resources (Guidelines for the Study, 1981; Methodology of the State, 1983).

Each ecological and geographical region should select varieties with an optimal development rate since potentially late-maturing genotypes in certain areas do not always determine the highest yield. That is why several characteristics have always been and remain the primary limiting factors in the Central Non-Black Earth Region: earliness of maturity, cropping capacity, large kernel size, resistance to lodging, and most dangerous diseases.

Our research aimed to single out new barley cultivars by their selection- and economy-wise traits, as well as by their group resistance to diseases, for transferring them to Nemchinovka Federal Research Center and other research institutes or breeding centers.

Methods

The research took place between 2009 and 2019 in the auspices of the Center for Gene Pool and Bioresources, at the All-Russian Horticultural Institute for Breeding, Agrotechnology, and Nursery (Mikhnevo, Moscow).

We studied 300 barley collection samples from different regions of the Russian Federation, Canada, the US, Denmark, Finland, Australia, Ethiopia, the UK, and the Baltic states. Field experiments were carried out using conventional farming practices

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under seven-field crop rotation. Winter wheat was the predecessor in this investigation. Seeds of collection samples were sown in optimal time (early May) at 2 m^2 plots. The control variety, k-26965 Zazersky85 (Belarus), was set out in each block of 10 samples.

The seeds fully sprouted on the 10th-15th day after planting. The growing season for the control Zazersky 85 lasted 81 to 92 days in different years, depending on weather conditions; collection samples matured between 65 and 93 days. The tested plots were harvested in the first two-thirds of August.

Field and laboratory assessments of the barley collection were conducted following guidelines from the N.I. Vavilov Research Institute of Plant Industry (VIR) (Guidelines for the Study, 1981; Guidelines for the Study, 2012) and using original methods (Temirbekova, 1996). Biochemical analysis of barley samples was carried out at Nemchinovka Federal Research Center using a Spectra Star 2400 spectrometer (USA). The protein content was determined using the total Kjeldahl nitrogen method applying conversion factors of N x 5.7 and N x 6.25 for malt; the hull content was defined by the method utilized by the State Committee for the Testing of New Varieties of Agricultural Plants (Methodology of the State, 1983).

Agricultural circumstances and weather in Moscow Oblast varied in different years of research:

2009. Conditions throughout the growing season were quite favorable. Spring was cold and arid. The first spring rain was observed on May 13; June and the first half of July were warm and dry; the season's second half was wet. Heavy rains and strong winds (mid-July) were factors that contributed to early lodging.

2010. The growing conditions were rather unfavorable. The average temperature throughout the growing season was +6.5ºC (22.9ºC) above the long-term average (16.4ºC). The last rain was on June 18. It had not rained until September 3. HTC = 0.8.

2011. Spring was warm. The average daily temperature was 1.9–6.1 ºC higher than the long-term average. In general, spring was 3.8 ºC warmer than normal. During the summer months, temperatures were still higher than normal. June was warm, 22.5 ºC (against the normal 17.7 ºC). June (14, 18, 19, and 20) saw heavy rainfall, which contributed to intensive spring barley growth. Precipitation in July and August was within the long-term average. Temperatures in July and August were higher than normal: by 4.8 ºC and 1.9 ºC, respectively. Six days with showers occurred in July and two in August. HTC = 0.9.

2012. The summer was marked by elevated air temperatures (by an average of 2.2 ºC compared to the long-term average). Precipitation was uneven. In August, maximum daily air temperatures dropped dramatically from +33.6 ºC at the beginning of the month to +13.4 ºC at its end. The last two-thirds of August received abundant precipitation, 70.9 mm, 24 mm higher than the long-term average. Daily average air temperatures fell from 20.4 ºC at the start of the second third of the month to 11.4 ºC at its end, approaching the long-term average. HTC = 1.2.

2013 was excessively wet. Precipitation was 334.8 mm during the growing season, against the long-term average of 264 mm. The temperature was 18.4 °C against the normal 15.1 °C. HTC = 1.6.

2014 was characterized by increased temperatures, standing at 17.7 °C, and insufficient precipitation, 175.4 mm against the normal 264 mm. HTC = 0.9.

2015 was excessively wet throughout May–July. Precipitation during the growing season was 548.3 mm (normal is 264 mm). The temperature was 17.6 °C. HTC = 1.7.

2016 was optimally wet. Precipitation was 280 mm during the growing season, against the normal average of 264 mm. The temperature was 17.5 °C (normal is 15.1 °C). HTC = 1.0.

2017. In total, precipitation was 330 mm during the growing season. The temperature was 18.1 °C (normal is 15.1 °C). HTC = 1.5.

2018. The growing season was arid. With a lack of precipitation (86.5 mm), three times lower than normal, moderate daily average air temperatures of 18 °C exceeded the long-term average by 2.9 °C. HTC = 0.45.

2019 was moderately wet. Precipitation was 212 mm during the growing season, against the long-term average of 264 mm. The temperature was 17.0 °C (normal is 15.1 °C). HTC = 1.1.

Results

The primary objective of studying domestic and foreign varieties was to identify ones with a set of economically valuable traits to be used as seed parents in selective breeding, as well as samples with high yield, early maturity, large kernels, short stems, good grain quality, immunity to especially dangerous diseases and pests, and other features for their use as genetic donors. For that reason, a multi-year field and laboratory research of the collection samples has been carried out in Moscow Oblast.

Earliness of maturity. The limiting factor of the Non-Black Earth Region is how fast specimens ripe. Usually, ultra-early varieties in our area do not show good cropping capacity. Hence, for a group of early-maturing samples, we chose the productive ones that matured 5–7 days earlier than the control. The growing season for Zazersky 85 lasted for 81 to 92 days in different years of study. Following the many years of research between 2009 and 2014, among the collected samples from different countries and regions, we selected varieties with a growing season from 65 to 75 days yielding from 65 to 300 g/m^2, while the control matured in 83 days and yielded 285 g/m^2, see Table 1.

Table 1. Outstanding early-maturing samples from the barley gene pool selected for 2009 and 2014, average.

IR catalog number	Origin	Variety	Growing season, days	Harvest, g/m^2
4321	European Russia	Local	65	265
9749	European Russia	Local	67	190
27051	Moscow Oblast	M-4799	67	295
16420	Kirov Oblast	Local	66	90
16397	Arkhangelsk Oblast	Local	68	160
9732	Karelia	Local	73	210
4826	Agin-Buryat Autonomous Okrug	Local	67	245
5001	Taymyr Autonomous Okrug	Local	68	250
9419	Komi Rep. (Perocha District)	Local	70	280
16478	Irkutsk Oblast	Tulinsky 23/61	68	180
19741	Irkutsk Oblast	Standing	69	400
15107	Primorsky Krai	Local	70	150
18684	Canada	Carre 180 CJ3390	73	130
11908	Canada	Charlottetown	74	170
18688	Canada	Dorsett CJ4821 nigrum	73	160
18694	Canada	Gateway	75	165
18741	Canada	Lander I	74	175
18745	Ontario, Canada	Br. 1239-11	73	185
18750	Canada	4804-19-4-22	75	105
18820	Canada	Algesian	73	75
19944	Canada	Wisconsin	74	70
29189	Canada	Tupper	75	65
30610	Canada	Bvn67-11	73	300
25759	Germany (before 1991)	Amsle-a-Soane	65	170
27981	Denmark	Ca 43504	67	200
28189	Finland	Arra	69	295
26186	Iceland	Sampos (line 04)	72	260
29226	Lithuania	Gausyan	70	290
26965	Belarus	Zazersky 85	83	285

For our studies from 2000 to 2008 (Emmerich, 1980; Kozlenko, 2009) and from 2010 to 2017, the following early-maturing specimens were selected: k-30452 Zadonsky 8, k-30827 Sokol, k-30828 Ratnik (Rostov Oblast), k-30826 Vulkan (Krasnoyarsk Krai), Bagan, Agul (Siberia), k-30601 Kasota (Canada), k-30774 Karabalyksky 5 (Chelyabinsk Oblast), k-30574 Filippa (Sweden), k-30837 Nosovsky 21 pr. 7821 Mriya, i-601179 Myt, Korsar (Ukraine), k-18579 Inar (Bulgaria), k-18203 Martonvassari Korai, Bankuti Korai (Hungary), k-18847, k-18874, k-18840 (Ethiopia), and k-30915 GC210 (Moscow Oblast). The growing season lasted for 75–77 days, the harvest was at the normal level exceeding in some varieties: Vulkan, Sokol, Ratnik, Bagan, and Agul. It is noteworthy that early-maturing collection samples were localized in Siberia and European Russia, Ukraine, Canada, Bulgaria, Hungary, Lithuania, Finland, Sweden, and Germany.

Cropping capacity. When studying the collection samples, it was found out that Western Europe and Canada were the primary sources of productive barley. Among Russia's regions, these were Volga-Vyatka, Central Non-Black Earth, and Central Black Earth's economic regions. The outstanding samples yielding above 400 g/m^2 are as follows: k-30943 Amulet, k-30927 Jersey, k-30933 Sabel (Czech Republic), k-30945 Belissime (France), k-30924 Linda (Latvia), k-18673 Bay c.j.7113, k-18731 C.I.2214 (Ontario, Canada), k-23911 WW6125, k-23925 WW6461, k-18411 Herta, k-23482 N6213, k-23899 WW6411 (Sweden), k-18559 Provost (UK), k-13837 Nosovsky 21, Symphony, k-30841 Syurpriz, k-30849 Prolisok (Ukraine), k-30826 Vulkan (Krasnoyarsk Krai), k-30883 Tandem (Kirov Oblast), k-30843 Zevs (Belgorod Oblast), k-30847 Yasny (Rostov Oblast), k-30820 Nur, k-311828 Moskovskaya 86, Nadezhny, (Moscow Oblast), k-30846 Signal (Novosibirsk Oblast), against the control Zazersky 85 harvest of 360–400 g/m^2.

Large kernel size. One of the main traits that affect the variety's yield is its ability to produce large kernels. The control, Zazersky 85, forms a midsize kernel. Its thousand-kernel weight (TKW) over the years of research fell within 34 to 43 g. Some of the high-yielding specimens had a heavy plump grain in different years, with TKW of 45.6 to 60.2 g. Here are those samples: Raushan — 54.3 g, Prometey — 50.1 g, Vladimir — 53.2 g, Moskovskaya 86 — 50.1 g, Nadezhny — 53.0 g (Moscow Oblast), k-30843 Zevs (Belgorod Oblast) — 52.2 g, k-30846 Signal (Novosibirsk Oblast) — 47.4 g, k-30847 Yasny — 51.3 g, Sokol — 47.5 g (Rostov Oblast), k-30845 Zolotnik (Altai Krai) — 49.2 g, k-30830 Partner (Tyumen Oblast) — 48.5 g, k-30824 Rodnik 98 (Voronezh Oblast), k-30925 Malwa (Latvia) — 48.3 g, k-31144 Jumara (Latvia) — 57.4, k-30924 Linda (Latvia) — 51.6 g, k-30933 Sabel (Czech Republic) — 60.2 g, k-30943 Amulet (Czech Republic) — 57.5 g, k-30927 Jersey (Czech Republic) — 49.4 g, k-30849 Prolisok — 50.2 g, Effekt — 50.9, i-601185 Garmoniya, i-601182 Obolon (Ukraine), k-31147 Hago (Belarus) — 54.3 g, k-31146 Vodar (Belarus) — 60.4 g, k-31171 Lipen (Belarus) — 57.2 g, k-31189 2144 — 58.1 g, k-19410 Ceres, k-19469 Gloire du Velan (France), k-19632 Gerda, k-19683 Johanna, k-19634 Allasch, k-19461 Una (Germany), k-19670 Grande, k-18404 Cebeda, k-19574 Manesin, k-19573 Ezond and others (USA) — 49.0 to 53.1 g**.** Zazersky 85's TKW is 39.5 g. Yields for large-kernelled varieties vary from 520 to 625 g/m^2, against 420 g/m^2 for the control. In certain years during recent decades, the kernel size in the barley varieties grown in Central Russia at Nemchinovka Federal Research Center exceeded that in the best European ones. The above data suggest that large-kernelled samples are concentrated in the Central Non-Black Earth, Central Black Earth and Siberian economic regions, Central and Eastern Europe, and the United States.

Lodging resistance. Another limiting trait for the Non-Black Earth region is resistance to lodging and related plant height. Earlier, in the 1980s, researchers noted a concentration of lodging-resistant varieties in Scandinavia known for the extensive use of radiation-induced mutations for crop breeding. Then followed samples from Hungary, East Germany, and the Czech Republic (Emmerich, 1980). In the present day, all cultivars since the 1990s are resistant to lodging. The selection for this feature in European Russia shows excellent results. All varieties of Nemchinovka, Volga-Vyatka, and Siberian breeding have high lodging resistance.

Valuable samples in breeding for short stems were as follows: k-30578 Margit (Sweden), k-30467 Jatke, k-30468 Ortega (Germany), k-30595 Priazovsky 9 (Rostov Oblast), k-30601 Kasota (Canada), k-30749 Impuls 90 (Sverdlovsk Oblast), k-30847 Yasny (Rostov Oblast).

Their culm was 9–15 cm shorter than that of the control Zazersky 85. Thus, even during the years when the soil is severely waterlogged and the entire collection is lodging, they do not fall over.

Grain quality. The collected samples were assessed for biochemical parameters from the two climatically contrasting years during cultivation, namely 2012 (optimally dry) and 2013 (excessively wet). Protein accumulation in investigated grains varied from 10.98 to 16.70%; starch content fell between 50.75 and 59.50%; the extraction rate was 76.9–80.5%. Here we should note that, in excessively wet 2013, the barley samples' protein content decreased by 0.70–2.96% compared to drier 2012 (Temirbekova, 2014). The highest protein content was observed in sample Moskovsky 86 (Moscow Oblast) during arid 2012 and excessively wet 2013, from 18.1 and 17.7%. Comparisons of protein contents in 2012 and 2013: 14.50% and 13.41% for Prikumskoy 47 (Sravropolsky Krai), 15.30 and 14.60% for Vadim (Russia), 15.37 and 13.90% for Luninsky (Penza Oblast), 14.49 and 13.99% for Rodnik Prikamye (Kirov Oblast), 16.0 and 15.24% for Kupets (Kirov Oblast), 16.0 and 15.56% for Odon (Buryatia), 15.3 and 14.29% for Dvina (Arkhangelsk Oblast), against 14.25 and 12.78% for the control variety Zazersky 85 (Belarus), respectively. The US samples k-31049 Bear, k-31051 Craft, k-31052 Haus, k-31055 Zenetah, k-31056 RWA 1758, k-31057 Tetonia in 2012 had a protein content of 12.15 to 14.0%, and in 11.46 to 13.40% in excessively wet 2013. Grains lost 0.60–0.69% of protein. The starch content averaged 58% in 2012 and 55% in 2013, i.e., the starch loss was 3% in an excessively wet year. Correspondingly, the extraction rate was 80% in 2012 and 78.5% in 2013.

The data indicate that the samples with the best quality grains were located in the Central Non-Black Earth Region, Northwest and Siberian Russia, and the United States.

Disease resistance. Summing up the years of research (2009-2017), the following samples have been selected for resistance to smut diseases and root rot: Moskovsky 3, Suzdalets, Ramos (Moscow Oblast), Bagan (Novosibirsk Oblast), Kazer (Rostov Oblast), Kumir Odessky (Ukraine), Bagrets, Kalita (Sverdlovsk Oblast), Inari (Finland), Veles (Belgorod Oblast), Dvina (Arkhangelsk Oblast), Krinichny (Leningrad Oblast), Rodnik Prikamye (Kirov Oblast), Guardin (Canada). It should be mentioned that the Bagan variety (Novosibirsk Oblast) was a loose smut resistance donor.

Loose smut-resistant specimens were k-19461 Una, k-19458 Juliana (Germany), k-19573 Ezond (USA), k-19304 Keystone (Canada), k-18847, k-18874, k-18840 (Ethiopia), Talan, Acha (Siberia).

The research made it possible to identify sources of resistance to fungal pathogens that cause covered and black smut: k-16699 local (Ukraine), k-18242 local (Ukraine), k-19353 Svaföle (Sweden), k-19472 Calmar (France), k-19067 Delta (Netherlands).

Sources of resistance to root rot and loose smut were localized in Northwest and Siberian Russia, Canada, Germany, Ukraine, and Ethiopia.

Resistance and tolerance to EMDS. Enzyme-mycotic depletion of seeds (EMDS) is a complex and harmful disease in cereals and other crops that leads to 30–50% yield losses with a simultaneous deterioration in the grain and seed quality. It is caused by abiotic (high humidity) and aggravated by biotic (ear blights) factors, see Figures 1 and 2. The disease proceeds in two, sometimes in three stages.

Figure 1. Downy mildew on a barley sample during grain filling.

Figure 2. Hidden biological damage in fully ripe barley grain (magnification x 150).

In the years of elevated and excess humidity during grain filling, the following sources of resistance were discovered: k-21903 Trumph (Germany), k-20934 Elgina (Germany), k-24740 Nosovsky 9 (Ukraine), k-26965 Zazersky 85 (Belarus), k-27038 Moskovsky 2, k-27954 Moskovsky 3, Moskovsky 86, Yaromir, Raushan, Nur, Suzdalets (Moscow Oblast), Bagrets, (Sverdlovsk Oblast), Inari (Finland), Veles (Belgorod Oblast), Dvina (Arkhangelsk Oblast), Rodnik Prikamye (Kirov Oblast), k-27975 Cebeco 7935 (Netherlands), k-20944 Laure (France), k-25954 Urania (Germany), k-29216 Dina (Kirov Oblast), k-22981 local (Ethiopia). These samples have a similar growing season as the control Zazersky 85, are 75–90 cm in height (medium), have a dense ear with a high kernel number of 22–26 pcs. Their TKW ranges between 41.4 and 53.4 g, against 36.8 to 48.6 for the control.

The distinguished samples are advised for breeding programs at Nemchinovka Federal Research Center and other plant breeding centers.

Conclusion

For use in breeding programs the cultivars from the following countries of origin can be recommended:

- for early-maturing: Siberian and European Russia, Ukraine, Canada, Bulgaria, Hungary, Lithuania, Finland, Sweden, and Germany;
- for high-yielding: countries of Western Europe and Canada. Among the regions of Russia, these are Volga-Vyatka, Central Non-Black Earth, and Central Black Earth's economic regions.
- for being large-kernelled: Central Non-Black Earth, Central Black Earth, and Siberian economic regions, countries of Central and Eastern Europe, and the United States.
- for high grain quality: Central Non-Black Earth Region, Northwestern and Siberian Russia, and the United States;
- for resistant to diseases: sources of resistance to root rot and loose smut are localized in Northwest and Siberian Russia, Canada, Germany, Ukraine, and Ethiopia; to enzyme-mycotic depletion of kernels, in Northwest and European Russia, the Central Non-Black Earth Region in Russia; single sources of resistance are found in the Netherlands, France, Ukraine, Germany, and Ethiopia.

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