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Genetic resources and main directions and results of barley and oat breeding in Russia

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Abstract. The oat and barley collections stored at the N. I. Vavilov Institute of Plant Industry (VIR) reflect worldwide genetic diversity. This vast array of materials undergoes comprehensive studies in the Institute's fields and labs, and the best accessions are forwarded to Russia's breeders. Every year dozens of genetic sources and donors produced or identified in the study process are dispatched to all national breeding centers. As a result, most of the oat cultivars currently listed in the Register of Breeding Achievements of the Russian Federation have been developed on the basis of the VIR collection or with the help of the Institute's researchers.

Key words: Genetic resources, breeding barley and oat, cultivated and wild species

INTRODUCTION

Carefully selected and thoroughly evaluated initial material is of special importance for breeding of agricultural crops. For the breeders in the Russian Federation, the global collections conserved at the N. I. Vavilov Institute of Plant Industry (VIR) serve as the main source of such material (Loskutov, 1999).

The VIR collections accumulate the global cultivar and botanical diversity (Malzev, 1930; Orlov, 1935; Bakhteev, 1953; Knupffer et al., 2003) including over 13 thousand oat and over 20 thousand barley accessions. Collections of the institute keep increasing thanks to the addition of the most interesting breeding, genetic and botanical material from the main centers of origin and diversity of these crops, from the countries which demonstrate a high level of research in the sphere of breeding and diverse utilization of the crop. To this end, researchers of the respective department pay constant attention to global achievements in breeding and genetics (Loskutov, 2007; 2009).

Theoretical research currently underway at the Department of Genetic Resources of Oat, Rye and Barley are concentrated on the development of methods of efficient utilization of the selected germplasm and on revealing regularities in variation and inheritance of the main traits of importance for breeding (Cultivated Flora…, 1990; 1994). The complex field evaluation is accompanied by studies performed by the methodological laboratories of VIR and aimed at selecting valuable oat and barley germplasm for solving urgent breeding problems in various regions of the boundless country. In barley and oat breeding, research achievements and the available initial material facilitate solving problems related to e.g. resistance to the main diseases,

earliness, semi-dwarfness, drought resistance, grain quality (in terms of protein, lysine, fat, starch, antioxidants content and composition of amino and fatty acids, etc.), and crop productivity (Trofimovskaya, 1972; Loskutov, 2007; Loskutov & Rines, 2010).

RESULTS AND DISCUSSION

Genetic stock collections of oat and barley have been created to ensure that the main breeding tasks are carried out at the state-of-the-art level, as well as to identify and localize newly revealed alleles of genes. The oat collection is composed of cultivars, cultivated lines and wild species where one or more identified allells of genes govern various morphological, agrobiological, biochemical and other traits. Most of the collection is made up of accessions with identified genes controlling semi-dwarfness, photoperiodic response, and, most importantly, resistance to powdery mildew, crown and stem rusts, and to smut species. At present, the oat gene collection at VIR includes over 600 accessions belonging to cultivated species *A. sativa*, *A. byzantina*, *A. strigosa* and *A. abyssinica* and to wild species *A. sterilis*, *A. barbata* and *A. magna* with over 200 identified genes controlling various morphological, physiological, biochemical and other traits (Genetics …, 1988, Loskutov, 2007).

The genetic stock collection of barley includes lines with morphological marker traits localized on 7 chromosomes (65 accessions), lines with male sterility (87 accessions), disease-resistant lines (65 accessions), testers with the identified genes and accessions with known genes that are of interest for breeding purposes (400 accessions). The diversity of available cultivars with the same alleles allows breeders from different zones of Russia to select appropriate initial material for breeding oat and barley (Genetics…, 1986).

Besides creation of genetic stock collections, the main task of the Department is comprehensive study of the collected germplasm and identification of sources and donors of the economically important traits for breeding purposes. Long-term study of the oat collection has revealed a large number of early local and breeding forms among *A. sativa* and *A. byzantina* accessions originating from different regions of oat cultivation. Considerable variation in the duration of different periods in plant development is characteristic of some wild forms too. The most important factors influencing the length of the vegetative period of a plant, especially the first half of the period, are the daylight duration and the temperature regime. Long-term studies performed together with the Department of Plant Physiology of VIR have demonstrated differences in response to photoperiod and vernalization.

Dwarfness is closely linked to the issue of lodging resistance in oat, occupying a special place among the breeding objectives for this crop. This problem attracts special attention because of the plant habitus features and high windage of the panicle. The evaluations of recent years have identified some perspective forms, which may be used as sources combining semi-dwarfness with high grain yield per panicle and good grain quality. Hybridization and multistage selections have yielded some stable, productive forms, which transfer the semi-dwarf stem trait in further crosses. The work has resulted in creation of 15 oat donors of semi-dwarfness and lodging resistance.

A comprehensive phytopathological evaluation of all specific diversity of the *Avena* genus facilitates selection and utilization of new genetic sources and donors of resistance, thus broadening the genetic basis of the newly created oat cultivars. Sources of resistance to the main oat pathogens and pests, including crown and stem rusts, various leaf blights, smuts and *Fusarium* fungi, have been found for different regions of the country. Numerous accessions of cultivated species and especially forms of wild oats have been identified as possessing a high degree of resistance.

From the point of view of nutritional and fodder qualities, biochemical characteristics of oat grain are of the highest importance. These are the protein content and amino acid composition, oil content and fatty acid composition. Recently, the list of biochemical components determining the high nutritional value of oats has been extended by β-glucans, tokopherols, sterols, avenanthramides and other components. At present, this trend in studies of the collection is the most promising one and has resulted in identification of interesting initial material (Loskutov, 2007; Loskutov & Rines, 2010).

Barley breeding around the globe has been successful thanks to the high ecological plasticity of this crop and its high adaptability to local cultivation conditions, which are realized due to barley earliness. The heading time is determined mainly by three factors, i.e. the genes governing the type of development, insensitivity to the photoperiod, and earliness. Currently, researchers of the Department pay most attention to the first factor as it is among the leading ones to control the earliness of heading in barley. Selection of appropriate cultivars with the optimal rate of development is carried out for each eco geographic region because in certain zones the use of potentially late genotypes does not always mean obtaining the highest yield, while the early cultivars may better realize their potential in these conditions and ensure secure yields. Studying the genetic diversity of barley from the perspective of the rate of development may increase the cultivars' adaptability and, finally, achieve high stable yield.

In the work with the barley collection, special attention is paid to comprehensive evaluation of the economically important traits of accessions; that makes it possible to identify genotypes meeting various breeding requirements. The selected accessions are forwarded to breeding institutions and successfully used in breeding highly productive cultivars.

Development of barley cultivars resistant to diseases and pests is an important breeding objective. Global practice shows that their cultivation is the cheapest and ecologically safe approach to control harmful organisms. The screening of the collection for resistance to diseases and pests is carried out jointly with the Department of Immunity. Several cultivars bred by the Agricultural Research Institute for the regions of the Non-Black Soil Belt (ARI NBSB) of Russia and featuring high productivity, high brewing quality and other economically important traits have been identified among those possessing resistance to two smut species.

Another priority trend related to the global warming is the investigation of acidity tolerance. High acidity of soils has a negative impact on plants growth and development. The most promising direction is creation of cultivars tolerant to soil acidity, as the application of only agro technical measures would be quite costly, would yield a transitory effect and have a harmful influence on the environment in the regions. By screening barley accessions, sources of tolerance to acidity have been

found from different regions of Russia, CIS countries, the Baltic States, Scandinavia, Western Europe and Japan has identified a number of sources of acidity tolerance.

In addition to such traditional qualitative characteristics of barley grain as protein, oil and starch content, content of different types of polysaccharides, vitamins and antioxidants is also of the highest importance. The latter group of substances includes β-glucans, tokopherols and some others. Studies in this field are quite promising and we are seeking opportunities to cooperate on this with other institutions in Russia and abroad.

In recent years, much attention is being paid to studies and creation of naked oat and barley cultivars. These forms show better grain quality, but possess a series of negative traits. The Department is involved in the identification of initial material that would be promising for these activities and supplies Russian breeding centres with it.

All the oat and barley germplasm material selected and created in the course of the work of the Department is forwarded to over 30 breeding centres in the Russian Federation for utilization in various breeding programs. As a result, the majority of oat and barley cultivars (90% according to some sources) included in the State Register of Breeding Achievements Approved for Utilization have been created on the basis of germplasm from the VIR collections or jointly with VIR researchers.

At present (2010), the State Register of Breeding Achievements Approved for Utilization in Russia includes 91 spring and 4 winter oat cultivars (among which 12 are foreign cultivars, 1 is from Ukraine, 2 are Byelorussian and 80 are Russian) (www.gossort.com/reestr/ree_13.html#14).

Winter oat breeding in Russia is carried out only in the Adygean Agricultural Research Institute that has produced all 4 commercial cultivars: Podgorny and Mezmai, Guzeripl and Verny. All cultivars are productive, resistant to diseases and display good winter hardiness, as prolonged periods with negative temperatures are quite frequent in this region.

In terms of the longest period of cultivation in Russia, the first place is shared by a Swedish cultivar (cv.) Guldregn, created at the Swalöf Breeding Station (Sweden) in 1904 and commercialized in the USSR in 1929, and a Russian cv. Narysmky 943, bred at the Russia's oldest, Narymsk Breeding Station (now the Narym Department of Breeding and Seed Growing of the Siberian Research Institute of Agriculture and Peat) and commercialized in 1973. In the USSR, the latter cultivar covered over 1 mln ha-s of the total land under this crop. In the 1970ies, Russian cv. Taezhnik (Narymsk Breeding Station), Ukrainian cv. Chernigovsky 83 (Chernigov Breeding Station) and two foreign cultivars – Selma (Sweden) and Astor (the Netherlands), all still cultivated in Russia. The majority of cultivars in the Register were included during the period from 1990 to 2007.

The cultivar Uzpek, the first naked oat cultivar in the USSR, was commercialized in 1981. The Uzbek Husbandry Research Institute in cooperation with the VIR developed it. After the disintegration of the USSR, this cultivar remained outside Russia, and the first Russian naked oat cv. Tyumensky golozerny (bred by the Agricultural Research Institute for the Northern Transurals) was commercialized only in 2000. Other naked oat cultivars, namely Levsha (bred jointly by the Kemerovo Agricultural Research Institute (KemARI) and the VIR) was approved for utilization in 2005, cv. Vyatsky (created by the Agricultural Research Institute for the Northeast (ARINE)) was approved in 2007, and cultivars Golets (the Krasnoyarsk Agricultural

Research Institute) and Sibirsky golozerny (the Siberian Agricultural Research Institute (SibARI)) were approved in 2008.

The most productive breeding centers in Russia are the ARI NBSB and ARINE. Fifteen oat cultivars presently listed in the Register have been bred at the ARI NBSB in cooperation with the Ulyanovsk Agricultural Research Institute (UlARI) and other breeding institutions. ARINE that together with the Falenskaya Breeding Station has released 10 commercial oat cultivars has proven to be another success story. Seven cultivars have been developed at the Narymsk Breeding Station (some of them jointly with other institutions); the SibARI released 6 cultivars, and another 4 by the Buryat Agricultural Research Institute. By now, approval has been granted for the utilization of cultivars bred by the following institutions (3 cultivars per each organization): SibARI, Altai ARI, KemARI, Tulun Breeding Station and the VIR. It is necessary to mention the great contribution of UlARI to the creation of new oat cultivars. Although the institute is not involved in hybridization activities, it participates actively at other stages of breeding programs and later grows initial seed for the released cultivars.

When speaking about characteristics of the approved cultivars, the high degree of adaptability of some of them should be noted. In 2010, the most widely spread oat cultivar in Russia is Skakun (ARI NBSB), which is cultivated in 9 out of 12 regions of the territory of Russian Federation. This cultivar, characterized by high yields and high grain quality, is on the List of the Valuable Quality Cultivars. Cultivar Konkur (ARI NBSB and UlARI) has been commercialized in 7 regions of Russian Federation, two cultivars, namely Borets and Dens (ARINE) – in 6 regions; two cultivars – Ulov (ARI NBSB) and Tyumensky golozerny (Tyumen ARI) – in 5 regions, and such cultivars as Drug, Kozyr (ARI NBSB), – Argamak and Faust (ARINE) have been commercialized in 4 regions. All these cultivars are highly productive, resistant to diseases and, with the exception of Dens and Faust, have been put on the List of the Valuable Quality Cultivars. The cultivars Privet, Lev, Yakov (ARI NBSB), Talisman (Narym Breeding Station), Kirovets, Krechet (ARINE), Fakir (Falenskaya Breeding Station) and Allyur (UlARI) have been commercialized in 3 regions.

At present (2010), the State Register of Breeding Achievements Approved for Utilization numbers 162 spring and 26 winter barley cultivars. The cultivars commercialized in Russia include 22 spring and 2 foreign winter cultivars, 6 Ukrainian and 1 Byelorussian cultivar. So, Russian breeders have created a total of 157 barley cultivars, 4 of which are naked barley cultivars. (www.gossort.com).

Significant work in the sphere of winter barley breeding is done at the Krasnodar ARI (12 cultivars), at the All-Russian Research Institute of Cereal Crops (ARRICC, 4 cultivars), at the Stavropol ARI (2 cultivars) and other institutions. All winter barleys are cultivated only in the Northern Caucasus region. Almost all of them are six-row barleys used mostly as forage.

Some spring barley cultivars currently cultivated in Russia were commercialized in the times of the USSR, back in the 1960's. These include e.g. Tammi (Finland) and Varde (Norway); 5 more cultivars were commercialized in the 1970's and 20 more – in the 1980's. A cultivar worth mentioning among them is Odessky 100 (Ukraine): it was commercialized in the USSR in 1984 and compared to other spring barleys it occupies now the largest areas in Russia. The majority of modern commercial spring barley cultivars (120 all in all) have been cultivated for less than 15 years.

The State Register of Breeding Achievements Approved for Utilization contains 3 naked barley cultivars: Omsky golozerny 1 (Omsk ARI) since 2004, Oskar (Krasnoyarsk ARI) since 2007, Omsky Golozerny 2 (Omsk ARI) since 2008 and Nudum 95 (Skiff Breeding Company) since 2010.

In terms of the numbers of commercialized spring barley cultivars and their cultivation areas, ARI NBSB and ARRICC, which have created 9 cultivars each, either individually or jointly with other breeding institutions shear the leading place. Over the years, breeding activities have successfully resulted in the release of new cultivars at SibARI (8 cultivars), ARINE (6), Siberian Research Institute of Plant Industry and Breeding (6), and Krasnodar ARI (5 cultivars).

The most widely spread barley cultivar in Russia is cv. Odessky 100 (Plant Breeding and Genetics Institute (PBGI), Ukraine), which is cultivated in 7 out of 12 regions of the Russian Federation. This high-yielding cultivar with good grain quality has been put on the List of Brewing and Valuable Quality Cultivars. The cultivar Dina (ARINE) has been commercialized in 6 regions, the cultivars Preriya (PBGI) and Elf (ARI NBSB), Zevs (Belselect), Nur (ARI NBSB), Priazovsky 9 (All-Russian Research Institute of Grain Legumes and Groat Crops) in 5 regions, and several cultivars, e.g. Acha (SibARI), Bios 1, Raushan (ARI NBSB), Gonar (Belarus), Veles (Belselect), Odessky 115 (Ukraine), and a German cultivar Annabel – in 4 regions. Most of these are highly productive cultivars from the List of Valuable Quality Cultivars.

CONCLUSIONS

All the cultivars of oat and barley listed in the State Register of Breeding Achievements Approved for Utilization in Russian Federation (most of which were created using germplasm from the VIR collections) are more productive and better adapted in the conditions of the regions they were intended for. The high quality of many of these cultivars and their resistance to the main diseases has to do with their pedigrees including germplasm from the VIR global collections, or testing carried out using the best VIR collection cultivars from around the globe as the standard.

At present, the requirements of agricultural production are changing and, primarily, the new cultivars created have to be qualitatively diverse, leaving the question of productivity to the background. The VIR collections contain the material required for creating cultivars of both naked and hulled oat and barley that can be used for producing food with good dietary and nutritional qualities. Many sources conserved in the collections display tolerance to a series of abiotic factors and possess resistance to the main diseases and pests.

The unique collections at the VIR have concentrated the entire global diversity of local and bred varieties and, while being the best researched among the similar collections elsewhere in the world, are still the richest sources of germplasm with traits of breeding importance for both national and foreign breeders.

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