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CONTENTS • 2021 • 25 • 4

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Plant breeding is the food security basis in the Russian Federation

N.P. Goncharov[1], V.M. Kosolapov[2]

[1] Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia
[2] Federal Williams Research Center of Forage Production and Agroecology, Lobnya, Moscow region, Russia
gonch@bionet.nsc.ru; vnii.kormov@yandex.ru

This issue of the *Vavilov Journal of Genetics and Breeding* is composed of reports of top Russian breeders delivered at the scientific session of the RAS Department of Agricultural Sciences "Scientific support of the efficient development of crop breeding and seed production in the Russian Federation" held in Moscow on December 7, 2020. This topic was chosen deliberately, as the food security concept in the Russian Federation determines the key directions and features of the modern development of Russian breeding. They involve the understanding and comprehensive analysis of breeding trends and the determination of prospects, particularly, in connection with import substitution[1] and produce of next-generation cultivars.

The issue starts with the article by B.I. Sandukhadze et al. "Scientific breeding of winter bread wheat in the Non-Chernozem zone of Russia: the history, methods and results". It reviews the main steps and achievements of winter common (bred) wheat (*Triticum aestivum* L.) in the region throughout one century of scientific breeding. It shows that breeders' efforts increased the yield of wheat cultivars to 14.0 t/ha, which is nearly ten times as high as in cultivars of early steps of scientific breeding in the central Non-Chernozem Area. Few residents of Moscow and Moscow region are aware of the "white spot" issue (a lot of rye was grown in the region in the early 20th century, as wheat production did not pay), successfully solved by prominent Russian breeder V.E. Pisarev by using early maturity cultivars from East Siberia. By now, cultivars produced by breeders of the FSC "Nemchinovka" have ensured the provision of the Non-Chernozem Area, a densely populated region of Russia, with locally produced food wheat grain and got the local population used to eating white bread. The Russian Federation is self-sufficient in producing not only wheat, barley, or oats but also rice (Gospadinova et al., 2016).

Area under grain legumes is second to cereals in Russia. They have accompanied cereals since the earliest steps of domestication on fields of ancient agriculturists. They diversified human diet and supplied domestic animals with high-protein fodder. The breeding of grain legumes is reviewed by V.T. Sinegovskaya "Scientific provision of an effective development of soybean breeding and seed production in the Russian Far East" and by V.I. Zotikov, S.D. Vilyunov "Present-day breeding of legumes and groat crops in Russia". They note that soybean is becoming a crop of strategic importance for Russia and that groat crops constantly rank high in the diet of its inhabitants.

The article by V.M. Lukomets et al. "Modern trends in breeding and genetic improvement of sunflower varieties and hybrids at VNIIMK" is dedicated to the breeding of the main oil plant in the Russian Federation. The Pustovoit All-Russian Research Institute of Oil Crops (VNIIMK), along with the Yuriev Plant Production Institute (Kharkiv, Ukraine) (Kirichenko et al., 2014) excels in the breeding of sunflower and other oil crops in the former Soviet Union.

The breeding of sugar beet, the main source of sugar in Europe, is considered by S.D. Karakotov et al. "Modern issues of sugar beet (*Beta vulgaris* L.) hybrid breeding". The paper presents the results of monogerm varieties and successful application of molecular methods for testing the bred material of sugar beet.

The imbalance in fodder production that has existed in Russia for many years remains unresolved despite all the efforts of plant breeders. Even the considerable reduction in livestock in agricultural companies (agrofirms) and redistribution of large volumes of animal husbandry to private subsidiary farms (up to 50 % on the average) had no effect (Semenov, 2012). The article by V.M. Kosolapov et al. "Fundamentals for forage crop breeding and seed production in Russia" is dedicated just to this burning problem and potential ways to solve it.

A series of three papers is dedicated to the breeding of fruit and small fruit crops, essential for balanced nutrition. It includes articles by E.A. Egorov "Grape breeding is a key link in the development of the grapes and wine-making industry", I.M. Kulikov et al. "Scientific support of small fruit growing in Russia and prospects for its development", and A.V. Ryndin et al. "Subtropical and flower crops breeding at the Subtropical Scientific Centre". At present, import substitution draws attention to new (or, rather, well overlooked old) natural sources of vitamins and biologically active substances and to the breeding of domestic subtropical and flower plants.

The progress in the breeding of medicinal and essential oil plants in Russia is considered by I.N. Korotkikh et al. "Breeding of medicinal and essential oil crops in VILAR: achievements and prospects". This field became particularly important with regard to the sanctions, the ensuing shortage of herbal medicinal materials, and their poor quality, failing to meet the requirements of the present-day pharmaceutical industry.

Russian seed growers do not provide sufficient volumes of production of seeds of vegetable crops' domestic varieties

[1] By import substitution we mean the substitution of imported goods and services for domestic ones. It implies the slowdown in the share of foreign manufacturers in the market and timely satisfaction of demand with domestic products.

(Soldatenko et al., 2020). Modern breeding is based mainly on the gene pool at hand to involve older high-yielding varieties into breeding and improve them. The article by Yu.V. Fotev et al. "Genetic resources of vegetable crops: from breeding non-traditional crops to functional food" follows traditional VIR themes. It considers the introduction of untraditional crops in Russia in the context of the greatly requested area: their use in functional nutrition (Fotev et al., 2018).

The issue is concluded by N.P. Goncharov's review "Scientific support to plant breeding and seed production in Siberia in the XXI century". It emphasizes the importance of breeding activity in the development of Russian economy and the necessity for the preservation of still existing research institutions and units of abolished Breeding Centers in Siberia. In the contrary case, the consistency of breeding works in the region will disappear, and the unique breeding material created by generations of Russian scientists in research and breeding institutions will be lost beyond retrieval. The following problems are especially acute: Why cannot the federal and regional governments protect their intellectual property and preserve biodiversity of cultivated plants? What and who hampers? These issues, typical of Siberia, as well as the availability of skilled staffing concern other regions of Russia, too.

Several articles in the issue mention the necessity of the immediate solution of urgent tasks concerning the training of breeders in higher schools as a major component of food security in Russia. Nothing changes for centuries. In the end of the 19th century, A.S. Ermolov (1891) incriminated the backwardness of Russian agriculture to the absence of an agricultural education system and to the shocking ignorance of science among peasants.

It is pertinent to make a point about the publication policy of the Ministry of Education and Science and Presidium of the Russian Academy of Sciences. It is a sore point for not only agrarians but also the entire Russian academic community. For an unknown reason, the governmental strategy of import substitution does not apply to the scientific publishing activities. The principal journal "Selektsiya i Semenovodstvo" (Breeding and Seed Production) has ceased to be published. Specialized agricultural journals on particular crops or groups of crops demand a nation-specific policy. A.N. Engelhardt (1987) wrote that the agricultural science in its broad sense has pronounced "national" features: "There is no Russian, English, or German chemistry; there is only one chemistry for the entire world; but agronomy may be Russian, or English, or German, or else. <…> We should create Russian agricultural science of our own, and it can be created only by combined efforts of scientists and practicians, and there should be academically trained practicians in between" (p. 190).

It was repeatedly noted that different branches of Russian science need their own national platforms (journals) for communication and effective exchange of information. In particular, A.V. Yurevich and I.P. Tsapenko (2013) state that most Russian papers on socio-humanistic sciences are unfit for international journals not because of their flaws but because of the national specificity of their content. However, to bring studies in line with the themes of international journals means to detach them from urgent Russian problems and to make the society think that the money of Russian taxpayers is spent in vain. Hence, the more patriotic is this or that branch of science and the more is it directed to the solution of domestic tasks, the less it fits into the international context. Even by the example of highly employable Vavilov's studies we see that most of them are beyond the scope of interests of our Western colleagues, although they are conceptually important for the present-day global science. Neither Ministry of Education & Science, nor the current Presidium of the RAS see room for Russian journals in the world academic community. However sad it be, the task of any import substitution seems costly to Russian officials; therefore, the publication policy is the worst weakness of Russian science. We expressly indicate that the intellectual property of Russian scientists or Russia is not protected in publications in top Western journals, and it is often unaccessible for the scientific community in this country (Gorbunov-Posadov, 2020).

For many years, breeding in Russia has been distinguished by the widespread use of genetic knowledge. Breeding and genetics schools are held in Siberia on a regular basis since 1976 (Zilke, 2005). We can also mention the All-Siberia program 'Diallel Analysis' (Dragavtsev et al., 1984). Unfortunately, the gap between breeding and modern molecular biology is still unplugged.

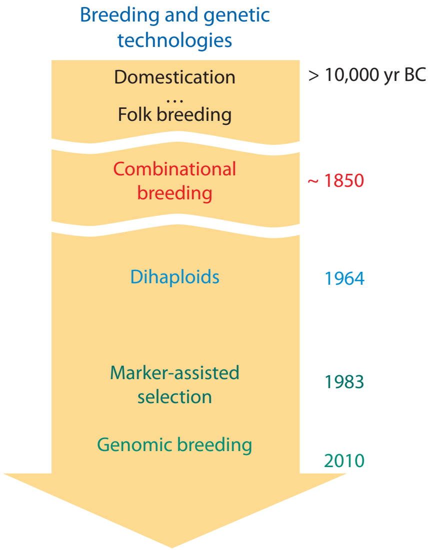
Academician I.I. Artobolevskiy (1967) believed on reasonable grounds that the promotion of scientific achievements is a first-order duty of scientists. We try to find out why leading breeding schools in Russia insufficiently and reluctantly employ recent discoveries in molecular biology, biotechnology, and IT technologies. Presently, significant breeding achievements reached by using molecular methods exist in Russia (Bespalova et al., 2012; Pershina et al., 2020; among others). Promising studies opening up fresh opportunities for breeding are being conducted. In particular, the Institute of Cytology and Genetics (Novosibirsk) took part in the assembly of the wheat genome (IWGSC…, 2018). Here we are at the very beginning, since the information on the genome sequence from one accession is not sufficient to capture the whole spectrum of diversity in a gene pool responsible for phenotypic variation, plasticity, and environmental adaption. The *de novo* construction of a pan-genomes for cultivated plants is a mandatory step after the establishment of reference genome sequences for them. Obviously, it will be the key step in future breeding (Pronozin et al., 2021). The low sequencing depths even for wheat, a staple crop in Russia, still limit the broad use of pan-genomic analysis (Rasheed, Xia, 2019).

Several important problems concerning IT technologies in breeding were discussed in the previous issue of the Vavilov Journal of Genetics and Breeding, No. 1, 2021; so, we will not touch upon them. Nevertheless, the technological gap between the performance of genomic analysis and phenotypical description of plants is still large. In breeding a new variety, one should rest upon today's perspectives and take into consideration both current requirements and remote prospects. Certainly, recent technological achievements in crop genomics generate new opportunities in the detection of genetic variations of traits important for breeding and permit one to create new-generation varieties. They come to the aid of breeders and allow fast, exact, and mass-scale description of plant phenotypes be it in the field or under laboratory conditions.

Functional genomics is a key to molecular breeding and basement for the development of diagnostic markers for gene introgression and molecular marker-assisted selection. Although the cloning of functional genes in crops was a slow process, few genes were cloned by conventional "positional cloning". On the other hand, high-throughput PCR-based KASP (Kompetitive Allele-Specific PCR) markers (Rasheed et al., 2016) are helpful in the use of SNP arrays for high-density genotyping of wheat (Wang et al., 2014; Allen et al., 2017; Cui et al., 2017) and related species (Winfield et al., 2016), as well as in the annotation and introduction of functional genes. It is evident, though, that the role of money in the application of these methods to ordinary breeding is not the least, and they will not become widespread, inexpensive, and routine before long (Rasheed, Xia, 2019).

A characteristic feature of modern economy, including agriculture, is the predominance of novelties as a factor supporting competitiveness and economic advance in the long run. The question whether molecular biology can serve as a pioneering factor in plant breeding is open. Presently, prebreeding (assessment of the starting breeding material) is an application domain of up-to-date molecular methods. However, it is differently viewed by molecular biologists (Rasheed et al., 2016; Riaz et al., 2018), geneticists (Goncharov N.P. et al., 2020), and breeders (Bespalova et al., 2012). In contrast, their views on breeding itself (analysis of breeding material and selection process) are similar. Molecular methods are currently used to accelerate selection in the stabilization of breeding material (Adonina et al., 2021), its homozygotization (Pershina et al., 2020), and so on. The raise of promising breeding material can be accelerated by removing the germplasm of wild species from the progeny of introgression hybrids (Leonova et al., 2020); thereby, fragments of alien genetic material can be reduced in the genome of a species to breed (Adonina et al., 2021). This process is aimed at the reduction of adverse effects of concomitant genetic material transferred with the target genes. It has been demonstrated that molecular markers allow efficient selection for dwarfism (Kroupin et al., 2020; Sukhikh et al., 2021; etc.), early ripening (Kroupin et al., 2020), and many other traits. Meanwhile, the breeding for such important traits as crop productivity and quality of production is still conducted by conventional methods.

The assessment of the efficiency of plant genome editing by CRISPR/Cas technologies, operating with single functional genes, presents an acute and complicated problem (Chen et al., 2021). We do not know whether this one-gene manipulation is a breakthrough technology in breeding, which deals with hundreds of functional genes. Generally, there are no single genes whose replacement would result in sustainable progress. In addition, the CRISPR-edited plants have high somaclonal variability. Nevertheless, the tools and methods for plant transformation clearly alter phenotypes, being able to benefit from gene overexpression and other manipulations formerly inaccessible for breeders (Borisjuk et al., 2019).



Milestones: the emergence of breakthrough technologies in plant breeding (after Kolchanov et al., 2017).

Serious progress based on advanced technologies occurs in large seed producing companies, where breeders, geneticists, and molecular biologists work under the same roof. For instance, DuPond-Pioneer developed the Seed Production Technology concept, which successfully combines conventional hybridization with transgenic methods of raising male-sterile (MS) lines, hybrid selection, and MS line support (Wu et al., 2016). The producing of nuclear MS lines by genome editing illustrates the applicability of this concept to wheat (Okada et al., 2019). Several more breakthrough technologies for hybrid creation are reviewed by Chen et al. (2021). The question remains open how soon this approach will become routine for breeding institutions.

Breeders' work was scrutinized repeatedly. Nevertheless, we do not know how profoundly paradigm shifts in breeding (see the Figure) affect the speed of the breeding process and achievement of goals. It is doubtless that in recent decades traditional schemes involving hybridization and, to a much lesser extent, chemical and radiational mutagenesis contributed much to crop improvement. However, the globalization epoch necessitates the search for new groundbreaking methods. Many seemingly revolutionary methods came and went from the scientists' toolkit and left an imprint only in breeding history records. Old-timers remember monosomic lines, which allowed the produce of varieties using the method of limited recombination and rapidly "repair" unique varieties. To tell the truth, the development of each from monosomic lines took 15–20 years. During this time, conventional breeders replaced the entire range several times and produced new remarkable varieties. It is natural that this approach did not provide a single commercial variety despite the huge scope of work (Worland, 1988). Protoplasts (Gleba, Sytnik, 1984), isoenzymes, and many others, looking modern in their days, did not change the breeding paradigm. It is worth mentioning that some breakthrough projects, such as domestication or green revolution (improvement of the range of wheat and rice varieties) were implemented by conventional breeding, and they were based on the choice of key traits regardless of the genetic and/or molecular mechanisms of their inheritance.

One of the targets of modern technologies is the acceleration of new variety breeding and introduction. For some reason, the powerful take it to mean the shortening of their producing time and make it the corner stone. It is a fringe concern, because the terms of variety submission to the Plant State Tasting System are insignificant in major breeding institutions, which produce series of new varieties massive. Present-day molecular Stakhanovites are nothing new. It is pertinent to recall the anecdote about the producing of cv. Lutescens 1163 common wheat by T.D. Lysenko et al. (1935) within 2.5 years by using know how: greenhouses and hybrids at hand instead of original accessions. It is sad that Stakhanovite methods of breeding are becoming nationwide again in the 21st century.

N.I. Vavilov likened a geneticist to a creator and stated that he "must act as an engineer; not only is he obliged to investigate his construction material, but he can and should construct new living species"[2]. The tasks are basically the same at present, it is the toolkit that has changed and expanded.

It is well known that genetics and breeding deal with heredity and variability and thus they interpenetrate. Breeding employs the laws of inheritance discovered by genetics, and genetics, in turn, obtains and generalizes data from breeding (Goncharov N.P., Goncharov P.L., 2018). While geneticists were seeking ways to overcome the abyss between genetics and breeding (Dragavtsev, 2005), molecular biology just revoked many of these problems (Moose, Mumm, 2008; Heffner et al., 2009; Abd-Elsalam, Lim, 2018; Ahmar et al., 2020). We have already mentioned that breeding received new tools. They provoked controversy as to whether they should be used extensively. Certainly, to know and master them is a must. However, business has an increasing share in the science of the 21st century. To conduct a modern study is a business operation. To obtain results is a business operation. To publish them in top-rated journals is a business operation. In the last case, to make a successful (in the eye of the Ministry of Education and Science) publication one should employ *up-to-date expensive* equipment, not necessary for the work itself. The organization of the breeding process is a business as well, since the development of crop production is increasingly considered only as the delivery of agricultural services. This situation reminds the notorious "arms race", and we can win it by promoting our own rules.

The applied aspect of Russian science progressively increases (Rakin, 2020). Breeding in many European countries, including former COMECON members, is becoming private business under the pressure of multinational groups of agrochemical companies. The consequences are the list of top-priority research fields, the mainstream innovational practice of support by the Russian Science Foundation, the technological orientation of sections of the national Nauka project, and such. The national foundations of the Russian Federation do not imply considerable support of academic studies in breeding, solely the mastering and preservation of skills and technologies. Therefore, the search for alternative large sources of support for agricultural sciences, including 21st century breeding, is of paramount importance.

[2] Vechernyaya Moskva. Jan. 17, 1929.

To conclude, we mention that breeding in the 21st century is directly associated with one of the global challenges, starvation. The 22nd session of the UN Food and Agriculture Organization of October 31, 1996, adopted the so-called Rome Declaration on World Food Security[3], whose purpose was to halve the number of the starving on the Earth (800,000,000 as to 1996) by 2015. In fact, as reported by the German philanthropy organization Welthungerhilfe, the number of the starving had increased to one billion by 2020[4]. With the current slow progress in increasing crop yields, 0.8 to 1.0 % annually, wheat, rye, and corn cannot be produced in quantities sufficient for the solution of the starvation problem.

Thus, varieties play an essential role in improving the performance of global agricultural industry; therefore, breeders are seeking new sustainable, efficient, and cost-effective methods to produce new varieties. One of the major objectives of this issue of the *Vavilov Journal of Genetics and Breeding* is the thorough consideration of this task.

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Scientific breeding of winter bread wheat in the Non-Chernozem zone of Russia: the history, methods and results

B.I. Sandukhadze ✉, R.Z. Mamedov, M.S. Krakhmalyova, V.V. Bugrova

Federal Research Center "Nemchinovka", Novoivanovskoye, Odintsovo, Moscow Region, Russia
✉ sanduchadze@mail.ru

Abstract. The article describes the main stages and achievements of the breeding of winter bread wheat (*Triticum aestivum* L.) in the Non-Chernozem zone for more than a century. The beginning of breeding work was laid by D.L. Rudzinsky on the experimental field of the Moscow Agricultural Institute. Beginning from the 1940s, under the leadership of Academician N.V. Tsitsin, and then Prof. G.D. Lapchenko, the method of distinct hybridization with blue wheatgrass (*Agropyron glaucum* (Desf. ex DC.) Roem. & Schult.) was actively used. The resulting wheat-wheatgrass hybrids had an average winter hardiness, increased grain quality and productivity. Cultivar Zarya developed in the 1970s (by individual selection from the F_3 cross combination of cv. Mironovskaya 808 × line 126/65 (in the pedigree of this line, there is a wheat-wheatgrass hybrid PPG 599)) had a high yield and was widely used in further crosses. In the 1980s, Academician B.I. Sandukhadze achieved a significant increase in yield by using the method of intermittent backcrosses due to the producing of varieties with a new morphoecotype (cvs Inna, Pamyati Fedina, etc.), namely, winter-hardy, short stemmed (dwarf), and productive. Cultivar Moskovskaya 39 (registration in 1999) was referred to strong wheat, with a stable protein content of 15–16 %, gluten 30–35 %. Produced in the 2000s, cvs Moskovskaya 56, Nemchinovskaya 57, Galina, Nemchinovskaya 24, Nemchinovskaya 17, and Moskovskaya 40 have a high adaptability to the environment of the region; give a high yield and quality of grain. The area of crops of these cultivars in Russia occupies more than 2 million ha. The current trends in wheat breeding are indicated, the production yield of commercial cultivars of breeding by the Federal Research Center "Nemchinovka" over 12.0 tons per ha and the protein content in the grain up to 17 % are shown. As a result of succession, originality and application of the methodology of scientific breeding, the yield of winter bread wheat in the period from the beginning of the last century to the present has increased from 1.0 to 12.0 and more tons per ha.

Key words: winter bread wheat, breeding; variety; winter hardiness; yield; lodging resistance; short stemmed plants.

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Научная селекция озимой мягкой пшеницы в Нечерноземной зоне России: история, методы и результаты

Б.И. Сандухадзе ✉, Р.З. Мамедов, М.С. Крахмалёва, В.В. Бугрова

Федеральный исследовательский центр «Немчиновка», р. п. Новоивановское, Одинцово, Московская область, Россия
✉ sanduchadze@mail.ru

Аннотация. Рассмотрены основные этапы и достижения селекции озимой мягкой пшеницы (*Triticum aestivum* L.) в Нечерноземной зоне более чем за столетний период. Начало селекционной работы в регионе было положено Д.Л. Рудзинским на опытном поле Московского сельскохозяйственного института. С 1940-х гг. под руководством академика Н.В. Цицина, а затем профессора Г.Д. Лапченко активно применялся метод отдаленной гибридизации пшеницы с пыреем сизым (*Agropyron glaucum* (Desf. ex DC.) Roem. & Schult.). Полученные пшенично-пырейные гибриды (ППГ) обладали средней зимостойкостью, повышенным качеством зерна и продуктивностью. Созданный в 1970-х гг. сорт Заря (индивидуальным отбором из F_3 гибридной комбинации сорт Мироновская 808 × линия 126/65, в родословной этой линии присутствует ППГ 599) имел высокую урожайность и широко использовался в дальнейших скрещиваниях. В 1980-е гг. академик Б.И. Сандухадзе методом прерывающихся беккроссов добился значительного увеличения урожайности за счет выведения сортов нового морфоэкотипа (Инна, Памяти Федина и др.) – зимостойких, короткостебельных, продуктивных. Сорт Московская 39 (районирован в 1999 г.) относится к сильным пшеницам со стабильным

содержанием белка (15–16 %) и клейковины (30–35 %). Созданные в 2000-х гг. сорта Московская 56, Немчиновская 57, Галина, Немчиновская 24, Немчиновская 17, Московская 40 характеризуются высокой адаптивностью к условиям региона, высокой урожайностью и качеством зерна. Площади посевов этих сортов в России занимают более 2 млн га. Обозначены актуальные направления селекции озимой мягкой пшеницы, показана производственная урожайность сортов селекции ФГБНУ «ФИЦ «Немчиновка» свыше 12.0 т/га и содержание белка в зерне до 17 %. Благодаря преемственности, оригинальности и методологии научной селекции, урожайность озимой пшеницы в регионе с начала прошлого века до настоящего времени выросла с 1.0 до 12.0 т/га и более.
Ключевые слова: озимая мягкая пшеница; селекция; сорт; зимостойкость; урожайность; устойчивость к полеганию; короткостебельность.

Introduction

At the beginning of the last century, wheat (*Triticum* L.) was not widely distributed in the Non-Chernozem zone of Russia. In production, "brown" breads were grown: winter rye and oats. Local varieties were cultivated from wheat and, as a rule, economic characteristics instead of names – "local", "winter", "spring". These cultivars of folk breeding were populations consisting of a mixture of cultivars, and sometimes species (Flaksberger, 1929).

The promotion of wheat culture took place in the first years of the XX century and was associated with the activities of the Committee for Plant Acclimatization at the Moscow Society of Agriculture. In the Non-Chernozem zone of Russia, scientific breeding of wheat and a number of other crops was started at the Shatilov Experimental Station (organized in 1896). In 1903, the foundations of scientific breeding of field crops were laid at the experimental field of the Moscow Agricultural Institute (now the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy), where D.L. Rudzinsky, S.I. Zhegalov, A.G. Lorkh, N.I. Vavilov and other outstanding scientists worked (Goncharov, 2005; Elina, 2007). More than 3,000 winter wheat variety samples from the Russian Empire, Europe, and North America were studied at the experimental field of the Moscow Agricultural Institute (Flaksberger, 1929). The signs, for the manifestation of which it was advisable to conduct the selection of elite plants, were determined. Assessing the twenty-year work of the Moscow Breeding Station of the Moscow Agricultural Academy, N.I. Vavilov (1929) noted the volume of the analyzed material. At the same time, he pointed to the fact that the conducted selections did not provide significant changes in the expression of traits and properties in the cultivars relative to the original selected populations, which, in his opinion, indicated the need to use interspecific and intergenerational hybridization more widely.

In the 1930s, the creation of winter-hardy, resistant to damping off and soaking plastic cultivars, immune to powdery mildew, brown rust and fusarium was continued. In 1940, Academician N.V. Tsitsin organized a laboratory of wheat-wheatgrass hybrids at the Zonal Institute of Grain Farming in the Non-Chernozem Zone (later NIISH CRNZ, Moscow NIISH "Nemchinovka", now the Federal Research Center "Nemchinovka") and continued the work on remote hybridization of wheat with wild wheatgrass (*Agropyron glaucum* (Desf. ex DC.) Roem. & Schult. = syn. *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey) for the production of winter bread wheat cultivars (Lapchenko, 1967). From 42-chromosomal forms of wheat-wheatgrass hybrids (PPG) with the wheat ear type, N.V. Tsitsin and G.D. Lapchenko first derived winter cultivars of bread wheat based on PPG 599 and PPG 186. The plants showed an average level of winter hardiness, individual breeding numbers contained up to 19 % protein in the grain. These cultivars were zoned in 18 regions and republics of the Non-Chernozem zone of Russia.

In the laboratory of winter bread wheat breeding organized by E.T. Varenitsa in 1951, intraspecific multi-stage hybridization of remote ecological and geographical forms with the use of selective fertilization was widely used in the Research Institute of Agricultural Research and Development of CRNZ. The best cultivars zoned in the area were used as maternal forms, and the cultivars with high yield, winter hardiness, resistance to pathogens and lodging, taken from other ecological and geographical zones, were used as paternal forms (Varenitsa, 1971).

The positive results of the breeding of winter bread wheat in the 1970s are associated with the creation of the cv. Zarya, obtained by individual selection from F_3 hybrids of the combination of crossing the Ukrainian cultivar Mironovskaya 808 with the line 126/65 (in the pedigree of which there is a PPG 599). In 1978, the cv. Zarya was zoned. The maximum area of its cultivation was 530 thousand hectares (Varenitsa, 1987). Later, by the individual selection of the cv. Zarya the cv. Yantarnaya 50 (zoned in 1985), characterized by high productivity, large grain, high weight of 1000 grains, but with weak winter hardiness was obtained.

Breeding of intensive type cultivars

In 1984, B.I. Sandukhadze headed the breeding of winter bread wheat in the NIISH CRNZ. In place of the cv. Mironovskaya 808, which was widely cultivated in the Non-Chernozem zone, it was necessary to create more technologically advanced intensive cultivars with high grain quality, more resistant to lodging, unfavorable overwintering conditions, and fungal diseases. It was necessary to overcome the negative relationship between high yield and high winter hardiness, as well as high winter hardiness and short-stemmed vegetation. The best short-stem donor was recognized as the Krasnodar Dwarf 1, bred in the Krasnodar Research Institute of Agricultural Sciences. Hybrids from crossing the cv. Mironovskaya 808 with it consistently inherited low plant height and increased winter hardiness over the years.

To obtain short-stemmed and winter-hardy varieties of intensive type, the method of intermittent backcrosses was used,

Table 1. Cultivars of breeding of FRC "Nemchinovka" (Laboratory of breeding and primary seed production of winter wheat) included in the "State Register of breeding achievements approved for use" in 2020

No.	Cultivar	Year of inclusion	Regions of zoning	Crop area, ha (average 2017–2019)
1	Zarya	1978	2–5	760.0
2	Yantarnaya 50	1985	3, 4	150.0
3	Inna	1991	2, 3, 5	86.0
4	Moskovskaya 70	1991	5	–
5	Pamyati Fedina	1993	3	–
6	Moskovskaya 39	1999	2–5, 7, 9, 12	605 745.9
7	Galina	2005	2, 3	6446.65
8	Nemchinovskaya 24	2006	3, 4	15 029.33
9	Moskovskaya 56	2008	3–5	605 745.9
10	Nemchinovskaya 57	2009	3, 5	142 913.5
11	Moskovskaya 40	2011	3–5	398 541.9
12	Nemchinovskaya 17	2013	3, 5	65 153.23
13	Viola*	2013	3, 5, 7	169 999.5
14	BIS**	2016	3, 4	103.47
			Total area	2 010 675.38

* Jointly with the Federal Scientific Agroengineering Center VIM; ** jointly with the Verkhnevolzhsky FARC.

which became the basis for cultivars of a new morphoecotype (Sandukhadze et al., 1996). The next backcross involved plants selected from families of F_3 hybrids for optimal overwintering, plant height and productivity. After three backcrosses, the breeding samples were compared for winter hardiness with the recurrent parent. Selection was more effective in BC_3–BC_4 populations with better productivity. In theory, this method of breeding allowed us to count on a higher probability of obtaining new combinations of genes in the offspring of the next backcross, in practice – on a higher efficiency of the entire selection process. The height of the plants increased depending on the number of backcrosses in F_1 hybrids. By this method, seven cultivars were obtained in Nemchinovka: Nemchinovskaya 52, Nemchinovskaya 86, Moskovskaya nizkostebelnaya, Moskovskaya 70, Inna, Pamyati Fedina and Nemchinovskaya 25, zoned in 12 regions and republics of the RSFSR. The cvs. Inna and Pamyati Fedina outperformed the others by 1.0 t per ha in productivity (Sandukhadze et al., 2001). Created by the early 1990s, a series of cultivars of a new morphoecotype with a high productivity potential and a yield exceeding 1.0 t per ha or more relative to the long-stemmed standard cultivar, adapted to the conditions of the central regions of the Non-Chernozem region, became a breakthrough in the breeding of winter bread wheat for this region.

As a result of purposeful breeding work, a number of cultivars of winter bread wheat were created in the FRC "Nemchinovka", currently occupying a total of more than 2 million hectares (Table 1). Since the end of the 1990s, the cvs. Moskovskaya 39 (1999), Nemchinovskaya 24 (2006), Moskovskaya 56 (2008), Nemchinovskaya 57 (2009), Moskovskaya 40 (2011), Nemchinovskaya 17 (2013), Nemchinovskaya 85 (2021) and Moskovskaya 82 (created together with the Nizhny Novgorod NIISH, a branch of the N.V. Rudnitsky Federal Agricultural Research Center of the North-East, zoned in 2021) have been zoned in more than 35 regions of the Russian Federation. The cv. Moskovskaya 39 was obtained by selection from the hybrid combination Obriy × Yantarnaya 50 and has the property of direct translocation of nitrogen-containing compounds from the soil to the grain during its filling, which enhances the biosynthesis of spare proteins. The uniqueness of the cultivar is that, in all quality indicators, it consistently exceeds all previously zoned cultivars, and the protein content in the grain is higher. Thanks to the cv. Moskovskaya 39, stable production of grain for baking in densely populated Central Russia has become possible (Sandukhadze et al., 2016). The areas of crops of the listed cultivars were indirectly calculated according to the data of the Russian Agricultural Center for 2017–2019 by the number of sown seeds based on the seeding rate of 200 kg/ha. The actual acreage is much larger.

Currently, the State competitive cultivar testing for the cv. Moskovskaya 27, which has been transferred in 2019, is taking place.

According to the 1916 census, the areas under winter crops in the provinces of the center of the Non-Chernozem region were as follows: winter rye – 1,196,448 ha (99.7 %), winter wheat – 3,120 (0.3 %) (Sekun, 1954). Now the situation is exactly the opposite. According to Rosstat (rosstat.gov.ru),

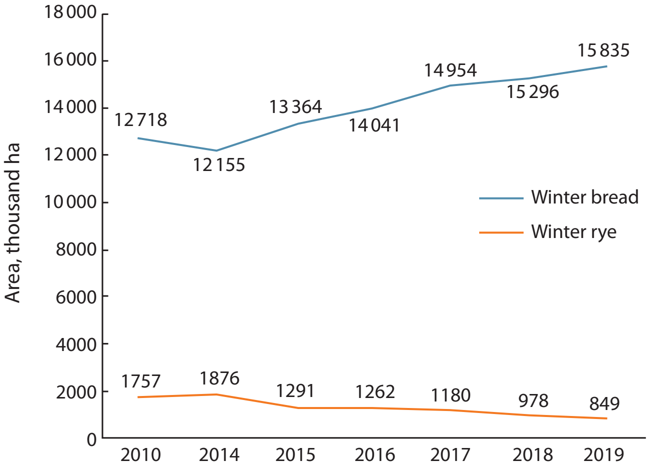

Fig. 1. Sown areas of winter bread wheat and winter rye in farms of all categories of the Russian Federation.

Fig. 2. Decrease in plant height of winter wheat cultivars as a result of breeding.

the share of winter bread wheat in the grain crop wedge is constantly increasing (Fig. 1).

By 2050, global demand for agricultural crops is projected to roughly double, driven by population growth, meat and dairy consumption, and the use of biofuels (Godfray et al., 2010; Tilman et al., 2011). Wheat is one of the main food crops around the world, and the need for new varieties of winter bread wheat is particularly relevant today (Sandukhadze, 2010; Ray et al., 2012; Kudryashov et al., 2016). The Laboratory of breeding and primary seed production of winter wheat at the FRC "Nemchinovka" has a priority role in its breeding for the Non-Chernozem zone and other regions of the Russian Federation. Next, we will consider the main directions of winter wheat breeding. In addition to these areas, work on early maturity, resistance to diseases and pests, drought resistance and other signs and properties is underway.

Breeding for frost and winter hardiness

Many authors note that breeding for adaptability allows combining high productivity and resistance to limiting environmental factors in the genotype of the cultivar (Romanenko, Lavrenchuk, 2011). In natural conditions, selection on this basis is possible only in severe winters, with early thaws in the spring, return frosts and other unfavorable factors.

In the FRC "Nemchinovka", to maintain a high level of winter hardiness, a local zoned variety is necessarily used as one of the parents in pair and backcross crosses. The cvs. Mironovskaya 808, Pamyati Fedina, Moskovskaya 56 and Nemchinovskaya 57 serve as donors of frost and winter hardiness for the Non-Chernozem zone.

Breeding for short-stemmed plants

Resistance to lodging is one of the priority areas for improving modern cultivars. Successful hybridization and subsequent breeding can only be based on attentive attitude to the forms of local origin, along with a constant search for sources and donors of useful traits and properties in the global gene pool (Likhenko, 2008). Russian breeders pay attention to the search, identification and creation of new highly productive and short-stemmed source material for winter wheat and other grain crops (Samofalova, 2016; Medvedev et al., 2017; Dyachuk et al., 2018).

Numerous studies have found that the lodging of crops not only reduces the yield, but also negatively affects the baking and sowing qualities of grain (Packa et al., 2015; Khobra et al., 2019; Ageeva et al., 2020). The main method of increasing resistance to lodging is to reduce the height of plants. The donor of this trait for winter cultivars of the Non-Chernozem zone, as a rule, is a geographically distant form. The breeding advantage of short-stemmed forms can be attributed to their high productive bushiness, the disadvantages – low winter hardiness and weight of 1000 grains (Sandukhadze et al., 1996). In the late 1980s, the Krasnodar Dwarf 1, a mutant obtained from the cv. Bezostaya 1 under the influence of nitrosomethyl urea, which is a donor of the *Rht-11* gene, was used in crosses (Divashuk et al., 2012). This mutant is present in the pedigree of the cvs. Inna and Pamyati Fedina, which, in turn, were one of the parent forms of the cvs. Nemchinovskaya 24, Moskovskaya 56, Nemchinovskaya 17, Galina, Nemchinovskaya 57, Nemchinovskaya 85 and Moskovskaya 27.

Since 2008, a sample from Italy called Agapik has played an important role in breeding for lodging resistance. The height of the plants is 65–70 cm. Thousands of lines were worked out in crosses with it. The cvs. Nemchinovskaya 85 (Agapik × Pamyati Fedina) and Moskovskaya 27 (Lutescens 982/08 × Moskovskaya 56) have this sample in their pedigree. The Lutescens 982/08 line is a paired Agapik × Pamyati Fedina hybrid (Fig. 2).

Breeding for grain quality

Recently, producers have been interested not only in high yields, but also in different cultivars, including those that can meet the market needs for increasing the protein content and dough weight (Vitale et al., 2020). The problem of wheat grain quality is an integrating indicator of the interaction of the variety genotype, natural and ecological features, agrotechni-

Table 2. Yield and protein content of winter bread wheat cultivars under high-intensity cultivation technology (2014–2016)

Cultivar	2014		2015		2016		Average	
	Yield, tons per ha	Protein content, %	Yield, tons per ha	Protein content, %	Yield, tons per ha	Protein content, %	Yield, tons per ha	Protein content, %
Moskovskaya 56	11.7	14.9	13.0	13.7	13.4	15.4	12.7	14.7
Nemchinovskaya 17	11.5	14.1	14.1	15.5	14.4	13.2	13.3	14.3
Nemchinovskaya 57	10.5	14.8	11.7	13.8	13.2	12.4	11.8	13.7
Nemchinovskaya 24	11.7	13.5	13.5	12.4	14.0	11.4	13.1	12.4
Galina	13.0	13.5	13.2	12.4	13.4	13.3	13.2	13.1
Moskovskaya 40	12.0	15.4	11.9	14.9	12.2	13.6	12.0	14.6
Moskovskaya 39	10.5	16.9	11.0	14.3	11.6	14.0	11.0	15.1

cal and organizational and economic conditions of cultivation (Rozbicki et al., 2014).

The attribute "total protein content in grain" is controlled polygenically (Mitrofanova, Khakimova, 2016). At present, wheat has many major and minor loci that affect the amount of protein in the grain, the prominence of which is not stable in its manifestation. The protein content in the grain and the yield are negatively correlated, which complicates the breeding to increase the prominence of both traits at the same time.

A distinctive feature of the winter bread wheat cultivars of the Nemchinovsky breeding is their high quality indicators. To create cultivars with such a level of protein and gluten content, we use the cvs. Moskovskaya 39 and Moskovskaya 40 (obtained by individual selection from Moskovskaya 39) in complex hybrid combinations, paired crosses, and in individual selections for the possibility of combining quality indicators with high productivity and adaptability of the new breeding material in one genotype (Sandukhadze et al., 2006).

Breeding for yield

The ultimate goal of wheat production is to produce high grain yields. Yield is a polygenic trait, and its formation is influenced by many factors. The main components of the crop: the number of productive stems per 1 m^2 and the weight of grain per ear (number of grains, weight of 1000 grains) (Krasnova, Zhivoderova, 2003; Goncharov, 2012; Voronchikhin et al., 2018). It should be noted that modern breeding methods, such as genotyping, selection using molecular markers, genome editing, and others, are ineffective without field testing of the created material (Hickey et al., 2019; Lozada et al., 2020). To obtain new cultivars, various types of crossing are carried out (simple, complex, backcrosses), the parent forms are selected both according to the ecological and geographical principle, and according to the elements of the crop structure. Modern cultivars of the Center's breeding are high-yielding, adapted to the conditions of the region, and actively used in crosses for these characteristics. The level of productivity of the Nemchinovsky breeding cultivars obtained in field tests is presented in Table 2.

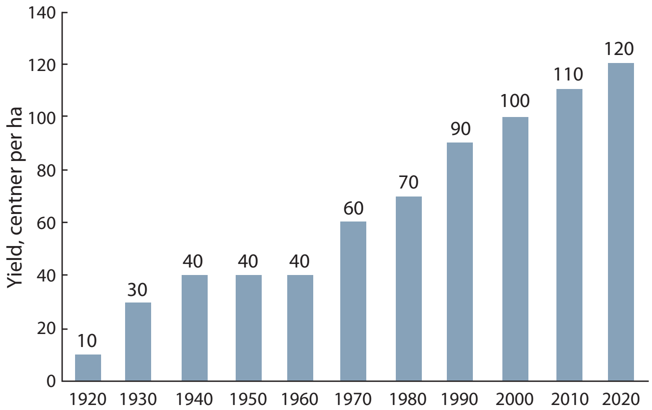

Fig. 3. Results of breeding for the yield of winter bread wheat in the Non-Chernozem zone for the centennial period (1920–2020).

Figure 3 shows the average yield of cultivated winter wheat cultivars in the Non-Chernozem zone. Scientific breeding of winter wheat allowed to increase the productivity of cultivated cultivars by more than 10 times (see Fig. 3). Since the 1970s, the main cultivated cultivars in the Non-Chernozem zone have been cultivars of our institute's breeding.

Conclusion

Leading domestic breeders developed and effectively applied advanced for their time methods and schemes of the breeding process, such as the hybridization of cultivars with identified economically valuable traits and properties, the remote hybridization of bread wheat with wheatgrass and PPG to obtain winter-hardy, disease-resistant plants with increased grain quality, the crossing of geographically distant forms, the use of intermittent backcrosses and the creation of a new morphoecotype of the cultivar (short-stemmed, resistant to lodging, with increased winter hardiness and grain quality), which allowed to provide Nechernozemye, a densely populated region of the Russian Federation, with its own grain. New cultivars of winter wheat of the Federal Research Center "Nemchinovka" have a high adaptability to the conditions of the region. This allows us to produce consistently high grain yields with good baking qualities. Over a hundred years of scientific breeding, the yield of soft winter wheat cultivars has increased to 14.0 tons per ha and is almost 10 times higher than the yield of cultivars of the first stages of breeding in the region.

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ORCID ID
B.I. Sanduchadze orcid.org/0000-0001-7184-7645

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Scientific provision of an effective development of soybean breeding and seed production in the Russian Far East

V.T. Sinegovskaya

Federal Scientific Center "All-Russian Scientific Research Institute of Soybeans", Blagoveschensk, Russia
valsin09@gmail.com

Abstract. In the Russian Far East, a highly profitable crop is soybean, which predominates in all farms' crop rotation in the region. An increase in this crop production occurs here both by increasing the sown area and increasing its yield. Therefore, in scientific institutions, great attention is paid to breeding varieties that can produce high yields in conditions with limited thermal resources with adaptation to the extreme soil and climatic conditions of the region's soybean growing zones. In 2020, 45 varieties developed by scientific institutions of the Far Eastern Federal District were introduced to the State Register of the Russian Federation and approved for use in production in code 12 region (Far Eastern), with the largest number of the entries coming from the All-Russian Scientific Research Institute of Soybeans. The share of cultivated areas in the Russian Far East occupied by domestic varieties was 63.7 %, the largest share of sown varieties – 48.9 % – belongs to the Federal Research Center All-Russian Scientific Research Institute of Soybean. The most popular were the varieties of the All-Russian Scientific Research Institute of Soybean, such as Alena, Kitrossa, Lydiya, Evgeniya, MK 100, Primorsky varieties (Musson, Primorskaya 4, Primorskaya 86, Primorskaya 96, Sphera) are in demand mainly in Primorsky Krai, and Khabarovsk varieties (Batya, Marinata) have an advantage in Khabarovsky Krai and the Jewish Autonomous Region. All varieties are not genetically modified and are created mainly by classical breeding methods. Breeders of the Federal State Budgetary Scientific Institution, "Federal Research Center of Agrobiotechnology of the Far East named after A.K. Chaika" and biotechnologists carry out the selection of pairs for crossing using biotechnological methods to assess their polymorphism, instead of long-term selection for phenotypic features in the field. Evaluation of domestic and foreign varieties for disease resistance revealed a high degree of damage to foreign varieties by dangerous viral and fungal diseases. Together with Japanese scientists from the University of Niigata, the astragalus mosaic virus was detected on Canadian and Chinese varieties in Primorsky Krai and the Amur Region using DNA analysis. The carrier of this disease is soybean aphid (*Aphis glycines*).
Key words: Russian Far East; soybean; cultivar; breeding and seed production; virus; fungal diseases.

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Научное обеспечение эффективного развития селекции и семеноводства сои на Дальнем Востоке

В.Т. Синеговская

Федеральный научный центр «Всероссийский научно-исследовательский институт сои», Благовещенск, Россия
valsin09@gmail.com

Аннотация. На Дальнем Востоке соя – высокорентабельная культура, ее посевы преобладают в севообороте всех хозяйств региона. Наращивание производства зерна этой культуры происходит за счет увеличения посевных площадей и повышения ее урожайности. Поэтому в научных учреждениях региона огромное внимание уделяется селекции сортов, обладающих способностью в условиях с ограниченными тепловыми ресурсами давать высокие урожаи. В статье приведены основные результаты, полученные в учреждениях Дальневосточного федерального округа (ДФО) по селекции сои. В 2020 г. 45 сортов сои, созданных научными учреждениями ДФО, зарегистрированы в «Государственном реестре селекционных достижений…» и допущены к использованию в производстве по 12-му (Дальневосточному) региону. Большинство из этих сортов принадлежит Всероссийскому научно-исследовательскому институту сои (ВНИИ сои). На долю посевных площадей сои Дальнего Востока, занятых сортами отечественной селекции, приходится 63.7 %, при этом 48.9 % составляют сорта ВНИИ сои. Самыми востребованными являются сорта ВНИИ сои, такие как Алена, Китросса, Лидия, Евгения, МК 100. Сорта приморской селекции – Муссон, Приморская 4, Примор-

ская 86, Приморская 96, Сфера – пользуются спросом в основном в Приморском крае, а сорта хабаровской селекции – Батя, Марината – имеют преимущество в Хабаровском крае и Еврейской автономной области. Все сорта генетически не модифицированы и создаются главным образом классическими методами селекции. Селекционеры ФГБНУ «ФНЦ агробиотехнологий Дальнего Востока им. А.К. Чайки» совместно с биотехнологами проводят подбор пар для скрещивания с применением биотехнологических методов по оценке их полиморфизма вместо многолетнего отбора по фенотипическим признакам в полевых условиях. Оценка отечественных и зарубежных сортов на устойчивость к болезням позволила выявить высокую степень поражения зарубежных сортов опасными вирусами и патогенными грибами. Совместно с японскими учеными из университета Ниигата обнаружен вирус карликовости астрагала (MDV, Milk vetch dwarf virus) на канадских и китайских сортах в Приморском крае и Амурской области. Переносчик этого заболевания – соевая тля (*Aphis glycines*).
Ключевые слова: Дальний Восток; соя; сорт; селекция и семеноводство; вирусы; грибные болезни.

Introduction

Soybean (*Glycine max* (L.) Merrill) as a valuable protein and oilseed crop plays a strategic role in the economies of many countries. Over the past decade, it has the highest production growth rates (Sinegovskii, Kuzmin, 2020). At present, Russia ranks 7th in world production with a sowing area of about 3.0 million hectares (Fig. 1). In world production, the 1st place belongs to Brazil – 36.9 million hectares (30 % of the global area), the second – the USA – 30.4 million hectares (25 %), the third – Argentina – 17.5 million hectares (14 %).

In recent years, soybean production in Russia has shown a stable positive trend (Malashonok, 2018; Dorokhov et al., 2019; Rasulova, Melnik, 2020). The increase in sown areas in 2020 compared to 2010 amounted to 134 %, and gross production increased by 279 %. The main regions of soybean cultivation in Russia are the Amur Region, Primorsky Krai, the Kursk and Belgorod Regions, Krasnodarsky Krai, which account for 62 % of all sown areas. The share of this crop in the Far East is 44 % of the total Russian (Sinegovskii, 2020). Soybean production is growing not only due to an increase in acreage but also due to an increase in crop yields, which is ensured by an increase in the potential productivity of new varieties (Sinegovskaya, Fokina, 2018; Butovets, Strashnenko, 2020).

The results of soybean breeding research

Three scientific institutions carry out scientific support of the soybean industry in the Far Eas: Federal Research Center All-Russian Scientific Research Institute of Soybean (Blagoveshchensk), Federal Research Center of Agrobiotechnology of the Far East named after A.K. Chaika" (Ussuriysk, Primorskiy Krai) and Far Eastern Agricultural Research Institute (Vostochnoye village, Khabarovsk Krai). The main direction of scientific work in all scientific institutions is the creation of varieties adapted to the Far East's extreme conditions and resistant to the main harmful organisms, the production of original seeds and the development of innovative methods of their cultivation (Table 1).

In 2020, the "State Register of Selection Achievements Authorized for Use for Production Purposes" of the Russian Federation contained 45 varieties of selection of the scientific institutions of the Far East, approved for use in production in 12 regions, the largest number of which belongs to the ARSRIS (State Register…, 2020). The share of sown areas in the Far East, occupied by varieties of domestic selection, was 63.7 %, the largest share of sown varieties belongs to the ARSRI of soybean – 48.9 % (Fig. 2). In Primorsky Krai, varieties of FRC of Agrobiotechnology of the Far East accounted for 7.2 %, and varieties of FEARI accounted for 6.5 %. Varieties of foreign selection occupied 36.3 % of all sown areas of the Far Eastern Federal District.

In general, in the Far East in 2020, 78 varieties of soybeans of domestic and foreign varieties were used for sowing, of which 19 varieties were of the breeding of ARSRI of soybean, occupying an area of sowing of 484.9 thousand hectares, three varieties – Far Eastern Agricultural Research Institute with a sowing area of 64.9 thousand hectares, ten varieties – FRC of Agrobiotechnology of the Far East, cultivated on an area of 72.0 thousand hectares. The total sowing area of domestic varieties of Far Eastern varieties was 621.8 thousand hectares, foreign varieties – 358.7 thousand hectares. The most popular were the varieties of the ARSRI of soybeans, such as Alena, Kitrossa, Lydiya, Evgeniya, MK 100, and others. In 2019, a new early ripening variety Sentyabrinka was included in the "State Register …" (2019), and already this year, at the request of farms, the institute produced 32 tons of original seeds of this variety, which is in demand by commodity producers as a high-yielding (3.0 t/ha) with a protein content of more than 40 %. Primorsky breeding varieties: Musson, Primorskaya 4, Primorskaya 86, Primorskaya 96, Sphera are in demand mainly in Primorsky Krai. Varieties of the Khabarovsk breeding Batya, Marinata are sown in the Khabarovsk Territory and the Jewish Autonomous Region. This year, a new soybean variety, Khabarovsky yubilyar, is included in the "State Register ..." (2020), and 0.8 tons of original seeds have already been grown for commodity producers (Table 2).

The protein content and yield of soybean seeds depending on a variety

In solving the country's food security, the size and the quality of the crop are important. In this direction, the

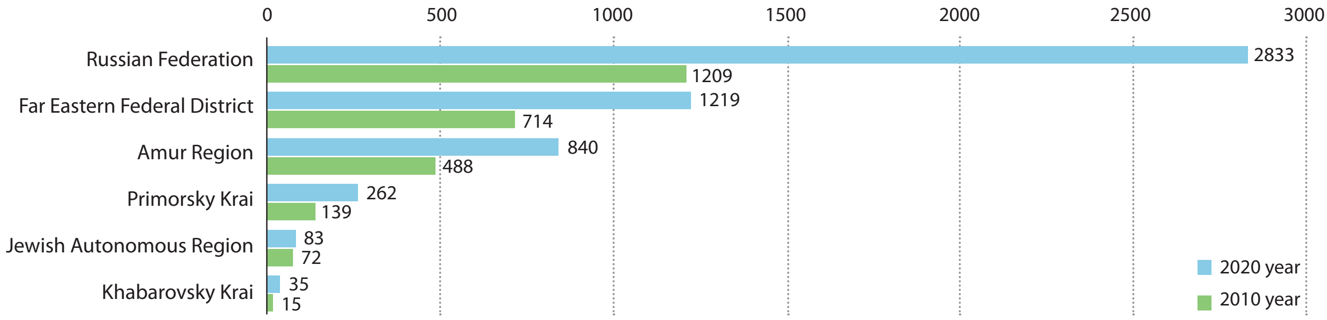

Fig. 1. The sown area of soybean in Russia (thousand ha) in 2020 and 2010 years.

Table 1. Soybean varieties approved for use in the Far East region, 2020 (State Register…, 2020)

Originator	Number of varieties, qty	% of the total
FRC ARSRI of soybean	28	32
FRC of Agrobiotechnology of the Far East named after A.K. Chaika	11	13
Far Eastern Agricultural Research Institute	6	7
Other domestic originators	10	11
Total		
domestic varieties	55	63
foreign varieties	32	37
Total	87	100

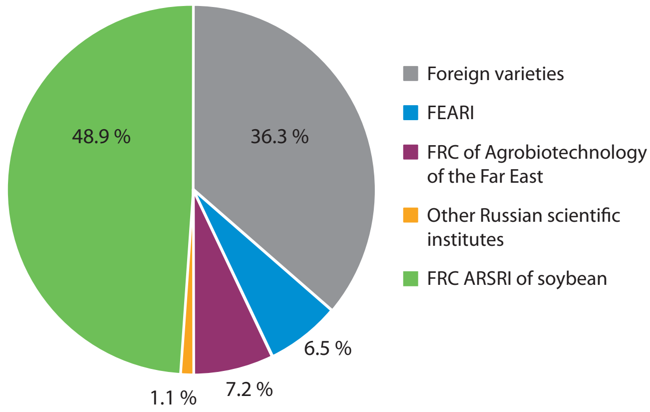

Fig. 2. Share of soybean varieties (%) used in production in the Far Eastern Federal District, 2020.

Table 2. Production of original soybean seeds by scientific institutions of the Far Eastern Federal District, 2020

Variety name	Year of registration in State Register	Acreage, ha	Seed production, t
FRC ARSRI of soybean			
Alena	2014	57 600	563
Kitrossa	2016	31 000	22
Lidiya	2005	31 200	779
MK 100	2011	15 120	383
Sentyabrinka	2019	New	32
Umka	2015	100 400	391
FRC of Agrobiotechnology of the Far East named after A.K. Chaika			
Musson	2015	13 767	800
Primorskaya 4	2014	15 934	800
Primorskaya 86	2014	4 619	600
Primorskaya 96	2014	23 706	700
Sphera	2016	1 327	800
Far Eastern Agricultural Research Institute			
Batya	2016	56 000	1800
Marinata	2002	24 000	540
Khabarovsky yubilyar	State variety testing	3	0.8

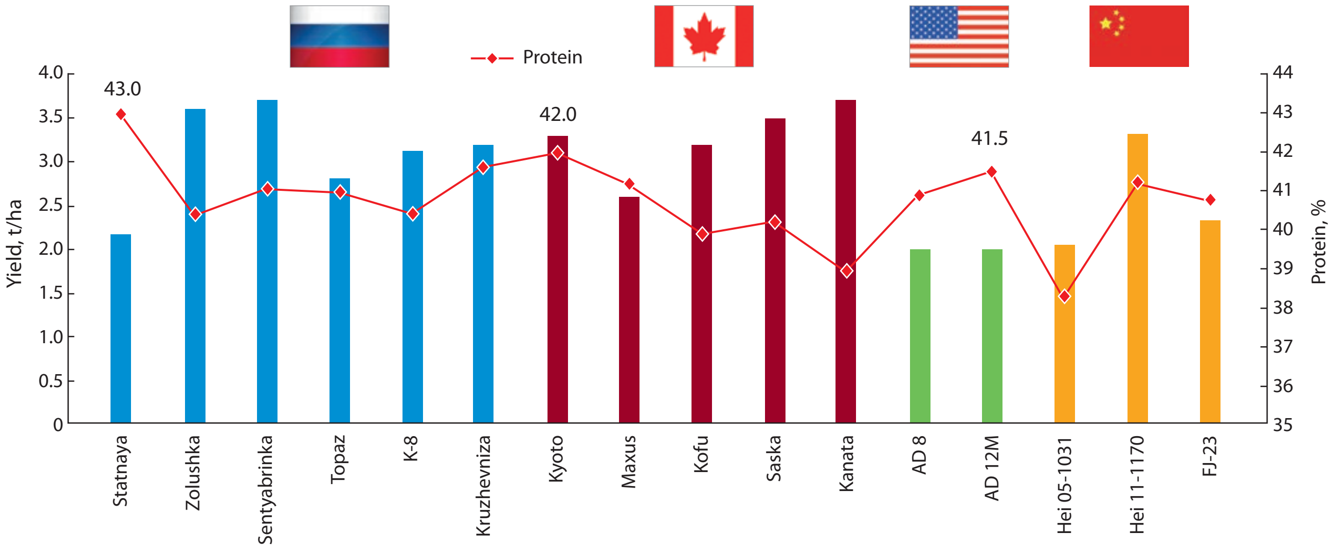

Fig. 3. Yield and protein content in seeds of soybean varieties of various genetic origin, the average for 2018–2019.

institutes are working on creating soybean varieties with high protein content in seeds (Fig. 3).

Evaluation of domestic and foreign varieties grown on the experimental field of the ARSRI of soybean in identical conditions in terms of the protein content in seeds and the value of yield showed that Far Eastern varieties are not only not inferior to Canadian, Chinese, and American varieties, but surpass them both in seed quality and terms of yield (see Fig. 3) (Kodirova et al., 2020; Sinegovskaya et al., 2020). Foreign varieties, generally, have a long growing season that exceeds the frost-free period of the cultivation region, and producers receive soybeans damaged by frost. Foreign varieties showed an adverse reaction to the length of the day, temperature regime, waterlogging of the soil during pod formation, which is confirmed by the high abortion rate of pod ovaries, a low number of seeds in pods, and a decrease in plant productivity. The varieties of Russian breeding, having a shorter growing season, have time to ripen in a short frost-free period and are resistant to the main diseases and pests of soybeans (Vasina et al., 2019; Butovets, Strashnenko, 2020).

In 2020, the yield of mid-ripening Amur varieties varied from 2.12 to 3.43 t/ha, and Chinese – from 2.03 to 3.32 t/ha. The yield of Canadian and American varieties was 0.19…0.63 t/ha less than the varieties bred by the ARSRI of soybean.

Assessment of soybean varieties for disease resistance

Far Eastern soybean varieties have advantages in disease resistance over foreign, mainly Canadian and Chinese varieties, widely advertised in the Far East and imported for sale to producers of the region (Barsukova et al., 2015; Vasina et al., 2019).

Evaluation of domestic and foreign varieties revealed a high degree of damage to Canadian and Chinese varieties by dangerous viruses and pathogenic fungi. In cooperation with Japanese scientists from Niigata University, using DNA markers, the astragalus dwarf virus (MDV, Milk vetch dwarf virus) was detected on Canadian and Chinese varieties in Primorsky Krai and the Amur Region. The carrier of this disease is aphids (Fig. 4).

The cultivars of the Amur breeding showed resistance to the development of this viral disease. The Canadian variety Maxus was affected by the virus mosaic of soybean (*Soybean mosaic potyvirus*) by the stage of seed filling up to 25 %, and the sample of the Chinese variety – by 50 %, which indicates weak resistance and danger for infection of other soybean varieties growing nearby. The virus causes leaf chlorosis and plant dwarfism.

During the research, for the first time bacterial wilt (*Curtobacterium flaccumfaciens* pv. *flaccumfaciens* (Hedges) Dowson) was discovered on American, Canadian and Chinese varieties, leading to the wilting of the plant and its further death (Fig. 5). The degree of infection with bacterial wilt (*C. flaccumfaciens* pv. *flaccumfaciens*) has not yet exceeded the harm threshold and amounted to 10 %, but the further spread of this bacterial disease can lead to significant death of soybean crops.

Severe disturbances in crop rotation in the Far East region led to the spread of soybean cyst nematode (*Heterodera glycines* Ichinohe). Inspection of the Amur Region fields for the presence of this pest has revealed lesions of the root system. Evaluation of our soybean varieties for resistance to nematodes artificially infected showed that the root system of plants of Sentyabrinka, Evgeniya, Sonata and Kukhanna varieties was completely free of the pest by the phase of full pods.

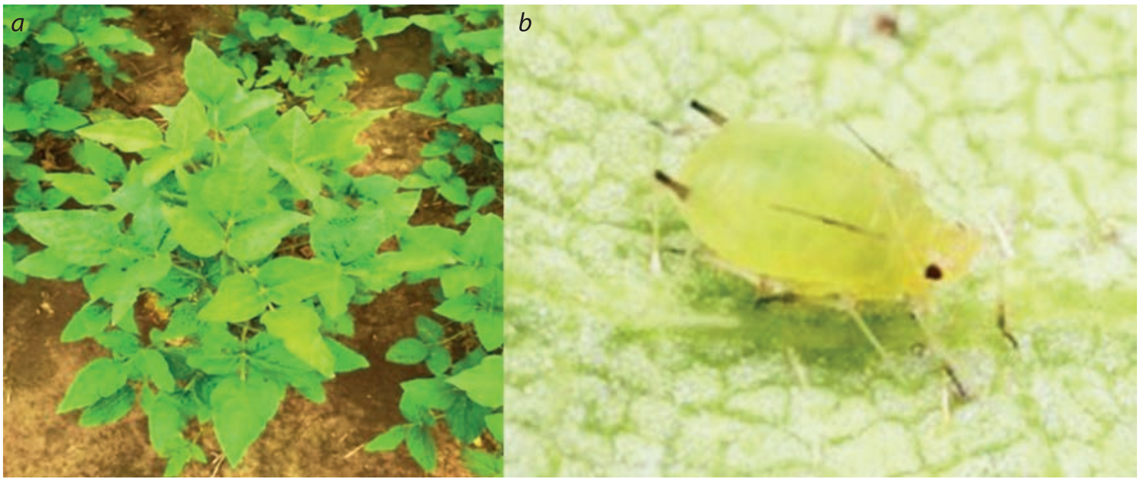

Fig. 4. Soybean plants infected with the astragalus dwarf virus (Milk vetch dwarf virus) (*a*); the virus carrier is soybean aphid (*Aphis glycines* Matsumura) (*b*).

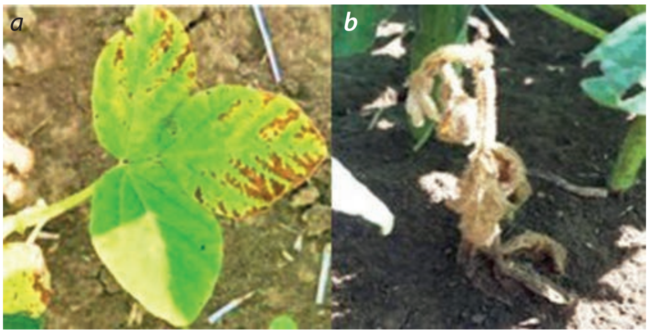

Fig. 5. Damage to leaves (*a*) and plants (*b*) of soybeans with bacterial wilt.

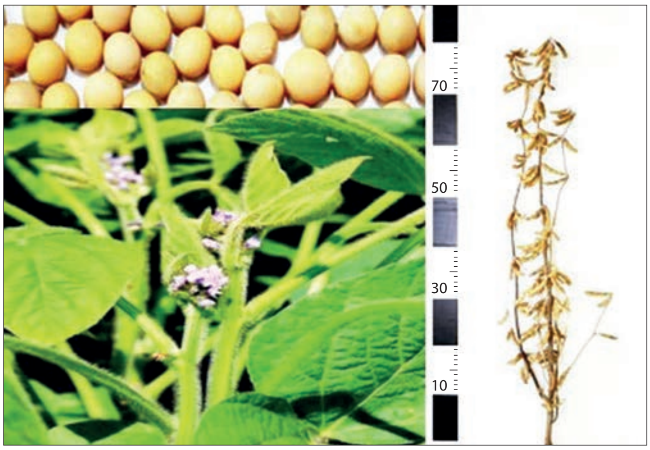

Fig. 6. Early maturing soybean variety Luchistaya.

Far Eastern varieties are also resistant to fungal diseases such as Peronospora sparsa (*Peronospora manshurica* Naum.), Cercospora (*Cercospora sojina* Hara.), Phyllosticta (*Phyllosticta sojaecola* Massal.), Cercospora blight (*Cercospora kikuchii* (Matsuet Tomoyasu) Yardn.) and Septoria (*Septoria glycines* Hemmi.). Work on creating varieties resistant to fungal diseases is carried out annually using quarantine areas, based on studying the physiological and biological characteristics of varieties. All varieties are not genetically modified, which attracts the attention of the countries of the Asia-Pacific region (China, Korea, Japan).

The results of fundamental research in soybean breeding

In recent years, fundamental research in soybean breeding has been significantly strengthened in the region, which is ensured by the interaction of joint works in physiology, biotechnology, and genetics. Under the national project "Science", in order to deepen fundamental research in 2019, two new laboratories were created and are operating at the ARSRI of Soybean, the laboratories of biotechnology and plant physiology, at the FRC of Agrobiotechnologies of the Far East – the laboratory for breeding and genetic research of field crops and Far Eastern Agricultural Research Institute – the laboratory of breeding cereals and legumes.

A multidisciplinary approach, including knowledge of genetics, biochemistry, physiology, and plant breeding, makes it possible to create varieties with a wide range of phenotypic plasticity and resistance to external unfavorable environmental factors (Koshkin, 2010; Rahimzadeh-Bajgiran et al., 2012; Shcherban, 2019). In the ARSRI of Soybean, in a long-term study of the genetic collection of soybeans, physiologists isolated varieties with a high level of assimilation of the photosynthetically active part of the daylight spectrum, which they passed on to breeders for inclusion in the breeding process (Sinegovskaya, Tolmachev, 2011; Sinegovskaya, Dushko, 2017). The joint work of physiologists and breeders created a new soybean variety with a high level of absorption of photosynthetically active light quanta. The new variety, called Luchistaya, has early maturity, exceeds the yield standard by 0.33 t/ha, with a productivity potential of 3.12 t/ha (Fig. 6). The variety belongs to the Manchurian subspecies (*Glycine max* ssp. *manshurica* (Enken) Zel. et Koch.), the approbation group – *flavida* Enk, the growing season is 105–107 days, the protein content is 39.8–40.7 %.

An indeterminate type of growth characterizes the variety, the stem is straight, forms 2–4 long and short branches. The height of the plants is 72–85 cm, the height of attachment of the lower pods is 14 cm, the leaf is pointed ovoid, the flower is purple. Seeds are yellow, spherical, hilum is seed-colored and oval-shaped. The mass of 1000 seeds is 124.8–148.8 g. The variety is resistant to common pathogens, waterlogging and lodging, it is characterized by the increased photosynthetic activity of the leaf apparatus.

The creation of a new variety of classical breeding methods requires 15–20 years. To reduce the time of breeding new highly productive varieties, the breeders of the FRC of Agrobiotechnology of the Far East named after A.K. Chaika together with biotechnologists select pairs for crossing using biotechnological methods based on the assessment of their polymorphism instead of long-term selection for phenotypic traits in the field (Fisenko, Butovets, 2019).

Conclusion

Scientific institutions of the Far East create highly productive soybean varieties, under production conditions, which are capable of providing soybean yield in the region of at least 2.5 t/ha, therefore the share of domestic varieties in soybean crops remains at a stable level and should increase, which requires an increase in the production of original seeds of new varieties and an improvement of their quality. The advantages of the varieties bred by the scientific institutions of the Far East are confirmed by their resistance to major diseases and harmful organisms compared to foreign varieties. The involvement in the breeding process of biotechnology methods and the study of physiological processes in photosynthesis is already yielding positive results and is the key to creating highly productive and high-quality varieties of a new generation. Besides, the low rates of renewal of the outdated material and technical base, as well as the lack of instrumentation of the regional scientific institutions engaged in the breeding and seed production of the strategic crop – soybean – restrain the rate of increase in this production of valuable high-protein crop.

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Present-day breeding of legumes and groat crops in Russia

V.I. Zotikov ✉, S.D. Vilyunov

Federal Scientific Center of Legumes and Groat Crops, Orel, Russia
✉ zotikovzbk@mail.ru

Abstract. The production of pedigree seeds is not only an important but also a cost-effective means of increasing the yield and efficiency of agriculture. The genetic potential of varieties can be unlocked only by choosing those adaptive to the soil and climatic conditions in a particular region, using modern tools for plant protection, and applying balanced mineral nutrition. These are the most important factors determining the performance. In the course of breeding and genetic work, the Federal Scientific Center of Legumes and Groat Crops (FSC LGC) has created new soybean varieties, whose high biological and economic potentials are combined with resistance to stress factors. Despite the close relationship between productivity and growing season duration, the highly productive and early-ripening (100–115 days) soybean varieties raised at FSC LGC can yield 2.5 to 3.5 t/ha, the grain having high contents of protein (37–42 %) and fat (18–22 %), depending on the climatic conditions in a particular year of cultivation. They are less temperature-sensitive than other domestic or foreign varieties. It is important that our soybean varieties are not genetically modified. New pea varieties created at FSC LGC in 2015–2020 differ in growing season duration and morphological features. They are adaptable to the soil and climatic conditions of a region, which ensures the maximum realization of their potential. The main factor in increasing yields and stabilizing the production of buckwheat and millet grain in the Russian Federation is the creation and adaption of new early-ripening and high-yielding varieties of the determinate type adapted to the specific natural and climatic conditions of different regions of Russia.

Key words: legumes and groat crops; breeding; pea; soy; buckwheat; millet; variety.

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Современная селекция зернобобовых и крупяных культур в России

В.И. Зотиков ✉, С.Д. Вилюнов

Федеральный научный центр зернобобовых и крупяных культур, Орел, Россия
✉ zotikovzbk@mail.ru

Аннотация. Производство сортовых семян – не только важный, но и экономически выгодный ресурс повышения урожайности и эффективности сельскохозяйственной отрасли. Реализация генетического потенциала сортов возможна лишь при условии внедрения в производство сортов, адаптивных к почвенно-климатическим условиям региона, использовании при их возделывании современных средств защиты растений, сбалансированного минерального питания, являющихся важнейшими факторами, определяющими уровень урожайности. В процессе селекционно-генетических работ в Федеральном научном центре зернобобовых и крупяных культур (ФНЦ ЗБК) созданы новые сорта сои с высокой биологической и хозяйственной продуктивностью, устойчивые к основным стрессовым факторам. Несмотря на тесную взаимосвязь между продуктивностью и длиной вегетационного периода, полученные в ФНЦ ЗБК скороспелые (100–115 сут) высокопродуктивные сорта сои способны давать урожай порядка 2.5–3.5 т/га с высоким содержанием белка (37–42 %) и жира (18–22 %) в зависимости от условий конкретного года возделывания. Они менее требовательны к теплу, чем другие сорта российской и зарубежной селекции. Важно, что эти сорта сои не являются генетически модифицированными. Новые сорта гороха, выведенные в ФНЦ ЗБК в период с 2015 по 2020 г., отличаются по длине вегетационного периода, морфологическим признакам, обладают адаптивностью к почвенно-климатическим условиям региона, что обеспечивает максимальную реализацию потенциала их урожайности. Основной фактор увеличения урожайности и стабилизации производства зерна гречихи и проса в Российской Федерации – создание и ускоренное использование в производстве новых скороспелых и высокоурожайных сортов детерминантного типа, адаптированных к конкретным природно-климатическим условиям различных регионов страны.

Ключевые слова: зернобобовые и крупяные культуры; селекция; горох; соя; гречиха; просо; сорт.

Introduction

Legumes and groat crops play an important role in providing people with high quality food and animal husbandry with fodder. Their main advantage is a high content of proteins and essential amino acids. In addition, leguminous crops play an important environment-forming role in crop rotations, providing the soil with 30 to 90 kg of nitrogen per hectare. At high fertilizer prices, they can significantly increase the profitability of grain crops grown after legume predecessors.

The areas under soybean (*Glycine max* (L.) Merrill) in the Russian Federation increase every year, and a significant leap occurred in 2017–2018. In general, over the past five years, they increased by 50 %. The structural changes in the regions of soybean cultivation involve, first of all, the Far Eastern Federal District of Russia (Sinegovskaya, 2021). Due to climatic conditions, the Far East occupies the main share in the structure of soybean planting areas. The Belgorod, Kursk, and Orel oblasts are in the lead in soybean cultivation in the Central Federal District. They comprise 58 % of the soybean hectarage in the district.

The land sown with the pea (*Pisum sativum* L.) in the Russian Federation fluctuates from year to year within 1.5–1.7 million hectares, and all legumes (other than the soybean) occupy 2.0–2.5 million hectares. Over the past 10 years, soybean crops in Russia have increased fivefold on the average and doubled the area of pea crops, and in terms of gross grain yield they doubled the total amount of all other leguminous crops grown in Russia. In the structure of leguminous crop (other than soybean) production, 74 % is constituted by the pea, 12 % by the chickpea (*Cicer arietinum* L.), 7 % by lupine (*Lupinus*), and 6 % by the common vetch (*Vicia sativa* L.). By geography of the Russian Federation, the Stavropol and Altai Territories and the Rostov Region are in the lead in pea hectarage.

In the Russian Federation, the pea and soybean have the greatest production value among leguminous crops, whereas buckwheat (*Fagopyrum esculentum* Moench) and millet (*Panicum miliaceum* L.) dominate among groat crops. Russia ranks second in the world in the hectarage and gross grain yield of peas.

About 40 research institutions located in different regions of Russia are engaged in the breeding of legumes and groat crops, according to the “Interdepartmental coordination plan for fundamental and applied research on the scientific support of the agro-industrial complex of the Russian Federation for 2016–2020”. The Federal Scientific Center of Legumes and Groat Crops (FSC LGC) is the coordinator of this work. In the course of introduction of modern genetic and biotechnological breeding methods in this period, over 80 varieties of legumes and groat crops were conveyed to the State variety testing, including 32 varieties of the common pea, 5 varieties of vetch and lentil, 6 varieties of chickpea, 6 varieties of common bean, 8 varieties of buckwheat, and 8 varieties of millet. Of them, 60 varieties were patented.

Pea breeding

Scientists at FSC LGC employ an effective technique, which accelerates pea breeding to improve symbiotic nitrogen fixation. In this technique, a host plant is obtained by hybridization of initial forms, one of which bears the recessive *sym2* gene. This gene determines the resistance of peas to local and master seed strains of nodule bacteria (*Rhizobium leguminosarum* bv. *viciae*). The progeny of the F_1 and F_2 hybrids is propagated on a nitrogen-free background and inoculated with a master seed strain of nodule bacteria. Plants that do not enter the symbiosis with nodule bacteria and, as a consequence, remain unable to fix atmospheric nitrogen, are colored yellow. All green plants are removed from the plot. Then mineral nitrogen is added to the substrate, on which etiolated hybrid pea plants are grown in a normal way, and genotypes homozygous for the *sym2* gene develop. After that, the first backcross is carried out. After a series of backcrosses and selection on the nitrogen-free background, the selected genotypes are propagated and tested for the effectiveness of interaction with a certain strain of nodule bacteria.

Pea breeding is aimed at increasing the productivity and quality of grain by improving the morphotype of plants, primarily by restructuring the architectonics of the leaf apparatus (Fig. 1). Modern varieties have changed not only the leaf apparatus but also the plant habit. The main result of this direction is the creation of leafless, or tendril varieties (see Fig. 1), which ensure the resistance of the agrocenosis to lodging. In this way, the complex task of increasing the technological effectiveness of pea cultivation and reducing grain loss during harvesting was solved.

Along with the solution of the tasks related to the adaptability and technological effectiveness, FSC LGC breeders created and put into production pea varieties combining the tendril leaf type and the determinate (self-limited) type of stem growth, which ensures uniform ripening of beans in different tiers to facilitate harvesting by direct combining. Currently, more than 75 % of such varieties are used in production.

A promising direction in pea breeding is the creation of heterophyllous varieties, or chameleons, characterized by layered variability of leaves and high resistance to lodging due to the transformation of leaf blades into tendrils, which hold plants in an upright position till their technical ripeness (Zadorin, 2013; Zelenov et al., 2018).

The first domestic variety obtained by FSC LGC breeders was the Spartak variety with longline heterophyllia (see Fig. 1), and in 2020, another variety of similar morphotype, Jaguar, was included in the “State Register of Selection Achievements Authorized for Use for Production Purposes” (see Fig. 1). Since 2019, two more leafless pea varieties, Estafeta and Biryuza, are under State testing. The latter is for marketing green. It surpasses all previous varieties bred at FSC LGC in protein content (26– 27 %). Breeders have obtained forms with protein contents within 30–32 %. This direction of pea breeding is promising for creating varieties intended for deep processing of peas into protein isolates to produce essential amino acids.

Soybean breeding

In modern agriculture, the soybean is becoming a key legume crop in crop rotation, which is of great national economic importance. Soybeans contain 35–45 % protein of high quality in

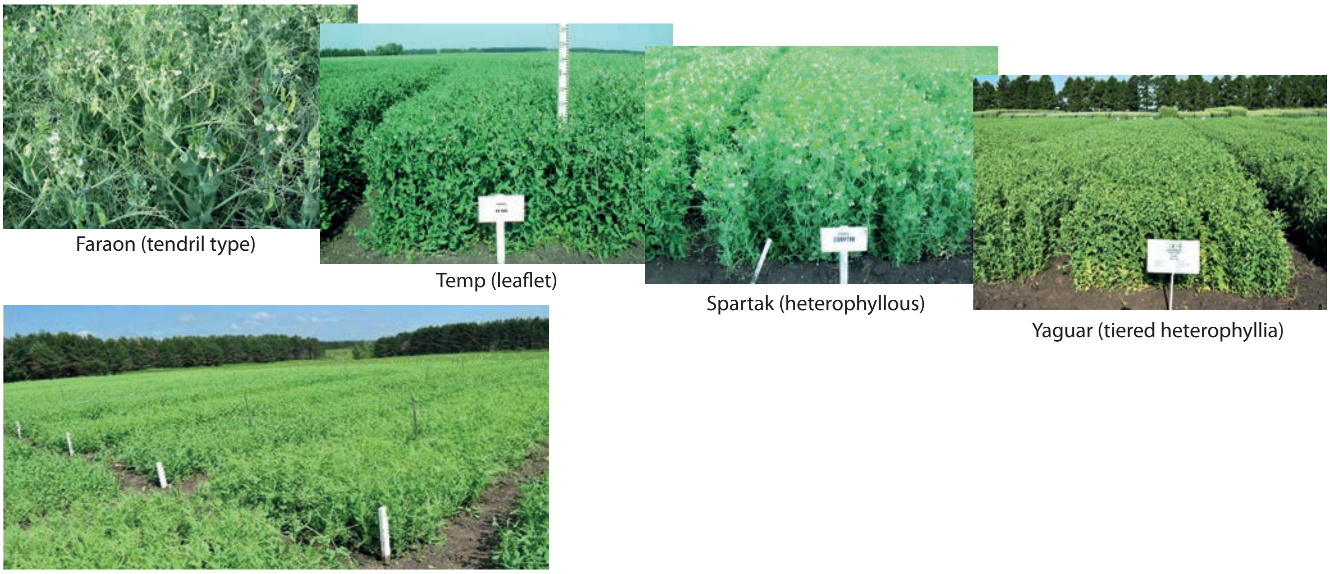

Fig. 1. New morphotypes of peas used in industrial production in the Russian Federation.

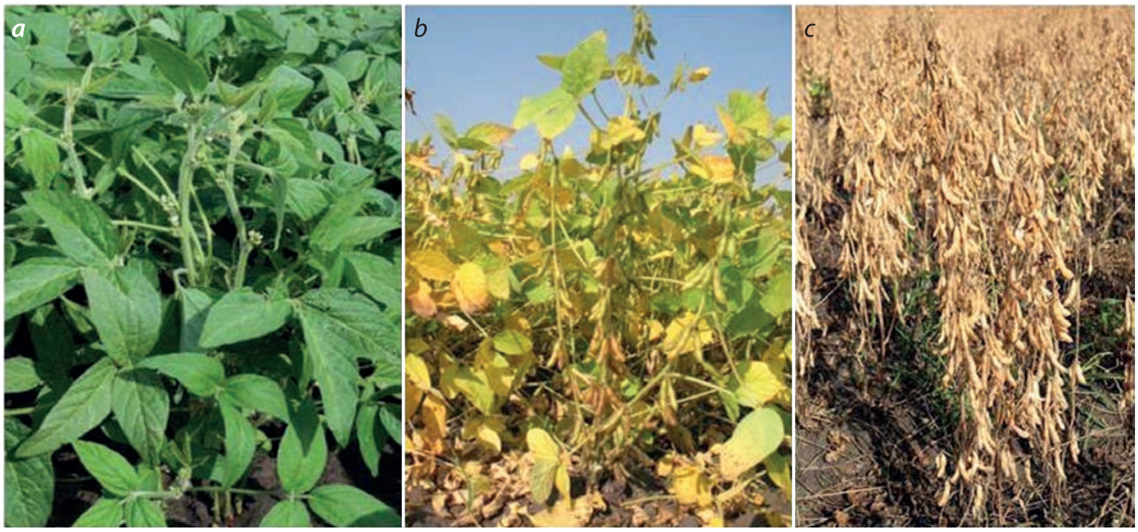

Fig. 2. A soybean variety of the determinate type from FSC LGC in different phases of development: (*a*) budding; (*b*) ripening of beans; (*c*) harvesting period.

terms of amino acid composition, solubility, and digestibility; 17–25 % oil suitable for food, feed, and technical purposes; 20–30 % carbohydrate compounds, including 10–12 % soluble sugars; 5–6 % ash mineral macro- and microelements; 12 essential vitamins and a range of other nutrients.

In general, as evidenced by research data, domestic soybean varieties, including those created at FSC LGC, are not inferior to foreign analogues.

Presently, FSC LGC possesses eight soybean varieties of different maturity groups with growing seasons within 105–115 days, i. e., all varieties in the Central Black Earth Region ripening in late August–early September. They allow the soybean, like pea, to be used in crop rotations as a good precursor for winter cereals.

In 2018–2019, the breeding material of FSC LGC soybeans was significantly expanded due to collection plantings, including the most productive foreign varieties with high protein contents. The expansion of the working collection of soybean varieties made it possible to include them in the breeding process. Attention was focused on varieties with yields of 3–5 t/ha and protein contents of at least 40 %.

This year, 38 FSC LGC soybean lines are under comparative and approval tests. In 2020, a new soybean variety Shatilovskaya 17 was included in the "State Register of Selection Achievements Authorized for Use for Production Purposes" (2020). The variety is early ripening, determinate type (Fig. 2). Its yield in plots of Orel oblast averaged over three years was 2.65 t/ha (maximum 3.73 t/ha), which exceeded the standard value by 0.31 t/ha, and the protein content in the grain was 37–40 %.

The primary role in increasing legume yield and bean quality is played by breeding methods that involve search for sources and the creation of donors of economically important traits for new varieties with specified commercially important parameters. Therefore, long-term breeding programs have been developed for soybean growth in a number of regions of Russia to increase yields and improve the consumer and technological qualities of soybeans. By using a promising technology of soybean cultivation, genotypes of this crop that combine high adaptivity with breeding value were identified. In general, trends in soybean breeding will be aimed at increasing productivity to at least 3.5–4.0 t/ha and protein content in beans to 40–43 % by means of the creation of single-stem and branching varieties of the determinate type with a highly developed generative sphere.

The northern boundaries of the soybean range will be expanded with the creation of new varieties characterized by a weak or neutral photoperiodic response, soil and air temperature tolerance, and responsiveness to inoculation with various strains of rhizobia. Varieties are being created with high bean quality indicators: protein content, fat content, and suitability for deep processing to obtain protein isolates and oil. It is important to create varieties with high adaptability to environmental stress factors, high air temperature during the flowering period, and water shortage in the budding phase. In connection with the expansion of soybean planting areas, it is advisable to make a point of breeding for plant resistance to major pests and diseases, whose spectrum will undoubtedly grow in connection with global and local climate changes.

With regard to the significant climate changes, the associated increase in temperature and aridity, and more frequent extreme events, one should choose a proper approach to the selection of crops, their maturity types, and the development of varietal technologies that would allow reaching the productivity potential and quality inherent in new varieties. For example, the productivity potential of the pea and soybean varieties cultivated in Russia is not reached in full. The main causes are the slow introduction of new varieties of the intensive type and the lack of special equipment for the timely implementation of agrotechnical techniques for sowing, tending, and high-quality harvesting.

It is advisable to expand the spectrum of legumes and increase the areas under crops that are still insufficiently popular in the Russian Federation: the common bean, chickpea, Indian pea, and lentil, the more so that breeders have created highly productive varieties of these crops suitable for cultivation in various climatic zones of Russia. First of all, this refers to the common vetch, whose seeds are in demand in the Arkhangelsk, Murmansk, Leningrad, and other regions of northwestern Russia and West Siberia (Goncharova, 2020). In recent years, the "State Register…" (2020) has included the common vetch varieties Livenka and Obelna. They are distinguished by high yields of green and dry matter and high protein content at the optimal harvest time: 25–30 %.

In 2018–2020, new broad bean varieties Krasnyi bogatyr' and Universal and common bean varieties Markiza and Khabarovskaya were obtained. Khabarovskaya was fruit of collaboration with the Far Eastern Research Institute of Agriculture (Khabarovsk). Neither bean variety has foreign analogs, and they are distinguished by plasticity and resistance to abiotic stressors. Their yield potential is 2.5–3.0 t/ha, and they ripen 5–7 days earlier than the standard. The seeds look highly marketable, having appropriate volume, shape, size, and excellent taste.

The same properties are possessed by lentil grain, which is used in a wide variety of dishes. Unlike peas or beans, lentil seeds are boiled soft 2–3 times faster. Their cooking time is 35–70 minutes. Among the most valuable is the new lentil variety Vostochnaya, bred at FSC LGC. In its development, the biotechnological method of germinating seeds on nutrient media *in vitro* was used. Vostochnaya is the world's first lentil variety created with the germplasm of the wild species *Lens orientalis.*

Breeding of groats and millet-like crops

Groat crops provide environmentally friendly products suitable for dietary nutrition. Protein content in buckwheat groats varies from 10.9 to 18.9 %, and in the hull, 4 %. Buckwheat groats contain 65–68 % carbohydrates (including 2 % soluble sugars), 12 % proteins, 4 % fat, and 7 % fiber. The compositions of amino acids in the protein and of mineral nutrients determine the dietary value of buckwheat dishes for people of any age.

The largest areas under groat crops in European Russia are concentrated in the Republic of Bashkortostan and in the Orenburg, Saratov, and Orel oblasts.

Of the group of cereal crops in the world, common buckwheat and millet are most widely used. Less common crops are foxtail, Italian, barnyard, and African millets. Buckwheat and millet, despite their small planting areas, contribute much to the food basket of the population.

In recent years, buckwheat and millet planting areas in the Russian Federation amounted to about 1,700,000 hectares. Both buckwheat and millet are characterized by high variability of gross grain harvest and low dynamics of yield growth. For buckwheat, it varies from year to year from 1.2 to 1.7 t/ha, and for millet, from 1.3 to 1.9 t/ha.

The "State Register…," contains 52 varieties of buckwheat and 58 varieties of common millet. Only in the last five years, the "State Register…" included five varieties of buckwheat bred at FSC LGC and characterized by the determinate growth type (Fig. 3). Their advantages are even ripening, large (32–34 g) weight of 1000 grains, high yield of groats (70–74 %), and high protein content (13–16 %) (Zotikov, 2020).

The leading farms of the Orel oblast consistently gather 2.5–3.0 tons of buckwheat per hectare. In recent years, FSC LGC has created a series of high-yielding buckwheat varieties, adapted to a wide range of soil and climatic conditions, capable of producing high grain yields in the field.

The breeding work on millet is aimed at creating new large-grain, highly productive varieties with a short growing season, resistant to major diseases. Breeding material and varieties of different biotypes differing in ripening terms and differently responding to weather conditions are being created for growing in the main regions of millet cultivation, including northern Russia and Siberia. The Quartet and Sputnik varieties provide high-quality grains when grown in Central Russia and Western Europe (Switzerland and Germany). A grain yield of more than 7 t/ha was recorded for the multilinear variety Quartet and more than 8 t/ha for Sputnik. Alba is the first practically bare-grain variety, not requiring hulling costs (Zotikov, 2020). It has a high content of protein and oil in the grain and is intended for poultry farming. The Kazachye variety combines coarse grain with high yields. It is designed for cultivation in central and southern Russia. The use of biotechnological methods in millet breeding continues. Promising lines of millet dihaploids, new for the Central Federal District forage crops, were obtained: barnyard millet (*Echinochloa frumentacea* Link.) and African millet (pearl millet, *Pennisetum glaucum* (L.) R. Br.). The main task of FSC LGC scientists is to develop highly adaptive varieties with high biomass potentials and stable seed yields, resistant to drought and lodging, for use in animal husbandry and poultry farming.

Federal Scientific Center of Legumes and Groat Crops attaches great importance to the creation of varieties that reduce the pesticide load on agroecosystems in crop production, which is a topical issue in the 21st century. This task is mentioned among the main directions in the reports and decisions of the 1992 United Nations Conference: "…increasing plant genetic resistance and good agricultural practices while minimizing the use of pesticides is the best possible option for the future as it guarantees yields, reduces costs, is environmentally friendly and promotes sustainable agriculture..." (Report of the United Nations Conference…, 1992, Chapt. 14).

All new Russian varieties of agricultural crops that are transferred to production carry different genes for resistance to major pests in particular cultivation zones. Moreover, in the modern context, the use of varieties not only resistant to certain races of the main pathogens but also reducing the likelihood of the appearance of their new virulent features, caused by overcoming the crop genetic resistance by the pathogen, becomes a factor of paramount importance. This task is facilitated by using controlled heterogeneity of multilinear varieties and mixtures of varieties (Browning, Frey, 1969). The transition from genetic homogeneity of a phenotypically aligned monoculture to the use of balanced controlled genetic polymorphism for resistance genes reduces the level of existing diseases without chemical treatments of crops (Sidorenko, Vilyunov, 1997; Vilyunov, 2019).

Studies of the millet variety Quartet, multilinear in resistance to smut, show that for more than 20 years of its cultivation, without chemical treatments against diseases, the variety successfully suppressed the development of smut and completely retained resistance to its local population (Fig. 4), maintaining a high stable yield. Note that for 20 years it retained genetic polymorphism in resistance to all local races of the pathogen (see Fig. 4), close to the initially modeled composition (proportions) of resistant components (lines), which overlapped the racial composition of smut in the Orel region to the greatest extent (Sidorenko, Vilyunov, 1997; Tikhonov et al., 2018; Vilyunov, 2019).

Varieties of many groat crops bred in Russia successfully compete in the world market of environmentally friendly products (Strahm et al., 2019). Russian varieties of millet and buckwheat, when tested in Switzerland, Austria, Germany, gave higher and more stable yields and higher groat quality

Fig. 3. Inflorescence of determinate green-flowered buckwheat with small flowers.

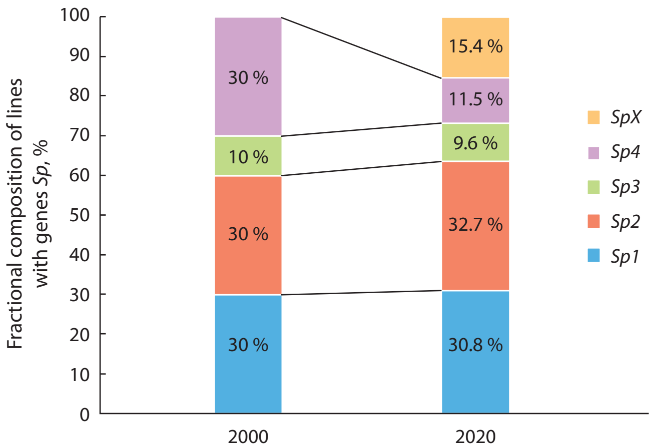

Fig. 4. The dynamics of polymorphism for the *Sp1*–*Sp4* genes, which control resistance to smut races, in the multilinear millet variety Quartet for 20 years of growing in the field, when reseeded with its own seeds, without chemical seed treatment.

SpX – component requiring additional genetic identification for smut resistance.

than local varieties. In particular, the FSC LGC varieties turned out to be more productive and earlier ripening. They were distinguished by better resistance to lodging and diseases. They were characterized by high vigor, which helped them suppress weed growth. They were superior to millet and buckwheat varieties bred in other countries, which did not ripen at all in some years and were harvested only for fodder. The Krupnoskoroe variety has been registered in the EU (Germany), and the registration procedure for the Quartet and Kazachye varieties is underway. The development of the production of organic food (bioproducts) in many countries generated the tendency to arrange process lines for the production of environmentally friendly millet and buckwheat grain and its processing into groats and flour.

To maintain the breeding process at a high level, genetic resources of legumes and groat crops should be mobilized, conserved, and employed. For this purpose, FSC LGC screens more than 20,000 accessions every year. The implementation of the breeding program for the main legumes and groat crops includes

– a comprehensive study of the best varieties and valuable forms and creation of starting material (mutants, regenerants, and recombinants);
– expansion of trait and pre-breeding collections;
– selection of appropriate breeding material, including identification of donors of commercially valuable traits for supporting tasks to solve;
– organization of the breeding process to create high-yielding varieties with resistance to stress and improved product quality, as well as expansion of the genetic base of new original source material at FSC LGC (Zotikov, 2020).

Scientific institutions of the Russian Federation carry out research and solve tasks concerning the Russian and global breeding of legumes and groat crops. Federal Scientific Center of Legumes and Groat Crops carries out a significant amount of research on the development of differentiated resource-saving systems and technologies for the cultivation of legumes, buckwheat, and millet. It also makes a significant contribution over substantial time and effectively implements governmental programs for breeding and seed production. Federal Scientific Center of Legumes and Groat Crops is the copyright holder and originator of 110 varieties of legumes, groat crops, grain crops, and fodder crops approved for use in various constituent entities of the Russian Federation. It holds 50 patents on breeding achievements in 21 crops, including 28 patents on new adaptive and technological varieties. When raising them, modern achievements of domestic and foreign selection of the Federal Research Center "N.I. Vavilov All-Russian Institute of Plant Genetic Resources" (VIR) weare widely used. Federal Scientific Center of Legumes and Groat Crops maintains its own gene pool collection. Production and environmental tests are carried out using a working collection of genotypes of various agricultural crops having high productivity rates, a complex of commercially valuable traits, and resistance to biotic and abiotic stressors. A significant stock of breeding material is being created.

In connection with the entry into force of the Federal Law No. 280 of 03.08.2018 "On organic products ..." in 01.01.2020, breeding programs in FSC LGC are included in academic research in order to increase crop productivity, minimize the application of pesticides and mineral fertilizers, and obtain environmentally friendly products (Gryadunova, Khmyzova, 2018).

Conclusion

The key vectors determining the rise of production of leguminous and groat crops in the Russian Federation involve crop breeding and the development of adaptive technologies. They play an exceptional role in such a rise through the production of certified seeds, which is an economically beneficial way to increase yields and the efficiency of the entire agricultural sector.

For all that, the main methodological problem of modern breeding is the fullest utilization of recent achievements in fundamental sciences, such as physiology, genetics, biotechnology, biochemistry, immunology, etc. The need for this approach stems from the fact that traditional methods of classical breeding, although used for long, cannot overcome the barrier in the creation of varieties with complex resistance to pests and abiotic stresses. The severest contradiction between productivity, grain quality, and plant resistance to edaphic factors has not been overcome.

Currently, breeding achievements in studying the mechanisms of plant resistance to drought, low temperatures, and excessive moisture are not used in full. The management of the growing season of new varieties by employing scientifically based crop rotation, as well as using micronutrient fertilizers and growth stimulants, can increase the profitability of crop production. An increase in the areas under legumes and their inclusion in crop rotations will reduce the demand for mineral fertilizers and improve environmental settings in the Russian Federation. In modern conditions of agricultural production, the soybean and pea become key legumes in crop rotations and acquire great national economic importance. The main factor in increasing yields and stabilizing grain production of legumes and groat crops is the creation and accelerated introduction of new early ripening high-yielding varieties of the determinate type, adapted for cultivation in specific climatic conditions of various regions of Russia.

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ORCID ID
V.I. Zotikov orcid.org/0000-0001-5713-7444
S.D. Vilyunov orcid.org/0000-0002-7373-5951

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Modern trends in breeding and genetic improvement of sunflower varieties and hybrids at VNIIMK

V.M. Lukomets, M.V. Trunova, Ya.N. Demurin ✉

V.S. Pustovoit All-Russian Research Institute of Oil Crops, Krasnodar, Russia
✉ vniimk@vniimk.ru

Abstract. Modern sunflower breeding is significantly diversified due to the different needs of agricultural production. The breeding of sunflower varieties and hybrids is carried out at V.S. Pustovoit All-Russian Research Institute of Oil Crops (VNIIMK) in all areas in demand on the market and is based on fundamental biological research. In the field of breeding for faster maturing, the following commercial cultivars were obtained: very early maturing, cv. Skormas and the three-way hybrid Achilles, early maturing cvs. Varyag and Uspekh, medium maturing cvs. Amelie, Aris and Aurus. Within the framework of breeding for immunity, eight hybrids and one variety have been produced. So at the Don experimental station (Rostov region), productive hybrids were bred, resistant to the virulent broomrape of the G race due to the presence of the *Or7* gene: 'Gorstar', 'Gorfild', 'Grant', 'Status', 'Fogor' and the three-way hybrid Nika. On the central experimental base, the following were obtained: the mid-early hybrid Typhoon and the early-maturing variety Platonych with resistance to common races of downy mildew and a high oil content of achenes (up to 53 %) as well as the mid-early hybrid Tayzar, which is simultaneously resistant to virulent races of broomrape and to the causative agent of downy mildew. The early maturing large-fruited sunflower variety Belochka was included in the "Russian State Register of Selection Achievements…", and the large-fruited varieties Karavan, Konditer and Kalibr are currently undergoing state tests. The breeding use of germplasm with genes for herbicide resistance was accompanied by their extensive genetic study. A practical recommendation for all three alleles of the ALS gene (*Imr*, *CLHA-Plus*, *Sur*) was the need to create homozygous hybrids for their reliable use in appropriate production systems. For Clearfield technology, the hybrids Imidzh, Arimi and Immi have been developed; for Clearfield Plus, the hybrid Klip; and for Express Sun (or SUMO), the hybrid Surus. Klip and Surus are mid-oleic. All newly developed fertile ornamental sunflower varieties – Aurelia, Fizalia, Zhemchuzhny, Rumyanets, Agat and Mazhor – were transferred for practical use to a sterile CMS RIG basis. Thus, new achievements have been attained across the entire spectrum of modern trends in sunflower breeding.

Key words: sunflower; breeding; variety; hybrid; early maturity; resistance to pathogens; large-fruited; herbicide resistance; ornamental.

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Современные тренды селекционно-генетического улучшения сортов и гибридов подсолнечника во ВНИИМК

В.М. Лукомец, М.В. Трунова, Я.Н. Демурин ✉

Федеральный научный центр «Всероссийский научно-исследовательский институт масличных культур им. В.С. Пустовойта», Краснодар, Россия
✉ vniimk@vniimk.ru

Аннотация. Современная селекция подсолнечника сильно диверсифицирована различными потребностями сельскохозяйственного производства. Во Всероссийском научно-исследовательском институте масличных культур (ВНИИМК) селекция сортов и гибридов подсолнечника ведется по всем востребованным на рынке направлениям и основывается на фундаментальных биологических исследованиях. В направлении селекции на сокращение вегетационного периода растений получены: скороспелые сорт Скормас и трехлинейный гибрид Ахиллес, раннеспелые сорта Варяг и Успех, среднеспелые гибриды Амели, Арис и Аурус. При селекции на устойчивость к болезням созданы восемь гибридов и один сорт. Так, на Донской опытной станции выведены продуктивные гибриды, устойчивые к вирулентной заразихе расы G за счет наличия гена *Or7*: Горстар, Горфилд, Грант, Статус, Фогор и трехлинейный гибрид Ника. На центральной экспериментальной базе получены среднеранний гибрид Тайфун и раннеспелый сорт Платоныч с устойчивостью к распространенным расам ложной мучнистой росы и с высокой масличностью семянок (до 53 %), а также среднеранний гибрид подсолнечника Тайзар, который обладает устойчивостью к вирулентным расам заразихи и к возбудителю ложной мучнистой росы. В «Государственный реестр селекционных достижений…» внесен

скороспелый крупноплодный сорт подсолнечника Белочка; проходят госсортоиспытание крупноплодные сорта Караван, Кондитер и Калибр. Результатом генетического изучения генов гербицидоустойчивости стала практическая рекомендация для применения в селекции подсолнечника трех генов устойчивости к ингибиторам ацетолактатсинтетазы (*Imr*, *CLHA-Plus*, *Sur*), которая заключается в необходимости создания гомозиготных гибридов для их надежного использования в соответствующих производственных системах. Для технологий Clearfield получены гибриды Имидж, Арими и Имми, для Clearfield Plus – гибрид Клип, а для Express Sun (или SUMO) – гибрид Сурус. Гибриды Клип и Сурус являются среднеолеиновыми по качеству масла. Все созданные фертильные декоративные сорта подсолнечника Аурелия, Физалия, Жемчужный, Агат, Мажор и гибрид Румянец переведены для практического использования на стерильную основу ЦМС RIG. Таким образом, по всему спектру современных направлений селекции подсолнечника во ВНИИМК имеются новые достижения.
Ключевые слова: подсолнечник; селекция; сорт; гибрид; скороспелость; устойчивость к патогенам; крупноплодность; гербицидоустойчивость; декоративность.

Introduction

Throughout the more than a century-old history of sunflower (*Helianthus annuus* L.) breeding in Russia, which began at V.S. Pustovoit All-Russian Research Institute of Oil Crops (VNIIMK) in 1912, several developments of the Institute's scientists have obtained a clear global priority. First of all, it is the academician V.S. Pustovoit's development of a practically new field crop of oil sunflower with oil content in achenes of up to 50 %. After that, there was a focused effort to change the fatty acid composition of sunflower oil, which led to the development of the world's first high-oleic variety Pervenets (Škorić et al., 2012). These two most significant breeding achievements formed the basis of the modern gene pool of oil sunflower and breeding trends in the world and significantly influenced the work of the agro-industrial complex of many countries.

Currently, at VNIIMK, both varieties-populations and the interline hybrids of sunflower are bred. For 2020, 41 sunflower varieties of VNIIMK's breeding have been included into the "State Register of Selection Achievements…" of the Russian Federation, which is 41 % of the total number of varieties permitted for cultivation in the country (State Register…, 2020). The sunflower hybrids (simple and three-way) are represented by 58 genotypes, which is 9 % of their total number. A total of 99 sunflower varieties and hybrids of VNIIMK's breeding occupy 14 % of their total number in the "State Register…". Moreover, among 16 varieties of ornamental sunflower included in the "State Register…" six ones are of VNIIMK's breeding, which is 38 %.

The modern sunflower breeding is largely diversified by various challenges of agricultural production and directions of crop usage (Škorić et al., 2012). On the other hand, the success of breeding at VNIIMK has always been based on fundamental agrobiological research, including efficient methods for evaluation of traits and selection of desired genotypes. This article presents the main recent results of this work (see the Table).

Breeding for decreasing the length of the growth season

Decreasing the period from seedling emergence to physiological maturity of sunflower, largely controlled genetically, allows expanding the crop acreage and carrying out replanting or resowing crops in one year. The main problem of using such cultivation technology lies in minimizing the yield decrease and not in the absence of hereditary variability in the length of the growth season. The period from physiological to harvesting (technical) maturity mainly depends on environmental factors, including air temperature, precipitation, and desiccation, and can vary from 14 to 20 days.

At VNIIMK, Krasnodar, the early-maturing variety-population Skormas was developed from the oil variety SUR by the classical breeding scheme, specifically by the method of multiple individual selection with an evaluation of progeny and subsequent pollination of the best families in terms of a complex of traits. The period from seedling emergence to physiological maturity of the variety Skormas is 79 days with a productivity of 2.96 t/ha and oil content of achenes of 50 % (Detsyna, Illarionova, 2018).

At the Siberian experimental station of VNIIMK (Isilkul, Omsk region), two early-maturing sunflower varieties for cultivation in the extreme conditions of Western Siberia were developed. One of them, the variety Varyag, was developed by the method of multiple self-pollination of plants of the variety Skorospely-87 and the use of individual selection, followed by pollination within the best families during free flowering. The period from seedling emergence to physiological maturity is 94 days with a productivity of 3.15 t/ha and oil content of achenes of 52 % (Puzikov, Suvorova, 2018). Another variety, Uspekh, was developed using individual selection from hybrids obtained by crossing the early-maturing varieties Rodnik and Ermak, followed by cross-pollination of the best families during free flowering. The period from seedling emergence to physiological maturity is 98 days with a productivity of 3.47 t/ha and oil content of achenes of 55 %. The variety Uspekh has one of the highest oil contents among the varieties of its region.

In addition, at VNIIMK, an early-maturing three-way hybrid Achilles was developed, which showed the growth season of 76 days with a productivity of 3.41 t/ha and oil content of achenes of 49 % in trial conditions of Krasnodar.

The sunflower hybrids of mid-maturing group are characterized by the highest productivity. At the Armavirskaya experimental station, the breeding in this direction led to the development of highly productive hybrids Amelie, Aris and Aurus.

Breeding for disease resistance

Numerous sunflower diseases can significantly decrease the productivity and seed quality. The accelerating racial evolution

The latest achievements of VNIIMK in sunflower breeding

The breeding direction	Variety	Hybrid
The growth season/ productivity	Skormas, Varyag, Uspekh	Achilles, Amelie, Aris, Aurus
Disease resistance	Platonych	Gorstar, Gorfild, Grant, Status, Fogor, Nika, Typhoon, Tayzar
Large seeds	Belochka, Karavan, Konditer, Kalibr	–
Herbicide resistance	–	Imidzh, Arimi, Immi*, Klip**, Surus***
Oil quality	–	Oksi (high-oleic), Klip, Surus (mid-oleic)
Ornamentation	Aurelia, Fizalia, Zhemchuzhny, Agat, Mazhor	Rumyanets

* For Clearfield cultivation technology; ** for Clearfield Plus cultivation technology; *** for SUMO cultivation technology.

of both the flower parasite of sunflower broomrape *Orobanche cumana* Wallr. (Khatnyanskij, 2020) and the obligate pathogen of downy mildew *Plasmopara halstedii* (Farl.) Berl. et de Toni makes breeding for resistance to them a constant process.

We revealed an incomplete dominance of the resistance gene *Or7* to the new virulent broomrape race G during the hybridological analysis carried out at VNIIMK (Guchetl et al., 2019). Moreover, we continue the search for molecular genetic markers loci that control broomrape resistance. Similar work is being carried out with genes that determine resistance to the downy mildew pathogen (Ramazanova et al., 2020).

In breeding for immunity, eight hybrids and one sunflower variety have been developed at VNIIMK in recent years. For example, at the Don experimental station, the following productive hybrids resistant to broomrape race G due to the presence of the *Or7* gene were developed: Gorstar (Gorbachenko et al., 2018), Gorfild, Grant, Status, Fogor (maximum broomrape resistance) and three-way hybrid Nika (Gorbachenko et al., 2020).

At VNIIMK, Krasnodar, were developed the mid-early maturing hybrid Typhoon with resistance to common races of downy mildew and a high oil content of seeds – up to 53 %, and the early-maturing variety Platonych with similar oil content and resistance to downy mildew (Detsyna, Illarionova, 2019).

The latest breeding achievement is the mid-early maturing productive hybrid Tayzar (Fig. 1), which has been submitted for State variety trial in 2021; it is simultaneously resistant to the virulent broomrape race G and five races of the downy mildew pathogen – 330, 710, 730, 334, and 734 (Demurin et al., 2020c).

Breeding of large-seeded varieties

The feature of Russian varieties of confectionery sunflower, such as SPK, Dzhinn, Lakomka, and Oreshek, is their intermediate place in terms of achenes between edible and oil forms. Exactly this type of achene is in demand in Russia and the CIS countries. The study of the inheritance of the trait “seed size”, estimated as a thousand-seed weight, showed polygenic

Fig. 1. Sunflower hybrid Tayzar at the flowering stage.
VNIIMK’s field (Krasnodar), photo by the authors.

control and a strong dependence of its expression on the applied cultivation technology (plant population).

In 2018, the new early-maturing large-seeded sunflower variety Belochka developed at VNIIMK was included into the "State Register of Selection Achievements…" (Detsyna et al., 2018). It was developed using the method of multiple individual selection with an evaluation of the progeny and pollination within the best families in terms of economic valuable traits, including broomrape resistance. In terms of productivity, the variety exceeded the standard variety Oreshek by 0.16 t/ha, with an average decrease of the growth season by three days. The variety is characterized by uniformity of flowering and maturing dates, with a thousand-seed weight of about 100 g with a plant population of 40 thousand pcs/ha.

Currently, new, more productive, large-seeded varieties Karavan, Konditer, and Kalibr are undergoing the State variety trial.

Breeding for herbicide resistance

Currently, for sunflower cultivation, three production systems of growing "hybrid–herbicide" were developed and are widely used, both in our country and abroad: Clearfield, Clearfield Plus, and Express Sun (or SUMO), based on the use of the *Imr*, *CLHA-Plus*, and *Sur* genes, respectively (Škorić et al., 2012).

At VNIIMK, the use of obtained sources with herbicide resistance genes in breeding was followed by their genetic study. In particular, we received important data on the dominance type of resistance to the selective herbicide tribenuron-methyl from the sulfonylurea class at various doses of the active ingredient (Demurin et al., 2016). The main practical recommendation when using the *Imr*, *CLHA-Plus* and *Sur* genes is the necessity to develop homozygous parent lines and hybrids for their reliable use in the mentioned production systems.

Imidzh and Arimi, the first Russian imidazolinone-resistant hybrids of the VNIIMK breeding suitable for cultivation with Clearfield technology, have been included into the "State Register of Selection Achievements…" since 2014. The Immi hybrid, also homozygous by the *Imr* gene and adapted for this cultivation technology, is currently undergoing the State variety trial.

A simple interline sunflower hybrid Klip was developed as part of a breeding and genetic program for the development of herbicide-resistant plants for growing by the Clearfield Plus production system. This hybrid, like its parental forms, is homozygous by the *CLHA-Plus* imidazolinone resistance gene. The hybrid belongs to the mid-early group of maturity, has high seed productivity, is resistant to races A–E of broomrape and to race 330 of downy mildew, and tolerant to Phomopsis blight caused by *Phomopsis helianthi* Munt. The period from seedling emergence to harvesting maturity is 115 days, the oil content of seeds is 50 %, the huskness is 21 % (Demurin et al., 2020a). The hybrid Klip is undergoing the State variety trial.

For the Express Sun production system was developed and is also undergoing the State variety trial a simple interline sunflower hybrid Surus, which is highly resistant to the tribenuron-methyl herbicide. Both parental forms, as well as the hybrid, are homozygous by the *Sur* gene. The hybrid Surus belongs to the mid-maturing group, has high productivity, is resistant to broomrape (races A–E) and downy mildew (race 330), and tolerant to Phomopsis blight. The period from seedling emergence to harvesting maturity is 120 days, the oil content of seeds is 50 %, the huskness is 22 % (Demurin et al., 2020b).

Breeding for oil quality

The trait of high oleic acid content keeps ranking high in the breeding programs of companies in most countries. The herbicide-resistant hybrids Klip and Surus have a medium oleic segregation type of oil in the commercial seeds of F_2 hybrids. Earlier, in 2014, we developed a high oleic hybrid Oksi with a modified composition of tocopherols (vitamin E). A molecular marker was validated to control the genetic purity of lines with a high oleic content mutation *Ol* (Guchetl, 2020).

Breeding for ornamentality

The development of ornamental forms of sunflower at VNIIMK initially led to the breeding of two varieties with an ornamental phenotype in 2016 (Fig. 2). The variety Aurelia was received during the study of the genetic collection by crossing the dwarf sample I5/303 and the ornamental variety, followed by self-pollination and individual selection based on morphotype traits. The main ornamental characteristics of the variety Aurelia (see Fig. 2, *b*) are low height, compact pyramidic habitus, large number of inflorescences, common branching of the stem, location of the central head above the lateral inflorescences, and long flowering period. The main ornamental characteristics of the variety Fizalia (see Fig. 2, *a*) are low height, compact cylindric habitus, large number of inflorescences, apical branching of the stem, location of the central head on the same level with the lateral inflorescences, and long flowering period.

In 2017, the ornamental variety Zhemchuzhny was submitted to the State Commission of the Russian Federation for Selection Achievements Test and Protection. It was received by crossing a dwarf sample LD4 and the line VIR721. Its main ornamental characteristics (see Fig. 2, *c*) are light yellow color of ligulate florets, light-green leaf with blue-grey tint, low height, compact single-head habitus (Peretyagina et al., 2018).

The hybrid of ornamental sunflower Rumyanets was received by crossing the parental lines LD110 and LD120. The main ornamental characteristics of the hybrid Rumyanets (see Fig. 2, *d*) are common branching of the stem, large number of inflorescences, crimson color of ligulate florets, long flowering period. The hybrid belongs to the late-maturing group.

In 2019, the ornamental variety Agat was submitted to the State Commission of the Russian Federation for Selection Achievements Test and Protection. It was received by crossing a dwarf sample LD4 and the line LD11. The main ornamental characteristics of the hybrid Agat (see Fig. 2, *f*) are active accumulation of anthocyanins in the mesophyll of young leaves, stems, and husk leaves; purple color of ligualte and tubular florets; large, bladder-like leaves creviced along the edges; low height; compact habitus; long growth season.

The ornamental variety Mazhor was received by crossing the ornamental variety and the line LD11, followed by self-pollination and individual selection based on morphotype traits. The main ornamental characteristics of the variety Mazhor (see Fig. 2, *e*) are yellow-red color of ligulate and tubular florets; weakly pleiopetalous inflorescence of the

Fig. 2. Ornamental varieties of VNIIMK breeding: *a*, Fizalia; *b*, Aurelia; *c*, Zhemchuzhny; *d*, Rumyanets; *e*, Mazhor; *f*, Agat.
Photo by the authors.

head; heavy habitus; large number of inflorescences; long growth season.

All fertile ornamental sunflower varieties have been transferred for practical use to a non-restorable sterile base CMS RIG to protect the copyright of breeders and eliminate the factor of pollen allergenic capacity, since the plants are used both for cutting for bouquets in a confined space, as well as in parks, gardens, and individual land properties.

Conclusion

Breeding of sunflower varieties and hybrids for all directions that are in demand on the market for this crop is being conducted at VNIIMK. The breeding process is based on fundamental agrobiological research. The genetic collection of this oil and ornamental crop collected and maintained at VNIIMK provides with the necessary sources and donors of economically valuable traits the breeding throughout the Russian Federation and several CIS countries. Further prospects for sunflower breeding in Russia and in the world will probably be focused on the development of competitive advantages of this crop in comparison with other agricultural plants in terms of profitable production of raw materials for the food industry, as well as for fodder, technical, and ornamental uses.

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ORCID ID

V.M. Lukomets orcid.org/0000-0001-9162-0317
M.V. Trunova orcid.org/0000-0002-0928-8202
Ya.N. Demurin orcid.org/0000-0003-3903-020X

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Modern issues of sugar beet (*Beta vulgaris* L.) hybrid breeding

S.D. Karakotov[1], I.V. Apasov[2], A.A. Nalbandyan[2] ✉, E.N. Vasilchenko[2], T.P. Fedulova[2]

[1] Shchelkovo Agrokhim Company, Shchelkovo, Moscow region, Russia
[2] The A.L. Mazlumov All-Russian Research Institute of Sugar Beet and Sugar, vil. VNIISS, Ramonsky district, Voronezh region, Russia
✉ arpnal@rambler.ru

Abstract. High efficiency of the cultivation of unfertilized sugar beet ovules and preparation of haploid regenerants (microclones) of pollinators – maintainers of O-type sterility and MS forms of the RMS 120 hybrid components has been shown. A technological method that accelerates the creation of new uniform starting material is proposed. It speeds up the breeding process two to threefold. The identification of haploid regenerants with sterile cytoplasm in initial populations is of great theoretical and practical importance for breeding, as it facilitates the production of homozygous lines with cytoplasmic male sterility and high-performance hybrids on sterile basis. As shown by molecular analysis, a single-nucleotide polymorphism never reported hitherto is present in the mitochondrial genome of the haploid plant regenerants. It allows identification of microclones as fertile and sterile forms. It has been found that DNA markers of the sugar beet mitochondrial genome belonging to the TR minisatellite family (TR1 and TR3) enable reliable enough identification of haploid microclonal plants as MS- or O-type forms. Fragments of 1000 bp in length have been detected in monogenic forms in the analysis of 11 sugar beet plants cultured *in vitro* by PCR with the OP-S4 random RAPD primer. Testing of the OP-S4 marker's being in the same linkage group as the genes responsible for expression of the economically valuable trait monogermity demonstrates its relative reliability. By the proposed method, dihaploid lines (DH) of the male-sterile form and the O-type sterility maintainer of the RMS 120 sugar beet hybrid have been obtained in *in vitro* culture. These lines are highly uniform in biomorphological traits, as proven under field conditions.
Key words: sugar beet; monogermity; cytoplasmic male sterility; homozygous haploid lines; PCR analysis.

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Современные аспекты селекции гибридов сахарной свеклы (*Beta vulgaris* L.)

С.Д. Каракотов[1], И.В. Апасов[2], А.А. Налбандян[2] ✉, Е.Н. Васильченко[2], Т.П. Федулова[2]

[1] Акционерное общество «Щелково Агрохим», г. Щелково, Московская область, Россия
[2] Всероссийский научно-исследовательский институт сахарной свеклы и сахара им. А.Л. Мазлумова, пос. ВНИИСС, Рамонский район, Воронежская область, Россия
✉ arpnal@rambler.ru

Аннотация. Показаны высокая эффективность культивирования неоплодотворенных семязачатков растений сахарной свеклы и получение гаплоидных регенерантов (микроклонов) опылителей – закрепителей стерильности О-типа и МС-форм компонентов гибрида сахарной свеклы РМС 120. Предлагается технологический метод, который способствует уменьшению времени создания нового выровненного исходного материала, что ведет к ускорению селекционного процесса. Идентификация гаплоидных регенерантов со стерильной цитоплазмой из исходных популяций имеет важное теоретическое и практическое значение для селекции, так как облегчает задачу создания гомозиготных линий с цитоплазматической мужской стерильностью и высокопродуктивных гибридов на стерильной основе. По результатам проведенного молекулярно-генетического анализа, в митохондриальном геноме гаплоидных растений-регенерантов обнаружен ранее не описанный в литературе однонуклеотидный полиморфизм, позволивший идентифицировать данные микроклоны как фертильные и стерильные формы. Установлено, что ДНК-маркеры митохондриального генома сахарной свеклы, относящиеся к семейству минисателлитов TR (TR1 и TR3), дают возможность с высокой эффективностью выявлять гаплоидные микроклональные растения МС- и О-типа. Установлена информативность маркера OP-S4 для определения раздельноплодных форм. При помощи метода культуры *in vitro* получены дигаплоидные линии (DH) мужско-стерильной формы и закрепителя стерильности О-типа гибрида сахарной свеклы РМС 120. Линии характеризуются высокой степенью выравненности по биоморфологическим признакам, что было подтверждено в полевых условиях.
Ключевые слова: сахарная свекла; односемянность; цитоплазматическая мужская стерильность; гомозиготные гаплоидные линии; ПЦР-анализ.

Introduction

Sugar beet (*Beta vulgaris* L.) is an important source of sucrose, and sugar is one of the essential ingredients in the human diet and a source of readily available energy for the body. The global demand for sugar is increasing at a rate of about 1 Mt (0.5 %) per year, while the population is growing about three times faster. The Russian Federation ranks first in the world in sugar beet planting hectarage (1 million ha), leaving behind such countries as the United States (490 thousand ha), Germany (350 thousand ha), and France (280 thousand ha) (www.fao.org). In recent years, however, approximately 98 percent of areas under sugar beet was planted in Russia with imported seeds of foreign breeding, which has a highly negative impact on the technological and economic sustainability of the whole sugar-beet industry in Russia.

The competitiveness of domestic hybrids depends on the feasibility of unleashing their inherent genetic potential. The use of modern biotechnological and molecular techniques in breeding practice accelerates twofold the development of genetically uniform material, which ensures a high uniformity of root morphology parameters (size, weight, height of head protrusion, depth of the fibrous root system, etc.), as well as sustainable implementation of major commercially valuable traits (monogermity, crop capacity, sugar content, abiotic and biotic stress tolerance during the growing stage, prolonged viability during storage, etc.) during the reproduction. The combination of biotechnology and conventional breeding methods permits one not only to increase the productivity of sugar beet hybrids, but also to improve the quality of seed material.

One of the major challenges in sugar beet industry is the need to breed monogerm hybrids on the basis of cytoplasmic male sterility (CMS). Spontaneously mutant monogerm plants that served as starting forms for developing monogerm beetroot varieties and components of hybrids were discovered more than 65 years ago (Kolomiyets, 1960; Popov, 1960). The phenotypic polymorphism of multi- and monogerm forms of sugar beet and its genetic control were investigated by many researchers; however, there is no general consensus on the inheritance and manifestation of this trait (Nagamine et al., 1989; Dubrovnaia et al., 2003; Hemayati et al., 2008).

The monogermity trait can be found in each and every *B. vulgaris* population. Presumably, choriflowered forms emerge in symflowered populations as a result of natural mutagenesis (Bordonos, 1966; Maletskiy et al., 1991). Earlier, researchers headed by V.F. Savitsky proved the monogenic pattern of inheritance for the M locus, controlling the phenotypic manifestation of multi- and monogermity (Savitsky, 1952). The recessive allele *m* (monogerm) is responsible for the monogermity trait, and the dominant allele *M* (multigerm), for multigermity. Monogerm (or choriflowered) genotypes are homozygous for the recessive allele *mm*. Multigerm (or symflowered) plants are either heterozygous (*Mm*) or homozygous for the dominant allele (*MM*). Deviations from the monogenic inheritance pattern are described in studies conducted by S.I. Maletskiy et al. (1991), who presumed a two-locus model of monogermity inheritance (*mmIi*). According to S.I. Maletskiy et al. (1991), M is a structural locus, and there is also a regulatory locus, named I (I for inhibitor). S.I. Maletskiy et al. define the dominant alleles of the regulatory locus, which inhibit the development of the symflowered SF (or multigerm) phenotype, as suppressors, or inhibitors, while the recessive alleles of this locus, which do not inhibit the development of the SF phenotype, as enhancers. According to this hypothesis, plants of the choriflowered (monogerm) phenotype should bear recessive alleles of the M locus and dominant alleles of I. More recent papers place the M locus to linkage group 2 on chromosome 4 on the genetic map of *B. vulgaris* (Schumacher et al., 1997; Amiri et al., 2011). Russian researchers have described a new recessive gene for monogermity, m^2. This gene is also mapped on linkage group 2 (Shavrukov, 2000).

Biotechnological methods for the development of double haploids (DH technologies) are currently implemented to obtain homozygous lines and increase the genetic diversity (Dunwell, 2010; Chen et al., 2011; Kikindonov et al., 2016). One of the major challenges in sugar beet breeding is the development of hybrids with the heterosis effect on sterile basis. To obtain these hybrids, monogerm male-sterile (MS) plants are used as a maternal component. Multigerm fertile pollinator plants are the paternal component. To achieve the constancy of the maternal component with regard to monogermity, MS-lines and maintainer lines that maintain the Owen-type (O-type) sterility are usually obtained by prolonged inbreeding during 5–10 generations, which results in inbreeding depression. To overcome this undesirable factor, the *in vitro* culture of unfertilized ovules is increasingly used in sugar beet breeding nowadays. This technique shortens the time required for producing homozygous genetically stable lines (DH lines, doubled haploids) with regard to such important breeding traits as monogermity, sterility/fertility, etc. The produced dihaploid DH lines require molecular testing of their monogermity, sterility/fertility, etc. at early development stages.

The objectives of this work are to develop appropriate technologies for producing *in vitro* sugar beet dihaploid lines and to perform their molecular examination and selection based on monogermity, sterility/fertility, etc.

Materials and methods

Experiments were conducted with parent components of sugar beet diploid hybrid RMS 120: MS-line and maintainer of O-type sterility RF8 (Ramonskaya fertile). The authors of this hybrid are V.P. Oshevnev, N.P. Gribanova, et al., and the originator is The A.L. Mazlumov All-Russian Research Institute of Sugar Beet and Sugar, hereafter referred to as VNIISS. The RMS 120 hybrid was enlisted to “State Register of Selection Achievements Authorized for Use for Production Purposes” in the Russian Federation in 2008 (https://reestr.gossortrf.ru).

PCR primers

Primer	Sequence (5′ → 3′)	T_m, °C	Reference
TR1	F: AGAACTTCGATAGGCGAGAGG R: GCAATTTTCAGGGCATGAACC	59	Nishizawa et al., 2000
TR3	F: AGATCCAAACAGAGGGACTG R: CGGATCACCCTATTCATTTG	56	
OP-S4	CACCCCCTTG	35	Amiri et al., 2011
nad1B	F2_ TTTCTCTTTATGGATAACCAATTCA R3_ AGGATTCCTTTTGTAACCCAAT	55	Soranzo et al., 2003

In our work with tissue culture, unfertilized ovules at the bud development stage were used as explants and 10 % chloramine B solution, as a sterilant. The exposure time was 60 minutes. Ovules isolated in sterile conditions under a microscope were placed into liquid culture medium. The differentiated explants were cultured on solid agar medium (agar 7 g/L) supplemented with auxins and cytokinins in different combinations (6-benzylaminopurine, kinetin, gibberellin, and naphthaleneacetic acid) (Butenko, 1999).

Liquid culture medium supplemented with 1.0 mg/L 6-benzylaminopurine was used for obtaining haploids. They were propagated on agar medium with the addition of gibberellin, 6-benzylaminopurine, and kinetin, 0.2 mg/L each. The haploid material was diploidized by adding 0.01 % colchicine to the culture medium and incubating explants for 36 hours. Rootage developed as microclones were cultured on the medium containing naphthaleneacetic acid (1 mg/L). The regenerants were incubated at 24–26 °C with the daylight time 16 hours, light intensity 5,000 lx, and 70 % relative humidity. The ploidy of samples was determined by flow cytometry (Partec, Germany) according to the recommended protocol (Cousin et al., 2009).

DNA was extracted from microclones produced via direct regeneration with kits for genomic DNA extraction (Sintol Company, Russia). The quality of DNA samples was tested by electrophoresis in 1 % agarose gel, and concentrations were measured with an HS QubitR Assay Kit (ThermoFisherScientific, USA). The PCR program was: (1) predenaturation at 94 °C for 5 min; (2) 30–33 cycles: denaturation at 94 °C for 30 s, annealing for 40 s, elongation at 72 °C for 60 s; (3) postextension at 72 °C for 3 min. PCR mixture: 1 × PCR buffer, 2.5 mM $MgCl_2$, 0.2 mM each dNTP, 1 unit of Taq DNA polymerase, 500 ng of DNA, and 0.5 μmol of primers (see Table).

The obtained amplification products were sequenced by the Sanger method on an ABI PRISM 310 Genetic Analyzer (Life Technologies, USA). The PCR amplification products were treated with ColGen kits (Sintol). The results of nucleotide sequence reads were analysed with Mafft software version 7 (Katoh et al., 2016).

Results and discussion

The study of the monogermity trait during the propagation of fertile pollinators-maintainers of O-type sterility demonstrated an increase in the percentage of descendants with complete (100 %) monogermity from 11 to 68.4 %, with more rigorous selection and rejection of multigerm plants (Oshevnev et al., 2018) (Fig. 1). Also, the mean value of this trait increased from 78.2 to 96 % with increasing the number of selection generations from G_1 to G_4.

The long-term field and laboratory studies conducted at VNIISS allowed developing a technology for producing sugar beet DH lines, which consists of a three-year cycle of biotechnological and breeding steps (Zhuzhzhalova et al., 2020) (Fig. 2). At early stages, regenerants are induced from unfertilized ovules. Plants are selected based on the

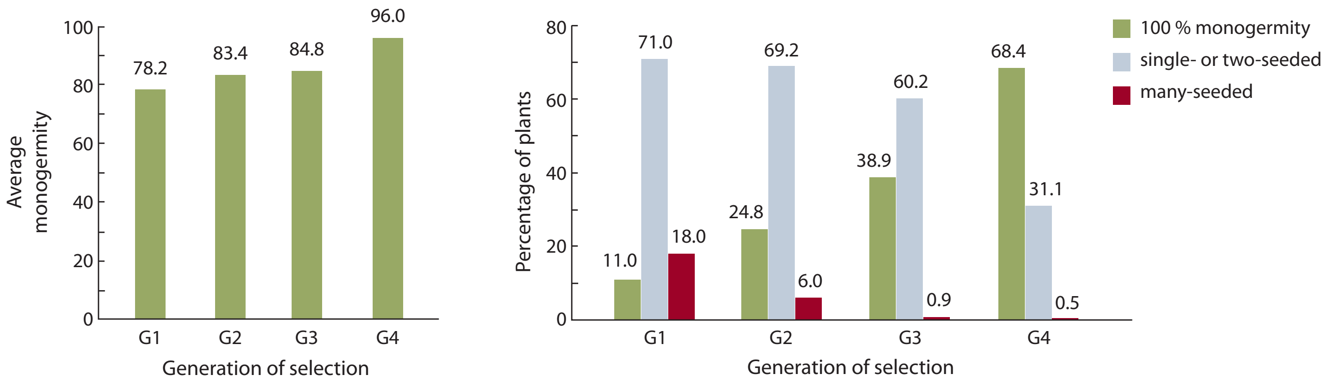

Fig. 1. Inheritance of the monogermity trait in the O-type pollinator (Oshevnev et al., 2018).

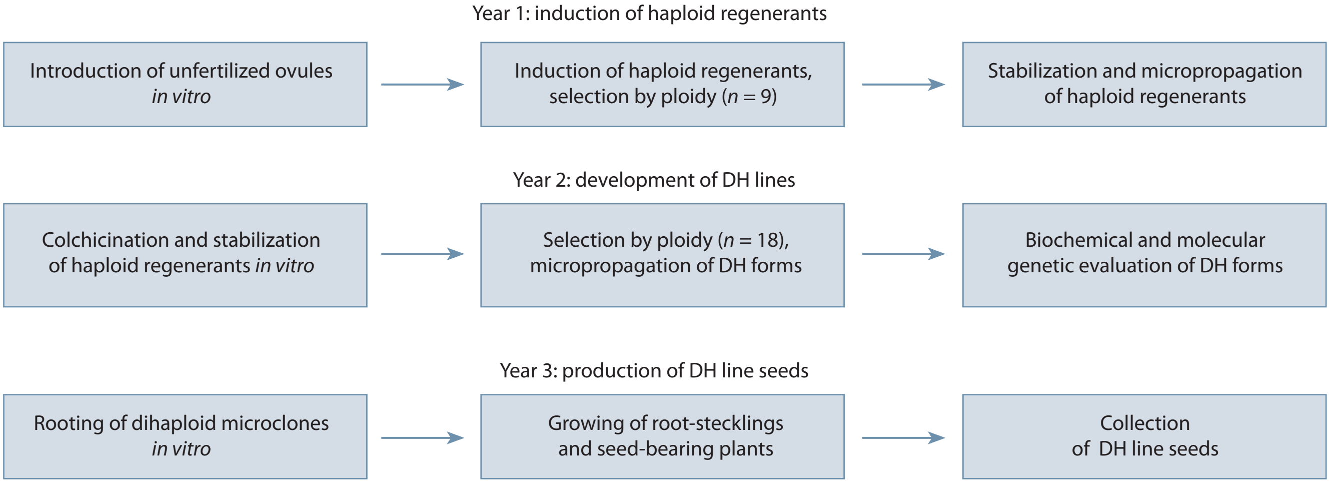

Fig. 2. Schematic representation of steps for producing dihaploid sugar beet lines.

mono- and multigermity traits and shrub mien (seed-rich multistemmed plants). Sprouts of the central ear of the pleiochasium cluster are generally used as donors of explants. Cytological studies allow selecting genotypes with a high degree of pollen grain fertility and sterility. The selected well-developed haploid regenerants are stabilized by *in vitro* micropropagation on agar medium.

The next step includes the diploidization of haploid material by colchicination, stabilization of colchicined regenerants, selection based on biochemical and molecular traits, and formation of *in vitro* DH lines.

At the final stages of the technology, dihaploid lines are rooted *in vitro*, steckling roots and seed-bearing plants are grown in a greenhouse, and seeds of DH lines are collected. The proposed technology produces genetically and morphologically uniform material two to three times faster, omitting the recurrent self-pollination of plants (see Fig. 2).

The selection of genotypes with valuable breeding traits is of great importance in producing homozygous sugar beet lines based on haploids. It is known that sugar beet populations contain plants with normal (N) and sterile (S) cytoplasm. The pollen of N plants is fertile and viable, whereas in S plants it can be either fertile or sterile depending on the interaction between the sterile (S) cytoplasm and recessive alleles (*rf1* and *rf2*) of the nuclear gene performing the fertility-restoring function. CMS is a result of a complex interaction of certain nuclear and mitochondrial genes (Matsuhira et al., 2012; Chen et al., 2014). This multilocus gene for fertility restoration (*Rf*), a suppressor of mitochondrial genes causing pollen sterility, is one of the best understood genetic factors involved in CMS manifestation (Arakawa et al., 2018).

There are also other important genetic factors insufficiently elucidated to date. One of them is the mitochondrial gene *nad1* (*BevupMp038*), which encodes subunit 1 of NADH-dehydrogenase in the NADH: ubiquinone oxidoreductase complex. The expression of this gene makes a significant contribution to the interaction between the nuclear and mitochondrial genomes. We employed markers for *nad1* to analyze sugar beet dihaploid regenerants, both fertile and sterile (Fig. 3).

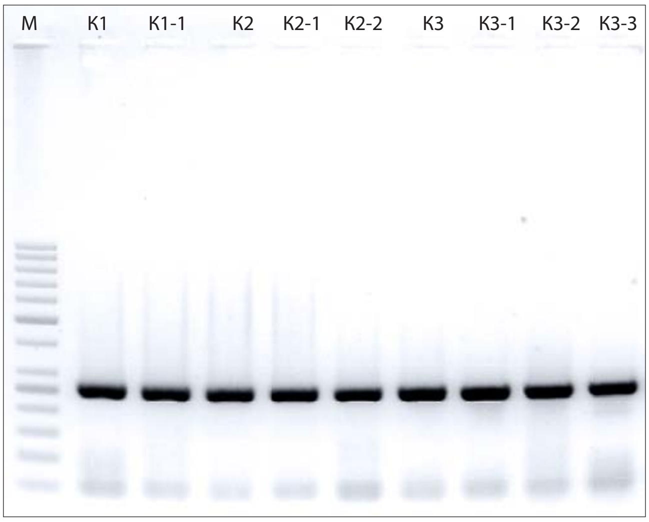

Fig. 3. Electrophoretic image of DH regenerant fragments with *nad1* gene markers.

K1 – control fertile plants; K3 – control sterile plants; K1-1, K2, K2-1, K2-2 – forms with normal (N) cytoplasm; K3-1, K3-2, K3-3 – forms with sterile (S) cytoplasm; M – molecular weight ladder (MassRuler™ DNA marker, 80–1,031 bp, ThermoScientific, USA). Band size: 400 bp.

The PCR analysis revealed a 400-bp DNA fragment in all samples. The amplificates were sequenced, and sequence alignment showed their identity except for one single-nucleotide polymorphism. It was shown that in all samples with fertile pollen, i. e. carriers of the nuclear gene dominant allele *Rf1*, nucleotide C was replaced by T, whereas all haploid sterile forms had only nucleotide C (Fig. 4).

The detected single-nucleotide substitution is presumed to be significant (non-synonymous), i. e., it can induce an amino acid substitution in the polypeptide, which seems

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CLUSTAL format alignment by MAFFT (v7,217)

ccK2          attcttatctgaattgcgagaataactgactaagccgtgcgtgccataagcggtcattct
ccK1-1        attcttatctgaattgcgagaataactgactaagccgtgcgtgccataagaggtcattct
ccK2-1        attcttatctgaattgcgagaataactgactaagccgtgcgtgccataagaggtcattct
ccK2-2        attcttatctgaattgcgagaataactgactaagccgtgcgtgccataagaggtcattct
ccK3-2        ------------attgcgagaataactgactaagccgtgcgtgccataagaggtcattct
ccK3-3        attcttatctgaattgcgagaataactgactaagccgtgcgtgccataagaggtcattct
ccK3          attcttatctgaattgcgagaataactgactaagccgtgcgtgccataagaggtcattct
ccK3-1        attcttatctg-attgcgagaataactgactaagccgtgcgtgccataagaggtcattct
ccK1          attcttatctg-attgcgagaataactgactaagccgtgcgtgccataagaggtcattct
                          ************************************************

ccK2          ccaaacgggacagggccaagcctttaggttgtttaagtaagttgggtgacagatcggcca
ccK1-1        ccaaacgggacagggccaagcctttaggttgtttaagtaagttgggtgacagatcggcca
ccK2-1        ccaaacgggacagggccaagcctttaggttgtttaagtaagttgggtgacagatcggcca
ccK2-2        ccaaacgggacagggccaagcctttaggttgtttaagtaagttgggtgacagatcggcca
ccK3-2        ccaaacgggacagggccaagccccttaggttgtttaagtaagttgggtgacagatcggcca
ccK3-3        ccaaacgggacagggccaagcccttaggttgtttaagtaagttgggtgacagatcggcca
ccK3          ccaaacgggacagggccaagcccttaggttgtttaagtaagttgggtgacagatcggcca
ccK3-1        ccaaacgggacagggccaagcccttaggttgtttaagtaagttgggtgacagatcggcca
ccK1          ccaaacgggacagggccaagcctttaggttgtttaagtaagttgggtgacagatcggcca
              ********************** *************************************
```

Fig. 4. SNP location in the *nad1* gene in regenerants.

ccK3, ccK3-1, ccK3-2, ccK3-3 – sterile forms; ccK1, ccK1-1, ccK2, ccK2-1, ccK2-2 – fertile forms.

to result in producing a functionally different protein. The presence of this SNP is likely to be related to differences in the CMS trait manifestation in sugar beet.

The genetic polymorphism of the *B. vulgaris* mitochondrial genome was investigated by using highly variable tandem repeats, or minisatellites. Four tandem repeat loci (TR1, TR2, TR3, and TR4) were found and described in earlier studies of the mitochondrial genomes of sugar beets (Nishizawa et al., 2000; Liu et al., 2017). The TR minisatellite family consists of 30 to 32-bp long sequences arranged in tandems of 2 to 13 in beet genotypes examined (Xia et al., 2020). It was shown that markers TR1 and TR3 are linked to genes controlling CMS (Nishizawa et al., 2000). This finding motivated us to analyze our regenerants with the aforementioned primers.

PCR analysis of DNA samples with the TR1 primer revealed 700-bp fragments in O-type haploid forms and 400-bp fragments in MS haploid forms. The sample No. 10 showed both bands (Fig. 5).

As both fragments are amplified in the genome of the sample No. 10, it is rather difficult to say with certainty whether it belongs to the MS- or O-type. Earlier, A.G. Bragin et al. (2012) showed that both N- and S*vulg*-specific markers can be found in all cytoplasms of plants with both the Owen plasmotype and the plasmotype ensuring the formation of fertile pollen. Their data strongly support the assumption of independent coexistence of mitochondrial genomes of N- and S*vulg*-types within mitochondria of plants of the same line.

PCR with the primer TR3 revealed 500-bp fragments in O-type haploid forms and 400-bp fragments in MS haploid forms. No DNA fragments were detected in the sample No. 9 (Fig. 6).

Minisatellites are widely used for evaluation of mitochondrial genome polymorphism. This fact may be responsible for the nonuniform patterns of samples No. 9 and 10 obtained by amplification with different TR family minisatellites.

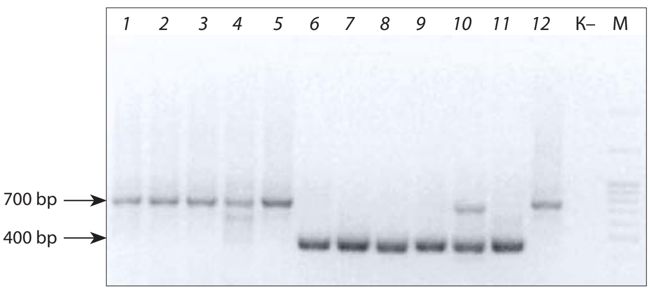

Fig. 5. Electrophoretic image of PCR products obtained with the TR1 primer.

Lanes: *1–5*, *12* – haploid regenerants of O-type pollinator; *6–9*, *11* – MS regenerants (haploids); *10* – haploid (mix). M – DNA molecular weight ladder GeneRuler™; 100–3,000 bp (ThermoScientific, USA). "K–" – negative control (sterile water without DNA). Band sizes: 700 and 400 bp.

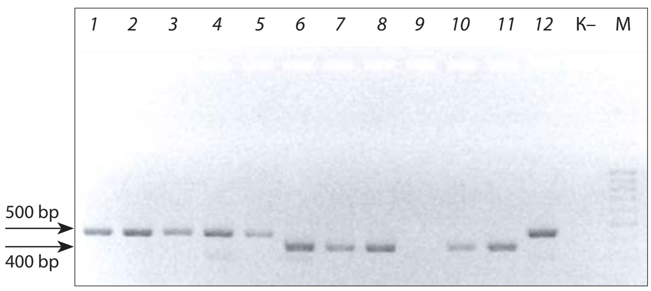

Fig. 6. Electrophoretic image of PCR products obtained with the TR3 marker.

Lanes: *1–5*, *12* – haploid regenerants of O-type pollinator; *6–9*, *11* – MS regenerants (haploids); *10* – haploid. M – DNA molecular weight ladder GeneRuler™, 100–3,000 bp (ThermoScientific, USA). "K" – negative control (sterile water without DNA). Band sizes: 500 and 400 bp.

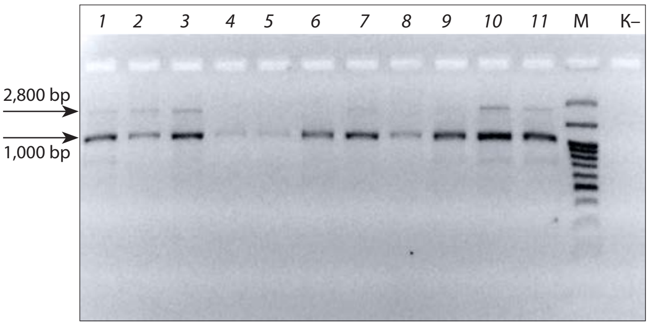

Fig. 7. Electrophoretic resolution of PCR products obtained with the OP-S4 primer.

Lanes: *1–3* – O-type; *4*, *5* – HP (heterosis pollinator); *6–11* – MS. M – DNA molecular weight ladder GeneRuler™, 100–3,000 bp (ThermoScientific, USA). "K–" – negative control (sterile water without DNA). Band sizes: 1,000 and 2,800 bp.

The results of molecular testing suggest that these primers allow early discrimination of haploid regenerants of O- and MS-types, which is of theoretical and practical significance for breeding. Exceptions are the samples No. 10 (two fragments when amplified with TR1) and No. 9 (no amplification product with TR3).

As mentioned above, the crucial breeding trait of sugar beet is monogermity, regulated by the recessive allele of the *M-m* gene. As with mitochondrial genes, the genes (loci) that control the monogermity trait have not been mapped precisely (Shavrukov, 2000). However, a locus linked to this trait in F_1 and F_2 populations has been identified. Scientists outside Russia tested 297 single-stranded decamer RAPD primers with an F_2 population of monogerm and multigerm sugar beet hybrids. The nearest genetic marker (closer than 50 cM) linked to the monogermity gene was OP-S4 (Amiri et al., 2011).

In our PCR experiments, 11 samples of sugar beet obtained *in vitro* with the OP-S4 primer produced 1000-bp fragments. A second fragment of about 2,800 bp was seen in some samples (No. 1, 2, 3, 10, and 11). DNA fragments from genotypes No. 4 and 5, which are multigerm according to the data from breeders (V.P. Oshevnev, N.P. Gribanova), were barely seen (Fig. 7).

The results obtained in testing primer OP-S4, belonging to the same linkage group as the gene for monogermity, do not presume reliable ranking of samples according to the monogermity trait at the stage of haploid microclones. This may be related to the low specificity and high sensitivity to conditions of the reaction, characteristic of RAPD primers. The identification of homozygous monogerm genotypes requires a more comprehensive analysis with a larger number of sugar beet plant samples and molecular markers with higher specificity.

Conclusions

In this study, an approach to the accelerated development of doubled lines (homozygotes) as components of highly productive hybrids was designed. Seeds were obtained from four *B. vulgaris* DH lines and used for the propagation of highest quality seeds of the male-sterile form of the RMS 120 hybrid component. Molecular analysis detected an SNP in the genomes of the haploid regenerants, and this SNP allowed the discrimination of fertile and sterile forms. It is shown that mitochondrial minisatellite markers TR1 and TR3 enable classification of haploid regenerants as MS- or O-type forms. Analysis of 11 monogerm and multigerm plants obtained *in vitro* by PCR with the RAPD primer OP-S4 revealed 1000-bp long fragments in monogerm regenerants.

By combining biotechnological and molecular methods with traditional breeding techniques, new breeding material can be produced to develop indigenous new-generation sugar beet hybrids.

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ORCID ID

A.A. Nalbandyan orcid.org/0000-0001-5959-047X

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Fundamentals for forage crop breeding and seed production in Russia

V.M. Kosolapov, V.I. Cherniavskih ✉, S.I. Kostenko

Federal Williams Research Center of Forage Production and Agroecology, Lobnya, Moscow region, Russia
✉ cherniavskih@mail.ru

Abstract. Plant breeding and seed production of new generation fodder crops is the groundwork for creating a fodder base for livestock production in sufficient quantities. The Federal Williams Research Center of Forage Production and Agroecology founded in 2018 based on of the All-Russia Williams Fodder Research Institute and other scientific institutions is the largest and most comprehensive center in the field of food production. It develops new techniques and methods for creating initial seed material based on a wide use of genetics, biotechnology, microbiology, immunology, ecology, biogeocenology, and cell selection. During the existence of the Fodder Research Institute and its experimental stations, up to 300 varieties of feed crops were created, which occupied leading positions in the production of fodder in meadows, pastures, and hayfields. Eighty-five modern varieties of fodder crops of the latest generation are widely used and zoned in all regions of Russia. However, the destroyed system of elite and commercial seed production does not allow these varieties to take their rightful place in fodder production, and the market still possesses a large share of non-varietal and mass scale reproduction seeds. In addition, imported seeds brought to the Russian market are often disguised as lawn varieties to reduce the cost and simplify their entry to the market. In this way, 107 varieties of winter ryegrass (*Lolium perenne* L.), 47 varieties of cane fescue (*Festuca arundinacea* Schreb.), 21 varieties of creeping clover (*Trifolium repens* L.), etc. appeared in Russia. In such circumstances, the attention of the Williams Center is focused on the development of techniques and methods for creating fundamentally new varieties based on its own research in genetics, biotechnology, immunology, and ecological selection. Much attention is paid to expanding the network of research stations throughout Russia in order to revive the system of elite seed growing, especially in the regions with the most favorable climate for growing seeds of particular crops. A seed production center was organized as a branch of the Williams Center at the end of 2020. In the future, it is planned to create a united coordinated interdepartmental complex for the breeding of fodder crops in accordance with the regional needs of animal husbandry.

Key words: fodder crops; plant genetic resources; source material for breeding; molecular certificate; DNA markers.

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Развитие современной селекции и семеноводства кормовых культур в России

В.М. Косолапов, В.И. Чернявских ✉, С.И. Костенко

Федеральный научный центр кормопроизводства и агроэкологии им. В.Р. Вильямса, г. Лобня, Московская область, Россия
✉ cherniavskih@mail.ru

Аннотация. Селекция и семеноводство кормовых культур являются фундаментом создания кормовой базы для производства животноводческой продукции высокого качества и в требуемом количестве. Федеральный научный центр кормопроизводства и агроэкологии им. В.Р. Вильямса (ФНЦ «ВИК им. В.Р. Вильямса»), созданный в 2018 г. на базе Всероссийского НИИ кормов им. В.Р. Вильямса и ряда других научных учреждений, – наиболее крупный центр в области кормопроизводства – разрабатывает новые приемы и методы создания селекционного материала на основе широкого применения генетики, биотехнологии, микробиологии, иммунологии, экологии, биогеоценологии, клеточной селекции. Было выведено около 300 сортов кормовых культур, которые занимали в СССР и занимают в Российской Федерации основные площади под этими культурами на лугах, пастбищах и сенокосах. Современные 85 сортов кормовых культур нового поколения нашли широкое применение и районированы во всех регионах России. Но разрушенная в стране система элитного и товарного семеноводства не позволяет этим сортам быть на положенном им месте в производстве кормов, так как на рынке еще велика доля несортовых семян и семян массовых репродукций. К тому же началась экспансия

импортных сортов, замаскированных под сорта газонных трав для удешевления и упрощения выхода их на российский рынок. Таким образом на наш рынок попали 107 сортов райграса пастбищного (*Lolium perenne* L.), 47 сортов овсяницы тростниковой (*Festuca arundinacea* Schreb.), 21 сорт клевера ползучего (*Trifolium repens* L.) и т. д. Основное внимание ФНЦ «ВИК им. В.Р. Вильямса» направлено на создание приемов и методов получения принципиально новых сортов на базе собственных разработок в области генетики, биотехнологии, иммунологии и экологической селекции. Расширяется сеть опорных пунктов по всей территории страны, воссоздается система элитного семеноводства с учетом использования регионов с наиболее благоприятным климатом для семеноводства отдельных культур. В конце 2020 г. на базе ФНЦ «ВИК им. В.Р. Вильямса» создан селекционно-семеноводческий центр. В дальнейшем планируется сформировать единый межведомственный комплекс по селекции кормовых культур, работающий по скоординированной программе согласно региональным потребностям животноводства.
Ключевые слова: кормовые культуры; генетические ресурсы растений; исходный материал для селекции; молекулярно-генетический паспорт; ДНК-маркеры.

Introduction

Fodder crop breeding and seed industry regain their paramount significance. Animal husbandry cannot be developed without well-handled fodder supply. In addition to the main function of fodder crops, which is the production of bulk feed for animals, they play other roles, no less important and sometimes outstanding: the formation of stable ecosystemic agrarian landscapes, improvement of performance and phytosanitary state of cultivated lands, soil protection from erosion by water and wind, and aesthetic function, as they form the basis for favorable living environment in cities.

Genetic resources of plants attract the attention of scientists throughout the world. They raise not only biological but also political challenges, being involved in the competition not only in the academic community but also among multinational food-producing corporations (Genetic Resources…, 2016). Breeding programs for fodder plants rest on the gene pool as the main source of commercially significant traits. The role of the initial material and the geographic distribution of plant genes is the basic tenet in breeding science (Vavilov, 1987).

The diversity of forage plant species, varieties, and ecotypes, including natural populations, permits breeders to involve diverse breeding material and raise cultivars for various purposes. Much attention is paid to the involvement of forage plant resources. In annual expeditions collecting forage plants, the gene pool department of the Federal Williams Research Center of Forage Production and Agroecology (hereafter the Williams Center) has assembled a collection of more than 7,000 accessions for long-term storage. Genetic resources of wild forage plants have been collected and examined in many regions of Russia: the Kirov oblast, Udmurtia, Tatarstan, Karelia, Altai, the Ryazan oblast, lower reaches of the Don River, and along the Oka River floodplain. The expedition route lengths in recent years have totaled over 20,000 km (Trofimova et al., 2019).

In addition to the mobilization, collection, and use of genotypes from natural vegetation, new materials for breeding are being produced by using mutagenesis, somaclonal variants, polyploidy, hybridization, and synthetic hybrid populations. Biotechnological methods for clonal micropropagation and somatic hybridization are in broad use. Cell selection is applied to breeding for fungus resistance and tolerance of some adverse environmental factors. The breeding material is tested against artificial infectious backgrounds and under laboratory conditions. Work on genetic markers is being conducted, and it brought about the Soleustoichivaya salt-tolerant alfalfa variety and a series of new-generation red clover (*Trifolium pratense* L.) varieties (Kosolapov et al., 2019).

The main direction in the modern fodder breeding strategy is targeting. It implies the necessity of a system involving a diversity of varieties whose climatic and ecological differentiation would make them fit for specific conditions of each region.

Ecological and geographical approach to the creation of new varieties of forage crops

The combined biogeocenotical approach is implemented via phytocenotic selection, based on the doctrine of competitive and neutral interactions among plants; edaphic selection, based on the response of plants to the physicochemical and biochemical features of the edaphic environment; and symbiotic selection, based on mutually beneficial interaction of plants with nitrogen-fixing microbes (Shamsutdinov, 2010).

By now, over 740 fodder plant varieties have been raised in Russia, of which over 240 – at the Williams Center. Eighty-five new generation varieties have become the most widespread (Kosolapov et al., 2019).

A significant part in fodder production and raise of high-performance agrophytocenoses is assigned to **clover**. Breeders of the Williams Center have raised over 20 red clover (*T. pratense* L.) varieties: Mars, VIK 7, Tetra VIK, VIK 84, Rannii 2, Trio, Dedinovskii 5, Zarya, VIK 77, Topaz, TOS 870, Orlik, Stodolich, Ratibor, Altyn, Dobrynya, Meteor, Mariya, Pamyati Lisitsina, Pamyati Burlakii, etc. They form the required set of zoned varieties for all Russian regions. A series of alsike clover (*Trifolium hybridum* L.) varieties have been raised (Kosolapov et al., 2019). This species is important in regions with poor heat supply and acidic waterlogged soils. The varieties Marusinskii 488, Pervenets, and Mayak may be of great importance on peaty soils of northern Russia.

With the intense development of organic agriculture and high-quality farming products, meadow forage production with the series of varieties including Smena, VIK 70, Lugovik, etc., swards can be formed in all zones of Russia where it is practicable.

Alfalfa (*Medicago* L.) is an important fodder crop forming the base of high fodder production and high-tech animal husbandry in the world (Chernyavskikh et al., 2012). The most urgent task is its expansion to the north, to the vast Nonchernozem Belt, and other regions with a short growing season (Urals and Siberia), acidic soils, and the flushing soil regime. Varieties sustaining on pastures and salinized soils are demanded.

Fundamentally new breeding approaches and methods brought about many unique varieties: Lada, Pastbishchnaya 88, Lugovaya 67, Selena, Soleustoichivaya, Sonata, Nadezhda, Nakhodka, Galiya, and Vega 87, the last variety being the most widespread in Russia. A new cultivar of subspecies *varia*, Agniya, shows a high level of symbiotrophism, which allows accumulation of 270–300 kg of fixed nitrogen per hectare.

Fodder grasses are the base for fodder phytocenoses on waterlogged, acidic, and cold soils as well as under the conditions of erosion by water on slopes and by wind on light soils.

With the grass collection of the Williams Center, cultivars for all regions of Russia can be raised. Scientists of the Williams Center have bred varieties of timothy (*Phleum pratense*) (VIK 9, VIK 85, and VIK 911), winter ryegrass (*Lolium perenne* L.) (VIK 66, Duet, Tsna, and others), tall fescue (*Festuca arundinacea* Schreb.) (Lira), festulolium (×*Festulolium* F. Aschers. et Graebn.) (VIK 90, Fest, and Alegro); meadow fescue (*Festuca pratensis* Huds.) (VIK 5, Kvarta, Binara, Dedinovskaya 8, Krasnopoimskaya 92, and others), Kentucky bluegrass (*Poa pratensis* L.) (Tambovets, Pobeda, and Dar), Hungarian brome (*Bromopsis inermis* (Leyss.) Holub) (Morshanskii 760, Fakel'nyi, Voronezhskii 17, Pavlovskii 22/05, and others), cock's foot (*Dactylis glomerata* L.) (VIK 61 and Dedinovskaya 4), crested wheatgrass (*Agropyron pectinatum* (M. Bieb.) P. Beauv.) (Pavlovskii 12), red fescue (*Festuca rubra* L.), Regel's tall fescue (*Festuca regeliana* Pavlov), black bent (*Agrostisgigantea* Roth), etc. (State Register…, 2021). The breeding process at the Williams Center involves the creation of varietal–microbial consortia, improvement of the ability of varieties to fix atmospheric nitrogen, and improvement of the phosphorus-mobilizing potential. The Williams Center works intensively on the breeding of lupine (over 20 varieties), vetch, and cruciferous vegetables.

Accessions are being tested for resistance to major pests. Data for the database for long-term phytosanitary monitoring of major fodder crop diseases have been obtained. New fungal pathogen isolates have been isolated from the root microbiota of red clover (*T. pratense* L.), grasses, and vetch (*Vicia* L.) The breeding and growing of varieties resistant to adverse biotic and abiotic environmental factors contributes much to the control of the phytosanitary state of farming ecosystems.

The breeding of **arid crops** holds a special place in the Williams Center. It is of prime importance with regard to the current climatic changes, the expansion of arid, blown, and salt-affected arable lands, and desertization. A prominent scholar school on arid crop breeding exists at the Williams Center. New varieties of *Haloxylon aphyllum* (Minkw.) Iljin, *Kochia prostrata* (L.) Schrad., *Salsola orientalis* S.G. Gmel., *Salsola subaphylla* C.A. Mey, *Camphorosma lessingii* Litv., *Poa bulbosa* L., *Elymus racemosus* Lam., and others are targeted at the formation of year-round pastures. The scientific substantiation of the environment-forming role of halophytic plants in vegetative reclamation, physical loosening of the soil pan and improvement of salinized soil drainage conditions by plant roots, organic matter accumulation for the nutrition of microbes in aridic and salinized plant ecosystems, salt lowering in the root layer of halophytes, etc. have been developed.

Main directions and ways of development breeding of forage crops in Russia

Another important line of inquiry is the development of a DNA marker-based system for molecular tagging aimed at the genetic identification and certification of fodder crop varieties (Chesnokov et al., 2019).

The Laboratory of Molecular Studies of Fodder Crops was founded in the Williams Center in 2019. Its primary task is the development of molecular tagging systems for cultivar certification, DNA tagging of traits essential for breeding, and study of the genetic variability of wild and cultivated fodder plant species (Klimenko et al., 2020). The results indicate that the identification of cultivars by DNA markers improves the protection of patents as intellectual property items and shortens the time for the development of high-performance fodder crop varieties resistant to adverse environmental factors. A molecular certificate form for crops based on SSR markers has been designed (Fig. 1). Comparison of a sample with a standard DNA certificate will help in genetic identification, testing varietal purity, and testing the compliance of seed material with the variety certificate.

For successful breeding of fodder crops, special attention should be paid to the activity of existing breeding units, the restoration of closed ones, and the creation of new ones in various regions of Russia. This notion is no novelty, but its effectiveness in ecological tests of new forms has been proven. All that is left is to remember our recent past. It is increasingly important with regard to the ongoing rapid global climatic changes (Chernyavskikh et al., 2012). The formation of the field station network should be continued. Fundamentals for the geographic distribution of crops have been developed (Fig. 2).

The distribution of these field stations correlates with regions of the most favorable location of fodder crop seed industry and the greatest seed yields (Fig. 3). It is a com-

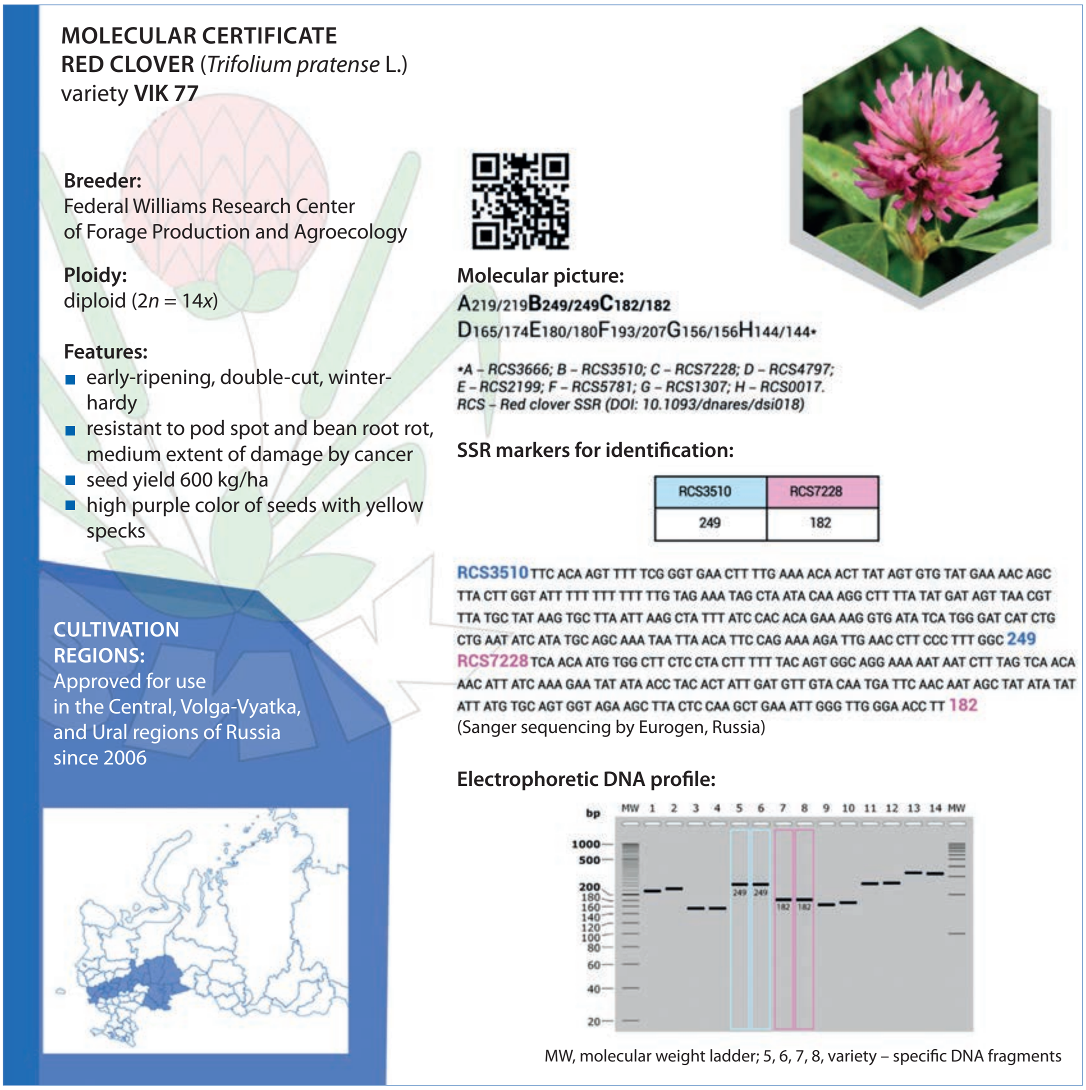

Fig. 1. An exemplary molecular certificate: red clover (*T. pratense* L.) variety VIK 77.

plicated piece of work, but the activity of the creative association of breeders (CAB) "Clover" has been a good practice. The collaboration of its members produced 12 new-generation winter-hardy high-performance varieties of red clover (*T. pratense* L.):

1. Trio (Williams Center + Federal Agrarian Research Center for the Far Northeast);
2. Meteor (Siberian Federal Research Center of Agrobiotechnologies + Williams Center);
3. TOS 870 (Buryatian State Agricultural Academy + Williams Center);
4. Ratibor (Federal Agrarian Research Center for the Far Northeast + Williams Center);
5. Orlik (Federal Scientific Center of Legumes and Groat Crops + Williams Center);
6. Altyn (Williams Center + Morshansk Breeding Station);
7. Mariya (Buryatian State Agricultural Academy + Williams Center);
8. Pamyati Lisitsyna (Federal Scientific Center of Legumes and Groat Crops + Siberian Federal Research Center of Agrobiotechnologies + Williams Center);
9. SOZh (Buryatian State Agricultural Academy + Williams Center);
10. VIK 84 (Williams Center + Moscow Breeding Station + Nemchinovka Federal Research Center);
11. Dobrynya (Williams Center + Nemchinovka Federal Research Center);
12. Prima (Siberian Federal Research Center of Agrobiotechnologies + Williams Center).

Five more red clover varieties are under official tests in Russia and Belarus (Ecological Selection…, 2012).

Seed production of forage crops: state of the art and prospects

Deeper insight into the current state and potential of fodder crop breeding and seed industry shows that seed farming is in the most trouble. The state of breeding in Russia is satis-

Fig. 2. Regions most promising for the creation of field stations for fodder crop breeding.

Fig. 3. The best regions for growing various fodder crops.

factory: many varieties have been developed, and some of them are outstanding, but primary and elite seed production are rated low. Unfortunately, the cooperation between fodder crop breeding and seed industry presents a lingering problem in Russia. The remark made by N.I. Vavilov at the All-Russia Conference on Fodder Plant Breeding and Seed Industry still sounds relevant: "We should combine our research with production, not only without descending from theoretical heights but raising them even higher. We should manage the work of all our facilities, including botanical nurseries, so as to arrange a pipeline towards production, reproduction, and seed industry." (Vavilov, 1935, p. 3).

The major issues are poor funding, obsolete machines, aging staff, uncertainty of intellectual property, etc. With the breakup of the Soviet Union, the interactions in the breeding and seed industry of fodder crops, in particular, perennial plants, based on the clear mediation system of breeding research enterprises, elite seed farms (group one seed farms), and farms producing seeds for reproduction (group two farms) were disrupted. The fancied market system, based on the economic concern of all participants, did not come into being. No prerequisites for the development of an efficient interaction system between breeding and seed production have emerged within the elapsed 30 years.

The succession breeding–primary seed production–commercial seed production–commercial farming experiences stagnation, most pronounced in the first two links. The cause is apparent: chronic underfunding because of no rapid remuneration. It is aggravated by the economic pressure of multinational companies, which are key stakeholders in the world seed and food market. For instance, 107 varieties of winter ryegrass (*L. perenne* L.), 47 varieties of cane fescue (*F. arundinacea* Schreb.), and 21 varieties of creeping clover (*T. repens* L.) were enlisted into "The State Register of Selection Achievements Authorized for Use for Production Purposes" (2021) as lawn grasses to make it simpler and cheaper to push them to the market. In this way, they came to the Russian market through a hole in Russian regulations to be sold as fodder crops. In most cases, such swards survived till the nearest winter. This situation not only jeopardizes the breeding research institutions and education of students and postgraduates. The very Russia and Russian nation are menaced (Kosolapov et al., 2012). The premise "we will buy everything" does not work. We will not. Fodder scientists and breeders are aware of the menace. Producers in major agrarian enterprises are also coming to this awareness.

With the groundwork in hand, we can rehabilitate the production of elite fodder crop seeds by collaboration of research institutions belonging to various departments and commercial enterprises, raise sets of appropriate varieties for most regions of Russia, and provide enough high-quality seeds to animal farming industry (Fig. 4).

Breeding science and primary seed production demand funding. Transparent interaction among governmental institutions, breeding institutes, private seed-producing enterprises, and agricultural commodity producers is essential.

Conclusion

While having a potent academic base, fodder breeding and seed industry in Russia need support from federal and regional authorities, large holding groups, and large farms. This is true for breeding all crops, this is our future, which we can make present in a short while.

We have a stepping stone to solving the tasks posed by fodder crop breeding and seed industry. Academic schools of experts in breeding alfalfa, clover, vetch, grasses, and arid crops exist and continue their development. They prime groups of followers, carry basic works on donor identification, and fill pre-breeding collections. A method for identification and certification of fodder crop varieties has been developed in order to test the varietal purity and conformity to varietal standards and to improve seed production efficiency. However, issues related to the system of elite seed production are still to be resolved, and they should be in the focus of science, production, and business.

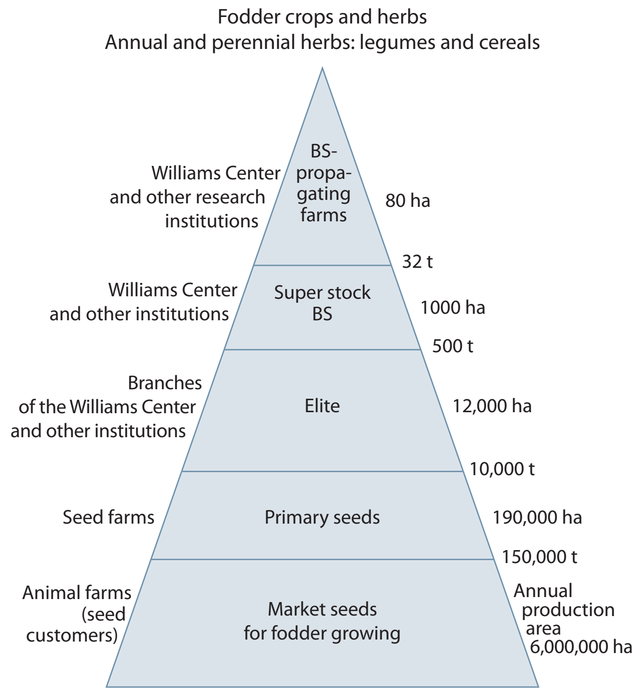

Fig. 4. Structure of fodder crop production.
BS – breeder seed.

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ORCID ID

V.M. Kosolapov orcid.org/0000-0002-3480-3464
V.I. Cherniavskih orcid.org/0000-0003-0014-4322
S.I. Kostenko orcid.org/0000-0001-9534-0603

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Grape breeding is a key link in the development of the grapes and wine-making industry

E.A. Egorov

North Caucasian Federal Scientific Center of Horticulture, Viticulture, Wine-Making, Krasnodar, Russia
kubansad@kubannet.ru

Abstract. The article considers the legislative and regulatory acts that specify the tasks in the implementation of breeding processes. The results of the creation, variety testing, patenting and introduction of grape varieties and clones into the State Register of the Russian Federation for 2010–2020 are presented. The article analyzes the relationship between the indicators of industrial development with the production volumes of planting material, the use of domestic varieties that are included in the State Register of the Russian Federation. The characteristic of ampelographic collections – the genetic resources of grapes – is given. A comparative analysis of many years' worth of data on the assessment of the adaptive potential of domestic varieties and introduced varieties is presented. The article describes domestic varieties, from which premium wines are produced, which not only competes with European varieties, but also surpasses the organoleptic properties and biochemical parameters of grape must and wine material. The main problems hindering the wide demand for domestic varieties on the market, including a substantial amount of imported European varietal planting material, are described. The necessity of accelerating breeding processes is actualized, modern methods are identified, including those of generative and genomic selection, transgenic technologies, cellular, mutational, and clone selection, and priority areas in breeding are presented. The numerical and qualitative analyses of the composition of breeding scientists is given, the trends of increasing the number and qualitative composition of breeders, the influx of young people, the growing need for training qualified personnel are noted. The number of bachelor's, master's and post-graduate students specializing in viticulture in general and in selection in particular as well as the number of defended dissertation studies on grape breeding has been found to be insufficient. The main scientific and practical problems in the organization and implementation of breeding processes in ensuring the development of the industry are updated, including a low share of domestic varieties in the produced planting material and planting, the lack of a systemically implemented varietal and technological policy, the imperfection of the legal system for the protection of intellectual property, a low availability of instrumentation and analytical equipment for the implementation of breeding by modern methods.

Key words: grapes; breeding; genetic resources; methods; varieties; breeding achievements; seedlings; introduction; scientific and practical problems.

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Селекция винограда – ключевое звено в развитии винограло-винодельческой отрасли

Е.А. Егоров

Северо-Кавказский федеральный научный центр садоводства, виноградарства, виноделия, Краснодар, Россия
kubansad@kubannet.ru

Аннотация. Рассмотрены законодательные и нормативные акты, конкретизирующие задачи в осуществлении селекционных процессов. Представлены результаты создания, сортоиспытания, патентования и введения в Государственный реестр Российской Федерации сортов и клонов винограда за период 2010–2020 гг. Проанализирована взаимосвязь показателей отраслевого развития с объемами производства посадочного материала, использованием сортов отечественной селекции, составляющих предмет Государственного реестра РФ. Приведены характеристика ампелографических коллекций – генетических ресурсов винограда, и сопоставимый анализ многолетних данных по оценке адаптивного потенциала сортов отечественной селекции и сортов-интродуцентов. Охарактеризованы сорта отечественной селекции, из которых производятся вина класса премиум; они не только составляют конкуренцию сортам европейской селекции, но и превосходят их по органолептическим свойствам и биохимическим показателям виноградного сусла и виноматериала. Обозначены основные проблемы, сдерживающие широкую востребованность рынком сортов винограда отечественной селекции, к числу которых следует отнести значительный объем импорта европейского сортового посадочного материала. Под-

черкнута необходимость ускорения селекционных процессов, обозначены современные методы, в том числе генеративная и геномная селекция, трансгенные технологии, клеточная, мутационная, клоновая селекция. Представлены приоритетные направления в селекции. Приводятся и анализируются сведения о количественном и качественном составе ученых-селекционеров, отмечены тенденции увеличения их численности и качественного состава, притока молодежи, растущей потребности в подготовке квалифицированных кадров. Актуализированы основные научно-практические проблемы в организации и осуществлении селекционных процессов в обеспечение развития отрасли, среди которых низкая доля сортов отечественной селекции в производимом посадочном материале и закладке насаждений, отсутствие системно реализуемой сортовой и технологической политики, несовершенство правовой системы по охране интеллектуальной собственности, низкая обеспеченность приборно-аналитическим оснащением для осуществления селекционных процессов современными методами.
Ключевые слова: виноград; селекция; генетические ресурсы; методы; сорта; селекционные достижения; саженцы; интродукция; научно-практические проблемы.

Introduction

The development of the grapes and wine-making industry is one of the priorities in the modern agricultural policy of the Russian Federation and is intended to increase not only the volume of production of high-quality products and equivalent import substitution, but also its own resource and technological support. One of the Subprograms prepared for approval of the Federal Scientific and Technical Program for Development of Agriculture for 2017–2025, approved by the Decree of the Government of the Russian Federation No. 996 of August 25, 2017, is the "Development of Viticulture, Including Nursery Farming".

In its goal setting, the Subprogram focuses on ensuring the growth of viticulture production volumes based on improving the assortment of grapes (primarily varieties and clones of domestic breeding), using domestic virus-free certified planting material. Complex research programs and complex scientific and technical projects, which are elements of the Subprogram, specify the volume of breeding work carried out by scientific and educational institutions, based on the needs of the industry for its further development (Egorov et al., 2020).

Federal Law No. 468-FZ "On Viticulture and Winemaking in the Russian Federation" was passed in December 2019 and was enacted in July 2020. The Law is a legislative act harmonized with similar European laws, the basis for legal, organizational, technological and economic regulation in the field of efficient production, turnover and consumption of grape growing and wine-making products. The Federal Law also directs the grapes and wine-making branch to determine the issues of import substitution, including the breeding of domestic varieties and clones, the production of planting material of the highest quality categories, and the laying of plantings mainly with planting material of domestic production.

The passed legislation and regulations, which specify the most urgent tasks of industry development, orient the breeding processes to the accelerated creation of varieties, the selection of clones of varieties (variety improvement) on the basis of modern methods in order to bring their quality characteristics into compliance with the requirements of production, technical regulations, international and national standards.

Results and discussion

The comprehensive research program of the Subprogram provides for the creation of 12 grape varieties and clones for the period 2020–2025: North Caucasian Federal Scientific Center of Horticulture, Viticulture, Wine-Making (NCFSCHVW)* – 6, All-Russian National Scientific Research Institute of Vine and Winemaking "Magarach" RAS (ARNSRIVW "Magarach") – 3, All-Russian Scientific Research Ya.I. Potapenko Institute for Viticulture and Winemaking – Branch of the Federal Rostov Agricultural Research Centre (ARSRIVW – Branch of FRARC) – 3. A complex scientific and technical project provides for the creation of 6 varieties and clones of grapes during the same period, according to the available applications of economic entities.

Until the present, the work on the breeding of grapes in the region has been carried out by scientific and educational organizations within the framework of the North Caucasian Center's Program for the Breeding of Fruit, Berry, Nut-fruited, Ornamental Crops and Grapes for the period up to 2030, passed by the coordination meeting on August 27, 2013. In order to ensure coordinated actions in the implementation of the Program, a Scientific Coordinating Council, which is the coordinating body, was established. It is formed from the leading scientists-breeders of scientific and educational institutions that are part of the area of activity of the North Caucasian Center for Breeding.

The corporate Program passed in 2013 provided for the creation of 35 grape varieties for the period up to 2030. Scientific institutions in the South of Russia created and submitted to the State Variety Testing a significant number of varieties that were entered into the State Register of the Russian Federation during 2010–2020 (see the Table).

The performed breeding processes for the creation of new varieties and variety improvement (selection of clones) should ensure the progressive development of the industry as a whole and the production of young plants from improved source plants with varietal identification at the gene level.

Due to natural and climatic features, grape growing is concentrated in the subjects of the Southern and North Caucasus Federal District (97.5 %): 27.5 thousand hectares or 28.7 % of the area of grape plantations of the Russian Federation are in the Krasnodar Region; 25.9 thousand hectares or 27.0 % – in the Republic of Dagestan; 25.7 thousand hectares or 26.8 % – in the Republic of Crimea and Sevastopol; 5.9 thousand hectares or 6.2 % – in the Stavropol Territory;

* The structural composition of the NCFSCHVW includes the branches of the Anapa Zonal Experimental Station of Viticulture and Winemaking (AZESVW) and the Dagestan Selection Testing Station of Viticulture and Horticulture (DSTSVH).

Creation of grape varieties and clones by scientific institutions of the South of Russia for 2010–2020

Institution	Number of varieties and clones that were created and submitted to the State Variety Testing	Number of patents for varieties that have been obtained	Number of varieties that were entered into the State Register
NCFSCHVW	30	20	8
ARNSRIVW "Magarach" RAS	15	3	21
ARSRIVW – Branch of FRARC	30	24	14
Total, where:	75	47	43
wine varieties	50		22
table varieties	25		20
universal varieties	–		1

4 thousand hectares or 4.1 % – in the Rostov Region (Egorov et al., 2018b).

The positive dynamics in the development of the grapes and wine branch over the past ten years should be noted: the total area of grape plantations in the Russian Federation increased by 33.8 thousand hectares, or an average of 5 % per year; the increase in whole yields amounted to 342.2 thousand tons, or 8.1 % per year; the yield increased by 22.2 centner/ha, or 1.3 times, due to the application of modern agricultural technologies, grape varieties most adapted to the edaphoclimatic conditions of cultivation (Egorov et al., 2020).

4.3 thousand hectares of grape plantations are laid annually in the Russian Federation, the largest area of laying in the Krasnodar Region is 1.5 thousand hectares (34.9 % of the level of the Russian Federation), the Republic of Dagestan – 1.4 thousand hectares (32.6 % of the level of the Russian Federation), the Republic of Crimea, including the city of Sevastopol – 0.84 thousand hectares (19.5 %).

The total annual requirement of planting material for the implementation of planned laying (on average more than 5.0 thousand hectares per year), repairs (on average 2 %) and renovation of grape plantations (with a renovation rate of 5 %) is more than 17.8 million pcs or 250 % of the actual production; the requirement of planting material will be more than 80 million pcs by 2025. The laying of plantings is provided by young plants of domestic production only by 50 %.

An important trend of ensuring the food security of the Russian Federation is to reduce dependence on imported grape planting material through the production of domestic young plants and the creation of varieties of domestic breeding with integrated technological equipment for the breeding process.

The basis of the breeding process is plant genetic resources. In Russia, the main holders of grape collections are AZESVW – Branch of NCFSCHVW – 5001, ARNSRIVW "Magarach" – 4620 samples, ARSRIVW – Branch of FRARC – 895 samples, DSTSVH – Branch of NCFSCHVW – 800 samples. The total number of cultivars in the collections is 10 526 pieces, and it has a positive trend: over the past 10 years, it has increased by 18 %, from 8860 to 10 526 pcs. The expansion of the collections to 11 316 samples is expected by 2025 (Egorov et al., 2018a).

Varieties and hybrid forms of Russian ampelographic collections are collected from more than 40 countries. The largest number of varieties are from Russia, as well as from Moldova, Uzbekistan, France, Georgia, Greece, Ukraine, Hungary, the United States, Armenia, the Czech Republic, Japan and other countries.

The samples of the collection are studied both by traditional methods to specificate the sources of breeding valuable traits, and by molecular genetic methods to identify donors of valuable genes for use in the breeding of new most popular varieties (Ilnitskaya, Makarkina, 2016).

Much attention has been paid to the study of autochthonous varieties in recent years, according to the results of the conducted studies; the following varieties have been identified as promising for high-quality winemaking: Makhrovatchik, Belobulanyi, Tsimladar, Sypun Chernyi. Research in this direction continues (Egorov, Petrov, 2020).

According to the "State Register of Selection Achievements…" (2020) 294 varieties are allowed to be used in industrial plantings in Russia in 2020. There are 180 units of domestic varieties and clones accounts, which is 65.5 % (Fig. 1, *a*). The industrial plantings are dominated mainly by Western European varieties (see Fig. 1, *b*). Domestic and autochthonous varieties account for less than 1 % of each genotype. As a result of the dominance of introduced varieties in grape plantations, there is a decrease in the level of realization of the potential of economic productivity of grapes (up to 60 % in the Krasnodar Region), as well as the agrobiological and environmental stability of grape agrocenoses under the influence of biotic and abiotic stressors (Petrov, 2016).

Since all the biological and economically valuable characteristics of a given variety are better realized in their places of origin, autochthonous and domestic varieties, in contrast to the introduced varieties, are characterized by high adaptability, productivity and quality (Ilnitskaya et al., 2018).

A comparative analysis of long-term data on the assessment of the adaptive potential of grapes indicates that it is significantly higher in domestic varieties than in introduced varieties: for example, the amount of evolved buds after wintering in introduced varieties averaged 87 %, and the yield is 110.9 centner/ha, while in domestic varieties the amount of evolved buds averaged 94 %, the yield is 128.9 centner/ha.

A number of varieties of domestic breeding are worthy of competition with classic European varieties (Fig. 2): in particular, the Granatovyi variety (NCFSCHVW breeding) is competitive with the Cabernet-Sauvignon variety for the

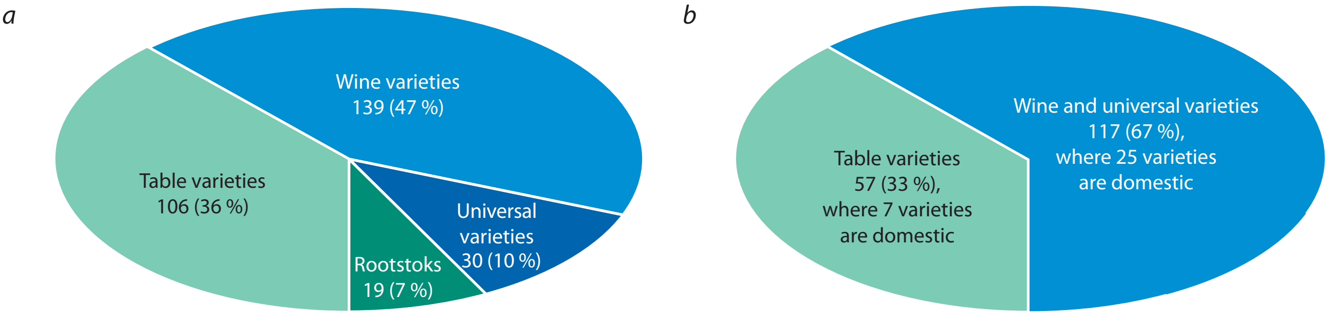

Fig. 1. Structure of grape varieties and clones approved (*a*) and used (*b*) in industrial plantings in Russia.

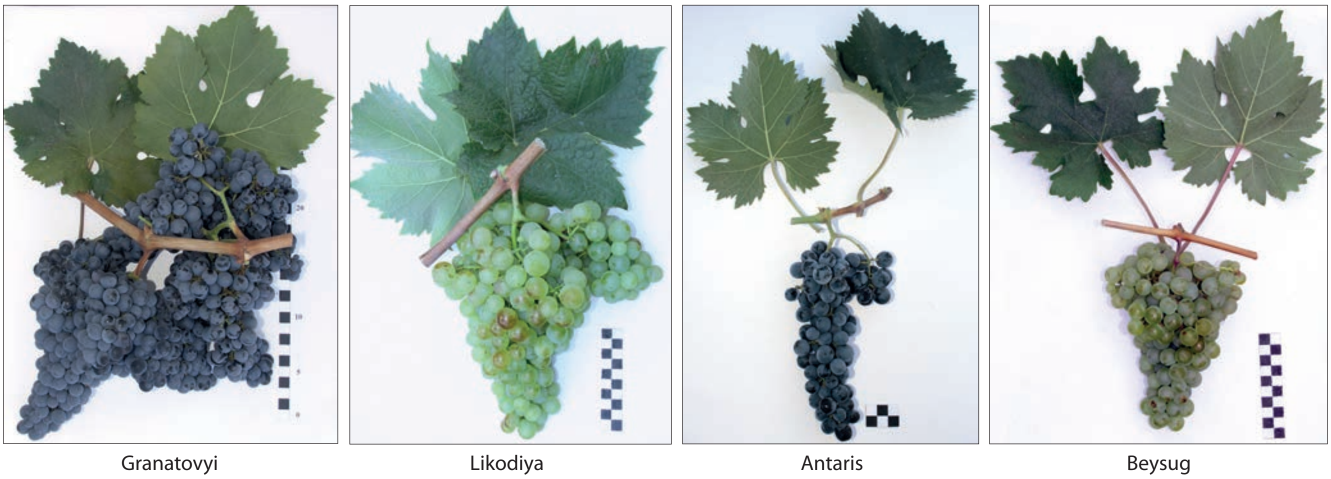

Fig. 2. Varieties of the NCFSCHVW breeding.

production of high-quality table and liqueur wines. Having high indicators of crop quality, Granatovyi variety surpasses Cabernet-Sauvignon in yield (130 centner/ha versus 90 centner/ha), parameters of resistance to fungal diseases, organoleptic properties and biochemical parameters of grape must and wine materials (Petrov et al., 2012).

The lack of modern infrastructure and outdated material and technical base of organizations participating in breeding and nursery production, the aggressive position of distributors of planting material of foreign varieties, the lack of a systemically implemented varietal and technological policy, combined with insufficient measures of state support, are the main reasons that most domestic varieties are not in demand. Specifically, the import of European varietal planting material increased from 4.4 million pcs to 15.4 million pcs for the period 2010–2020, the provision of bookmarks with imported planting material was 38 % in 2010, 56 % in 2019.

The Civil Code of the Russian Federation (Part four) of 18.12.2006 No. 230-FZ (eds. on 31.07.2020) establishes the right to a breeding achievement, by which the object of the right is recognized and protected subject to state registration of the breeding achievement in the State Register of Protected Breeding Achievements, in accordance with which the federal executive authority for breeding achievements issues the applicant a patent for a breeding achievement.

The exclusivity period and the patent certifying this right is thirty-five years for grape varieties. The specific responsibility of the patent owner of a breeding achievement as an object of intellectual property is their duty to maintain the variety during the term of the patent, in a way that the characteristics specified in the description of the variety, breed, compiled at the time of registration in the register are preserved.

The need for the permission of the patent owner to use the breeding achievement (conclusion of a license agreement) is established, in particular, in the production and reproduction of the variety.

Article 1446 of the Civil Code of the Russian Federation prescribes actions that violate the rights of the author of a breeding achievement or other patent owner; however, measures of influence against agricultural producers who violate the rights of the patent owner are not regulated. The federal executive authority in the field of registration of rights on a breeding achievement is the Federal State Budgetary Institution "Gossortcommission".

The grape was included in the "List of genera and species for which the economic utility of the variety is evaluated according to the results of state tests" until 2019. The state tests in the North Caucasus region of admission (6) were conducted at eight state strain-trial stations (Blagodarnenskiy, Volgodonskiy, Levokumskiy, Prokhladnenskiy, Rostovskiy, Sudakskiy, Khasavyurtovskiy and Anapskiy), evaluating new grape varieties; in the Lower Volga region of admission – at one state strain-trial station (Astarakhanskiy). Variety tests were carried without charge.

The grape was transferred to list B "The list of genera and species for which the economic utility of the variety is evaluated by expert assessment" in 2019, according to which it is necessary to place a mandatory laying of the variety to confirm the distinguishability, uniformity and stability on the Sudak state strain-trial station (at least 7 young plants) and the presence of plantings of the grape variety with an area of at least one hectare with the provision of yield data for at least three years. Expert evaluation is carried out on a fee basis.

The main reasons for the long duration of the breeding process of grapes are a certain complexity in conducting genetic research and carrying out breeding work, the imperfection of the scientific and technical base for conducting research. The duration of the process of creating a variety with varietal tests before its inclusion in the State Register of the Russian Federation is 25 years in accordance with the existing regulations, which, in turn, actualizes the need to accelerate the breeding process.

Currently, the creation of new grape genotypes can be carried out by generative breeding, transgenic technologies, cell and mutation breeding, as well as clone selection in grape plantations (Petrov, Ilnitskaya, 2017). The combined use of generative breeding and DNA marker selection or genomic breeding shows high efficiency. The use of DNA markers in breeding work is most effective in virtue of necessity to combine a number of genes (for example, genes that control plant resistance to pathogens) or due to the manifestation of a trait that can be evaluated only when the bushes enter fruiting (for example, the trait of seedless berries). The active use of this approach in the practice of the world's leading centers of grape breeding indicates the prospects of this direction for domestic science.

Additionally, a significant direction in the grapes breeding is clonal selection, which can be considered as a way of variety improvement, the allocation of more adapted genotypes to specific agro-climatic conditions with a higher level of productivity and quality of grapes. Clone selection is very important for introduced varieties, given that their long-term use in domestic agroecological conditions leads to mutations that reduce the economically valuable and biological characteristics of the varieties.

Currently, breeders pay special attention to the combination of traits of complex resistance to biotic and abiotic environmental factors in one genotype in combination with stable yield and high quality of grapes (Ilnitskaya et al., 2016).

The main priority characteristics of marketability for table grape varieties are large berry, elegant cluster, good taste, seedlessness, transportability and storability. The early ripening period is also a valuable feature – as usual, the price for the harvest of early varieties reaches the maximum values.

The quality requirements for wine grape varieties are based on the characteristics of the types and brands of wines for which they can be used. In general, the main task in the breeding of wine varieties is to preserve the quality of classic European varieties and at the same time increase resistance to dominant pathogens, adaptability to abiotic stressors. For zones of extreme viticulture in Russia, winter-hardy varieties, suitable for cultivation without covering for the winter, are needed.

Solving these problems requires high professional qualities of breeders. Currently, the total number of researchers working in seven scientific and two educational institutions in the field of grape breeding is currently 54 people: with the degree of Doctor of Science – 7, Candidate of Science – 21, young scientists – 15.

In general, the dynamics of the number of breeders is positive. Over the past 10 years, the number of breeders has increased by 15 %. There is a positive trend in the level of qualification of breeders. The number of doctors has increased 2.5 times over the past 10 years, and the number of candidates of science has remained unchanged. The influx of young scientists increased by 1.2 times. By 2025, it is necessary to ensure continuity by increasing the number of breeders by more than 20 % in relation to 2020.

It should be noted that the training of bachelors and masters in the field of "Horticulture", the profile "Horticulture, viticulture" is conducted by 7 agricultural universities of the Russian Federation, of which only the Kuban State Agrarian University has a group in the profile "Viticulture and wine-making" in the number of 25 full-time students and 20 part-time students.

Currently, there are no dissertation studies on grape breeding in the educational institutions that carry out postgraduate training. Only in the NCFSCHVW two postgraduate students prepare dissertations related to the grapes breeding.

Over the past ten years (2010–2020), in eight dissertation councils working on the basis of five scientific and three educational institutions of the Russian Federation, which accept dissertations in the specialty 06.01.05 "Breeding and seed production", have been defended six thesis works on viticulture, of which three have focused on grape breeding, including one for the degree of Doctor of Science.

Conclusion

Analyzing the organization and implementation of multifactor processes related to the grapes breeding and ensuring the development of the industry with varieties of domestic breeding, it is necessary to focus on:

- low share of varieties and clones of domestic breeding in the produced planting material and laying of grape plantations;
- the absence of a systemically implemented varietal and technological policy to increase the share of the most adapted to the cultivation conditions of domestic grapes varieties in industrial plantings, allowing to produce premium wines that would be of better quality compared to wines from varieties of European breeding;
- imperfection of the legal system of the protection of intellectual property, in particular, domestic breeding achievements;
- low availability of instrumental and analytical equipment for the implementation of breeding processes by modern methods that allow to speed up the creation of varieties and the selection of clones;
- insufficient number of bachelors and masters training in the direction "Viticulture" with the specialization "Breeding";
- insufficient effective activity of post-graduate schools for targeted training of scientists-specialists and the minimum number of dissertation research defense in breeding against the background of the growing need for highly qualified personnel of scientists.

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ORCID ID
E.A. Egorov orcid.org/0000-0002-5330-0352

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Scientific support of small fruit growing in Russia and prospects for its development

I.M. Kulikov, S.N. Evdokimenko, T.A. Tumaeva ✉, A.V. Kelina, F.F. Sazonov, N.V. Andronova, M.A. Podgaetsky

Federal Horticultural Research Center for Breeding, Agrotechnology and Nursery, Moscow, Russia
✉ vstisp@vstisp.org

Abstract. It is possible to achieve the target indices of the Russian Doctrine of Food Security (self-sufficiency in fruits and berries should be at least 60 %) by combining the competencies of science and business. At present, hundreds of varieties of small fruit crops are included in the State Register of Breeding Achievements Admitted for Use. Domestic breeders have obtained substantial results; the share of their assortment is 79–100 %. Federal Research Center of Horticulture (Moscow) (101 pcs.), Federal Altai Research Center of Agrobiotechnology (Barnaul) (85 pcs.), Michurin Federal Research Center (Michurinsk) (42 pcs.) are the leaders in the number of created hybrids and varieties. Over the past five years, 133 new breeding achievements of traditional small fruit crops have been submitted to the State variety testing, the originators of which are research institutions, private companies and individuals. The creation of modern seed-breeding (nursery-breeding) centers (SBC) on the basis of leading specialized research institutions is expected to be the solution to the problems of modern breeding and nursery breeding and to give impetus to the development of domestic small fruit growing. The research programs of the SBC involve an integrated approach that combines the knowledge and capabilities of researchers from different disciplines, the concentration of a complex analytical instrument base in the Centers of collective use, the using of biotechnological and molecular genetic research, along with traditional methods of breeding. An analysis of the achievements in small fruit growing in research institutions under the jurisdiction of the Ministry of Science and Higher Education of the Russian Federation revealed a huge scientific potential (genetic collections, hybrid funds) for creating competitive commercial varieties and technologies for their cultivation by establishing plantations with certified planting material in accordance with international requirements. Information from literary sources indicates that one of the main criteria for the value of varieties is resistance to harmful viral diseases. The cultivation of such varieties will reduce the cost of producing planting material for small fruit crops of the highest quality categories. In the near future, the most relevant areas for the breeding of small fruit crops will be: breeding for resistance to the most harmful viruses, winter hardiness, increased transportability and long-term post-harvest storage of fruits, suitability for mechanized cultivation, high content of biologically active substances.
Key words: scientific research institutions; small fruit crops; breeding; varieties; nursery production; certified planting material; repository; breeding and seed centers.

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Научное обеспечение ягодоводства России и перспективы его развития

И.М. Куликов, С.Н. Евдокименко, Т.А. Тумаева ✉, А.В. Келина, Ф.Ф. Сазонов, Н.В. Андронова, М.А. Подгаецкий

Федеральный научный селекционно-технологический центр садоводства и питомниководства, Москва, Россия
✉ vstisp@vstisp.org

Аннотация. Достижение целевых индикаторов Доктрины продовольственной безопасности (самообеспечение плодами и ягодами не менее 60 %) возможно при объединении компетенций науки и бизнеса. В настоящее время в Государственный реестр селекционных достижений, допущенных к использованию, включены сотни сортов ягодных культур. Отечественными селекционерами получены весомые результаты (79–100 % сортимента). Лидерами по количеству созданных гибридов и сортов являются ФНЦ Садоводства (Москва) – 101 шт., ФАНЦА (Барнаул) – 85 шт., ФНЦ им. И.В. Мичурина (Мичуринск) – 42 шт. За последние пять лет в государственное сортоиспытание поступило 133 новых сорта традиционных ягодных культур, оригинаторами которых являются научные учреждения, частные компании и лица. Решить проблемы современной селекции и питомниководства, придать импульс развитию отечественного ягодоводства призваны создающиеся на базе ведущих профильных научных учреждений современные селекционно-семеноводческие (питомниководческие) центры (ССЦ). Научно-исследовательские программы ССЦ предполагают комплексный подход, объединяющий знания и возможности ученых разных дисциплин, концентрацию сложной аналитической приборной базы в центры коллективного пользования, использование, наряду с традиционными методами селекции, биотехнологических и молекулярно-генетических исследований. Анализ достижений по ягодоводству в научно-исследовательских учреждениях, подведомственных Министерству науки и высшего образования России, выявил огромный научный потенциал (генетические коллекции, гибридные фонды) для создания конкурентоспособных промышленных сортов и технологий их возделывания путем закладки насаждений сертифицированным в соответствии с международными требованиями посадочным материалом. Информация из литературных источников указывает на один из главных критериев ценности сортов – устойчивость к вредоносным вирусным заболеваниям. Возделывание таких сортов позволит сократить затраты на производство посадочного материала ягодных культур высших категорий качества. В ближайшее время наиболее актуальными направлениями селекции ягодных культур будут: селекция на устойчивость к наиболее вредоносным вирусам, зимостойкость, повышенная транспортабельность и длительное послеуборочное хранение плодов, пригодность к механизированному возделыванию, высокое содержание биологически активных веществ.

Ключевые слова: научные исследовательские учреждения; ягодные культуры; селекция; сорта; питомниководство; сертифицированный посадочный материал; репозиторий; селекционно-семеноводческие центры.

Introduction

Fruit growing production mostly determines the physiological basis of people's health. Fruits and berries are dietary low-caloric products, rich in easily digested carbohydrates, pectin, organic acids and biologically active substances that include A, B_1, B_2, B_6, E, K_1, C, P and others, microelements (more than 50 items), anthocyans, flavonoids, tannins and others (Hummer, Barney, 2002; Saveliev et al., 2004; Sedov et al., 2007; Xiao et al., 2017; Mushinsky et al., 2019). Thanks to a wide range of phytonutrients, fruits and berries possess antioxidant, anti-inflammatory, anti-tumor and other treatment-and-prophylactic properties (Landele, 2011).

The consumption of fruits and berries in the Russian Federation is more than 5.0 mln tons or 34 kg per a person at average while the recommended medical norm is 88 kg without citrus fruits and grapes. At the same time, this parameter achieves 50 kg in China, 126 kg in Germany, 135 kg in France, 187 kg in Italy. According to the data of the Ministry of Agriculture of Russia, the record harvest of fruits and berries was gathered in 2019 – 3.5 mln tons, meanwhile domestic production supported only 39.5 % of the medical norm.

To solve the task of providing the population with fruits and berries and the problem of import substitution, one of the most reliable and effective sources of quick increase of the production is the growing of small fruit crops (strawberries, raspberries, black and red currants, gooseberries, honeysuckle and others). Firstly, the areal of their natural growth and industrial production is much wider than the geographical area of fruit cultures. Secondly, small-sized small fruit crops plants characteristically exhibit easy vegetative propagation, quick start of fruiting, early and nonsimultaneous period of fruits ripening (from June to October). Thirdly, high regular crop yield (till 10–15 tons of berries/ha), ecological flexibility, maturity of cultivation technology using mechanical means create cost-effective conditions for their growing (Kazakov et al., 2016).

Results and discussion

Small fruit crops plantations in Russia occupy nearly 100 thousand ha, 85 % from which belong to private subsidiary plots that are generally the source of self-production. However, they are not fully able to satisfy the demand of population in fresh berries and provide the processing industry with raw materials.

Small fruit growing in Russia can take the leading place by reviving and developing industrial production in close cooperation of science and business thanks to the implementation of new breeding achievements, the use of planting material certified in accordance with the international requirements and modern technologies of cultivation, storage and processing. At present, scientific support of the industry is fulfilled by Federal Horticultural Research Center for Breeding, Agrotechnology and Nursery (FRC of Horticulture, Moscow), Federal Research Center named after I.V. Michurin (FRC named after I.V. Michurin, Michurinsk), Ural Federal Agrarian Research Center of the Ural Branch of the Russian Academy of Sciences (UrFARC UrB RAS, Ekaterinburg), Federal Altai Research Center for Agrobiotechnology (FARCA, Barnaul), All-Russian Research Institute of Fruit Crop Breeding (VNIISPK, Orel Region), North Caucasian Federal Scientific Center of Horticulture, Viticulture, Wine-Making (NCFSCHVW, Krasnodar), Federal Research Center the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR, Saint-Petersburg), Buryat Research Institute of Agriculture (Buryat RIA, Ulan-Ude) and others, as well as specialized departments of institutions of higher education. Meanwhile there is a lack of qualified staff, especially young specialists, both in scientific and production spheres.

The main item of the complex system of small fruit production is variety. The contribution of a variety in increasing the harvest quantity and the quality can be 50–80 %, and the role of genetic-breeding researches will constantly increase (Zhuchenko, 2003; Lugovskoy et al., 2004). Incorrect choice

Table 1. The number of the main small fruit varieties included in the State Register of Breeding Achievements approved for use in Russia, 2020

Crop	Varieties in the Register					
	Totally	Foreign breeding, pcs./%	FRC of Horticulture	VNIISPK	FRC named after I.V. Michurin	Altai FRC for Agrobiotechnology
Raspberries	91	0/0	43	0	3	14
Black currants	204	10/4.9	18	14	16	32
Strawberries	106	22/20.7	24	0	4	9
Red currants	42	6/14.3	7	12	1	0
Honeysuckle	119	0/0	0	0	5	17
Gooseberries	50	2/4	9	0	10	4
Golden currants	23	0/0	0	0	3	9

of variety will lead to a decrease in crop yield and cost efficiency, and sometimes to premature death of the plantation and great losses (Knyazev et al., 2012).

At present, dozens of the main small fruit varieties are included in the State Register of Breeding Achievements approved for use in Russia (https://reestr.gossortrf.ru/). Russian crop breeders have received essential results: the proportion of the domestic assortment is 79–100 % depending on the crop. The following institutions created the majority of the varieties: FRC of Horticulture (Moscow) – 102 cvs., FARCA (Barnaul) – 85 cvs., FRC named after I.V. Michurin (Michurinsk) – 42 cvs. (Table 1).

It should be admitted, that from the enormous number of varieties approved for use, one part was received 30–40 years ago and does not correspond to the consumers' requirements and modern technologies of cultivation. In this respect, an urgent necessity of revising approaches to the operation of the system of the state crop variety testing has appeared.

Domestic small fruit crops producers have at their disposal varieties of almost all the crops that possess reliable adaptation to environmental conditions, high crop yield and small fruit quality. Based on comprehensive study, the scientists of FRC of Horticulture formed the industrial assortment of small fruit crops recommended for different regions of Russia. However, wide implementation of these varieties is constrained by the absence of a nursery system based on science in Russia. Because of nonobservance of zone cultivation technologies, the biological potential of small fruit crops varieties yield is used only to 20–50 %. Thus, the best varieties of strawberries are able to give 20–25 tons of small fruits from 1 ha in the conditions of high agrotechnique, but in fact the average yield of this crop does not exceed 6 t/ha. The average yield of strawberries varies from 2 to 4 t/ha, while according to the data of the state variety test plots, the potential yield of such varieties as Balzam, Kirzhach, Peresvet and others can achieve 8–10 t/ha.

The use of perspective varieties and the observance of the main technological methods of their cultivation allow to increase the yield essentially. Thus, when cultivating such new primocane varieties of raspberries as Atlant, Zhar-Ptizha, Poklon Kazakovu, Podarok Kashinu in "P(F)H Sychev" of Bryansk Region, the average yield achieved 11–12 t/ha for 3 years with yearly under-winter mowing.

A little portion of small fruit plantations in huge specialized households is mostly connected with high labor intensity of hand harvesting which takes up to 70 % of all expenses (Sazonov, 2006; Kazakov et al., 2009). Depending on the crop, variety or yield this operation requires 200–300 man work units/ha, which is 3–5 times higher than is necessary for fruit crop harvesting. These expenses can be greatly decreased with the help of wide implementation of mechanized harvesting. To achieve it, varieties should correspond to certain requirements (even ripening, easy separation, increased strength and so on). This breeding branch is well developed on black currants. There are nearly 30 varieties of this crop in the State Register of Breeding Achievements of Russia that are suitable for mechanized harvesting (Bagira, Malenky Prints, Mif, Ocharovanie, Orlovskaya Serenada, Orlovsky Vals, Rita, Tamerlan, Charodey, Sharovidnaya, Fortuna and others) (Table 2). The varieties of red currants, raspberries and honeysuckle suitable for machine harvesting have been bred (Bryksin, 2017). Though the list of such varieties is not large, the existing assortment allows to cultivate these crops using totally mechanized technologies.

Despite the achieved successes of domestic breeding schools, onrush of modern cultivation technologies, changes of ecological conditions, constant evolution of blasts and diseases require further modernization of assortment. Over the last 5 years, 133 new varieties of the main small fruit crops, the originators of which were not only research centers, but private companies and individuals as well, were applied to the State Variety Commission (Table 3).

Along with it the number of applications for the varieties of foreign breeding has increased greatly, especially for the positions where there are gaps and lags of Russian science. Besides, highly marketable varieties of strawberries appli-

Table 2. Varieties of the main small fruits crops of Russian breeding recommended for mechanized harvesting

Institutions originators/ Patent holders	Raspberries common/primocane	Currants black/red	Honeysuckle
FRC of Horticulture	Balzam, Brigantina, Sputnitsa, Peresvet / Atlant, Evraziaya, Medvezhonok	Mif, Kudesnik, Strelets, Charodey	–
FRC named after I.V. Michurin	–	Bagira, Malenky Prints, Tamerlan, Charovnitsa, Chernavka / Viksne	Antoshka, Goluboy Desert, Diana, Lyonya, Troe Druzey, Everest
UrFARC UrB RAS	–	Slavyanka, Dobryy Dzhinn, Udalets, Shaman, Fortuna	–
FARCA	–	Rita, Mila, Garmoniya, Kanakhama, Altayskaya Pozdnyaya, Ruslan, Gerkules, Sharovidnaya, Yubileynaya Lisavenko	Berel, Galochka, Salut, Selena
VNIISPK	–	Azhurnaya, Arapka, Ocharovanie, Orlovskaya Serenada, Orlovsky Vals, Chernookaya Asya, Gazel, Vika, Nika	–

Table 3. Applications for breeding achievements of small fruit crops submitted in 2016–2020

Institutions originators/ Patent holders	Strawberries	Black currants	Honeysuckle	Raspberries	Gooseberries	Red currants
FRC of Horticulture	2	2	2	5	2	2
FRC named after I.V. Michurin	1	3	4	0	1	0
UrFARC UrB RAS	2	2	2	0	2	2
FARCA	2	4	1	1	0	0
VNIISPK	0	3	0	1	0	1
Foreign organizations	26	0	0	5	0	0
Totally	47	30	29	15	7	5

cable for industrial cultivation technologies and the use in areas under glass are actively imported. Availability of relatively cheap planting material and the lack of quality seed pieces of domestic varieties facilitate the expanse.

Analysis of the applications for breeding achievements shows the absence of problems in variety formation of such crops as honeysuckle and black currants. Until recently, honeysuckle was considered as not widespread small fruit crop. The first two varieties (Bakcharskaya and Tomichka) were included in the State Register of Breeding Achievements in 1987. The breeding of this crop develops very quickly. Now, there are 119 varieties and 29 applications for new varieties in the Register. More than that, all of them are domestically bred. Active work in new varieties creation is held mostly in FSUE "Bakcharskoe" (Tomsk region), FRC named after I.V. Michurin, FARCA, Nizhegorodskaya State Agricultural Academy.

The breeding of black currants has been carried out very successfully. 20 breeders in 15 scientific institutions situated in the main cultivation regions of this crop (from Bryansk to Transbaikal) are occupied with this work. Essential bioresource collections and hybrid funds of this crop are created in FRC of Horticulture, VNIISPK, FRC named after I.V. Michurin and UrFARC UrB RAS. These institutions bred productive varieties with high adaptation to cultivation conditions and resistance to American mildew (Orlovskaya Serenada, Orlovsky Vals, Rita, Selechenskaya 2, Strelets, Tamerlan, Sharovidnaya), to currant big bud mite (Dar Smolyaninovoy, Kipiana, Litvinovskaya, Mif, Chudnoe Mgnovenie, Shalunya), and suitable for mechanized cultivation technologies including harvesting (Tamerlan, Rita, Mif, Orlovskaya Serenada, Dobryy Dzhinn and others).

One of the burning issues in blackcurrant cultivation is the absence of varieties immune to the big bud mite. The high degree of mechanization favors the pest dispersal over a plantation and shortens its commercial use by two years on the average (Vityaz et al., 2015).

In the last few years, a tendency of raspberries variety breeding slow-up has been observed. Over the last 5 years, 15 applications for new varieties were submitted to State Variety Commission, from which 5 varieties were of foreign origin. Active breeding work with raspberries is held at Kokinsky base station of FRC of Horticulture. The first domestic raspberries varieties suitable for machine harvesting were bred there; a special branch in breeding – the creation of primocane varieties with prior ripening on one-year shoots – was created there. New large-fruited primocane varieties of raspberries Medvezhonok and Yubileynaya Kulikova are characterized by large biological potential of productivity (2.5–3.0 kg/bush), early ripening, high quality of fruits and do not have foreign analogues with the combination of the same parameters.

Analysis of foreign references points at one of the main criteria of the value of small fruit crops varieties (raspberries, currants, strawberries) – resistance to destructive virus diseases. Cultivation of such varieties allows to decrease the expenses for production of young plants of small fruit crops of high quality. That's why, in the nearest future, the most relevant areas of the raspberries breeding will be: breeding for resistance to viruses RBDV (raspberries bushy dwarf virus), TBRV (tomato black ring virus), RpRSV (raspberries ring spot virus), ArMV (Arabis mosaic virus), SLRSV (strawberries latent ring spot virus), winter hardiness, increased transportability and long-term post-harvest storage of small fruits, suitability for mechanized cultivation, high content of biologically active substances.

The assortment of red currants and gooseberries is modernized slowly, which is connected with a limited number of breeders working with these crops. The questions of shoots spinosity and the resistance of many varieties to American mildew (Sphaerotheca) continue to be very important for gooseberries (Kurashov et al., 2019). The cultivation of such varieties will definitely enlarge the interest to the expansion of plantations of such valuable high productive crop.

Conclusion

Four modern seed production and breeding centers created on the base of leading specialized scientific institutions (FRC of Horticulture, Moscow; FRC named after I.V. Michurin, Michurinsk; NCFSCHVW, Krasnodar; VNIISPK, Orel) have to solve the problems of modern breeding and nursery selection of small fruit crops, to give impetus to the development of domestic small fruit growing. The most important working branch of such centers is the establishment of field repositories that can help objectively evaluate fruits quality and productivity. Combined work of breeders, nurserymen, virologists and other specialists on such plantations will allow to find perspective varieties and clones, to use healthy pollen and to receive parent plants without using expensive and continuous sanitation (Egorov et al., 2020). The research programs of the seed production and breeding centers involve an integrated approach that combines the knowledge and capabilities of researchers from different disciplines, the concentration of a complex analytical instrument base in the Centers of collective use, the use of biotechnological and molecular genetic research along with traditional methods of breeding.

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ORCID ID
I.M. Kulikov orcid.org/0000-0001-6843-4866
S.N. Evdokimenko orcid.org/0000-0001-9187-7593
T.A. Tumaeva orcid.org/0000-0002-9256-0798
A.V. Kelina orcid.org/0000-0001-8434-190X
F.F. Sazonov orcid.org/0000-0002-1760-5992
M.A. Podgaetsky orcid.org/0000-0002-0289-1092

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Subtropical and flower crops breeding at the Subtropical Scientific Centre

A.V. Ryndin ✉, R.V. Kulyan, N.A. Slepchenko

Federal Research Centre the Subtropical Scientific Centre of the Russian Academy of Sciences, Sochi, Russia
✉ ryndin@vniisubtrop.ru

Abstract. This paper presents the results on the breeding work carried out by the Subtropical Scientific Centre of the Russian Academy of Sciences. Currently, the Centre's breeders are doing a lot of work aimed at breeding new fine yielding cultivars of subtropical and flower crops that will be resistant to growing conditions; they include kaki persimmon, feijoa, mandarin, freesia, crown anemone, pelargonium and chrysanthemum. The sources of high-level priority traits in flower crops that are valuable for further breeding in order to improve decorative (colour, flower shape, inflorescence), economic and biological traits (flowering period, a large number of flowers in the inflorescence, storage period of cut flowers, disease resistance, high reproduction coefficient) were recorded. The aim of the research is to improve the subtropical and flower crops assortment. The objects of the research were 989 hybrid forms: 136 citrus crops, 56 persimmon, 36 feijoa, 38 tea plant, 11 pear, 24 hazel, 108 freesia, 398 crown anemone, 120 pelargonium and 62 chrysanthemum hybrids. New cultivars with a complex of valuable traits have been created as a result of the scientific work. Over the past five years, FRC SSC of RAS has created 50 new cultivars: 26 pelargonium, 15 anemone, 5 freesia, 2 chrysanthemum, 1 persimmon and 1 apple and submitted them to the State Cultivar Commission. The "State Register of Selection Achievements Authorized for Use for Production Purposes" has included 63 cultivars developed by FRC SSC RAS, including 26 pelargonium, 13 anemone, 9 chrysanthemum, 7 freesia, 4 hazel, 3 feijoa and 1 tea plant cultivars. 46 patents for breeding achievements have been obtained.

Key words: biodiversity; genetic collection; subtropical and flower crops; breeding.

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Селекция субтропических и цветочных культур в ФИЦ «Субтропический научный центр РАН»

А.В. Рындин ✉, Р.В. Кулян, Н.А. Слепченко

Федеральный исследовательский центр «Субтропический научный центр Российской академии наук», Сочи, Россия
✉ ryndin@vniisubtrop.ru

Аннотация. Представлены результаты селекционной работы ФИЦ «Субтропический научный центр Российской академии наук» (ФИЦ СНЦ РАН). Селекционерами ФИЦ СНЦ РАН проводится большая работа, направленная на выведение новых урожайных, высококачественных, устойчивых к биотическим и абиотическим факторам сортов субтропических и цветочных культур: хурмы восточной, фейхоа, мандарина, фрезии, анемоны корончатой, пеларгонии и хризантемы. Выделены источники хозяйственно ценных признаков цветочных культур, которые представляют интерес для селекции на улучшение декоративных (окраска, форма цветка, соцветия) и хозяйственно-биологических признаков (период цветения, большое количество цветков в соцветии, период стояния в срезе, устойчивость к болезням, высокий коэффициент размножения). Цель исследований – совершенствование сортимента субтропических и цветочных культур. Объектами исследований служили 989 гибридных форм, из них цитрусовых – 136, хурмы – 56, фейхоа – 36, чая – 38, груши – 11, лещины – 24, фрезии – 108, анемоны корончатой – 398, пеларгонии – 120, хризантемы – 62. Результатом работы стало выведение сортов с комплексом ценных признаков. За последние пять лет в ФИЦ СНЦ РАН создано и передано в Госсорткомиссию РФ 50 новых сортов, в том числе 26 – пеларгонии, 15 – анемоны, 5 – фрезии, 2 – хризантемы, 1 – хурмы и 1 – яблони. В «Государственный реестр селекционных достижений…» включено 63 сорта селекции ФИЦ СНЦ РАН, в том числе 26 сортов пеларгонии, 13 – анемоны, 9 – хризантемы, 7 – фрезии, 4 – фундука, 3 – фейхоа, 1 – чайного растения. Получено 46 патентов на селекционные достижения.

Ключевые слова: биоразнообразие; генетическая коллекция; субтропические и цветочные культуры; селекция.

Introduction

The humid subtropical zone on the Black Sea coast of Krasnodar Territory is the only suitable zone in Russia for cultivating subtropical fruit crops, citrus crops and tea plant (Ryndin, Tereshkin, 2012; Tutberidze, 2015; Ryndin, 2016). One of the main objectives for the development of subtropical fruit growing in this zone is to expand and improve the subtropical fruit and flower crops assortment. It should be noted that interest in these crops is also increasing in other regions of the Russian Federation, thanks to the development of greenhouse, indoor and office gardening, as well as the ongoing work carried out to create geographical areas and expand the subtropical crops range (Ryndin, Tuov, 2010; Pchikhachev, Korzun, 2017; Collections..., 2019; Omarov et al., 2020).

Currently, the flower crops cultivation in our country is mainly based on imported assortment. The Black Sea coast is promising for cultivating cut flowers in the winter-early spring period, when the overall flower assortment is small and the population's demand for these products is greatly increasing. One of the strategy principles in developing flower and ornamental crops production, including import substitution, is to apply the latest breeding achievements (Ryndin et al., 2015). The creation of new highly decorative forms that will be productive, competitive, environmentally hardy, very early and late-flowering, original in flower shape, and rare in colour, remains an urgent task for flower crop breeding (Gutiyeva, 2014, 2015; Mokhno et al., 2014; Bratukhina, Paschenko, 2015; Kozina, 2015, 2018).

The climatic conditions in the given zone allow us to create collections and carry out the breeding work, both in open ground conditions and in glass greenhouses without additional heating, in many flower crops (tulip, chrysanthemum, hippeastrum, pelargonium, freesia, crown anemone, and others). The main methods of creating material for breeding were and still are intervarietal and interspecific crosses, clonal selection and selection on a nucellar basis. New cultivars are more flexible and resistant to adverse environmental conditions. The essential significance of the local cultivars is provided by their high adaptive potential.

Federal Research Centre the Subtropical Scientific Centre of the Russian Academy of Sciences – FRC SSC of RAS (earlier Russian Research Institute of Floriculture and Subtropical Crops) is one of the oldest scientific institutions of our country: in 2019 it celebrated its 125th anniversary. From the first days of the institution's existence, the research program included the following issues that are still relevant today: creation and maintenance of subtropical, fruit and flower crops collections, introduction and study of the possibility to cultivate new species and cultivars for the zone. The rich genetic collections of both cultivated plant species and their wild relatives are collected on the basis of FRC SSC of RAS, which helps to preserve economically valuable species and forms. They are the objects of diverse research that contributes to the in-depth study of ecological and biological features, the development of new technological cultivation methods, the solution of plant protection issues and the allocation of material for further breeding work (Omarov et al., 2014, 2020; Ryndin, Kulyan, 2016; Kulyan et al., 2017; Volk et al., 2018; Collections…, 2019; Ryndin, Slepchenko, 2019).

The breeding work was begun in the FRC SSC of RAS in 1930. The number of subtropical, southern fruit, berry and tea cultivars, which have been bred and recommended for production and use, is shown in Fig. 1, and flower cultivars – in Fig. 2. Some of them are used in the production and landscaping not only within the region, but also in other parts of southern Russia.

Currently, the work to create new cultivars of mandarin, kaki persimmon, feijoa, pear, tea plant, freesia, crown anemone, pelargonium and chrysanthemum continues (Loshkareva, 2014; Kulyan, Omarova, 2018; Kiseleva, 2020; Omarov, Omarova, 2020; Yakushina, 2020).

The purpose of this paper is to analyze the main collection samples and the development of new cultivars that meet the requirements of intensive gardening, and to identify promising

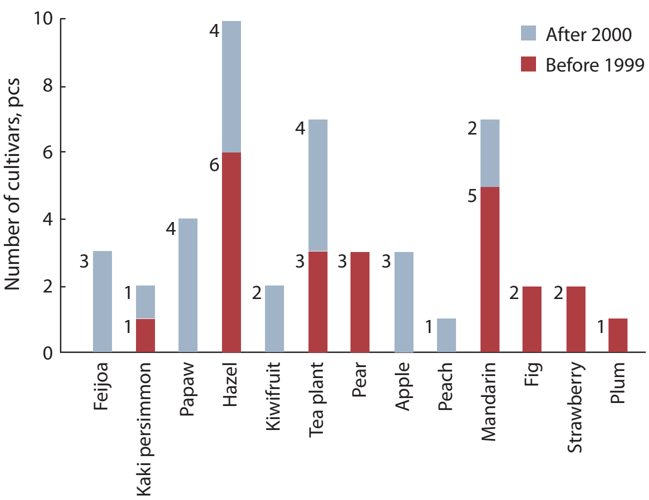

Fig. 1. The number of subtropical, southern fruit, berry and tea cultivars, created in FRC SSC of RAS.

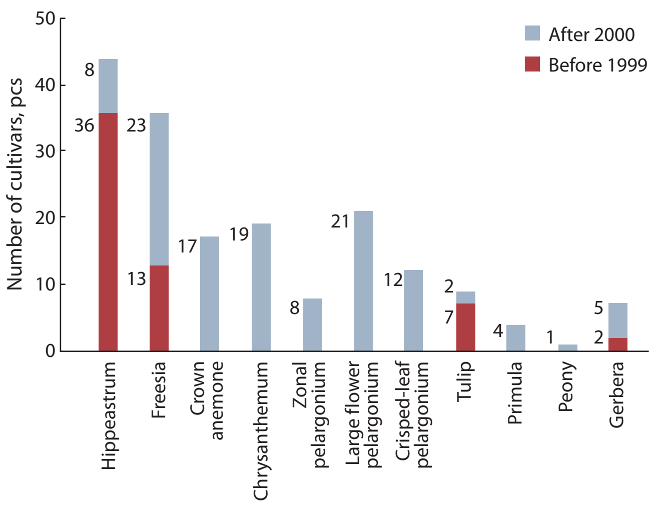

Fig. 2. The number of flower cultivars, created in FRC SSC of RAS.

fields in breeding, allowing us to improve the assortment of humid subtropics in Russia.

Materials and methods

For this purpose, the hybrid fund of subtropical, southern fruit and flower crops is currently being studied at FRC SSC of RAS (Fig. 3). The objects of research are: hybrid forms of citrus crops (frost resistance, resistance to biotic stressors, productivity) presented in the amount of 136, 50 of which are promising, 24 are elite; kaki persimmon (resistance to biotic and abiotic factors) – 56, 18 of which are promising; feijoa (high yield, high fruit quality, early ripening) – 36, 7 of which are elite; pear (high productive and adaptive potentials) – 11, 2 of which are promising; tea plant (productivity, high biochemical (tannin not less than 26 %) and organoleptic indicators) – 38 forms, 3 of which are elite and 5 are winter-hardy; hazel – 24 promising forms; flower crops (decorativeness, productivity, abundant flowering): freesia – 108, 6 of which are promising; anemone – 398, 98 of which are promising; pelargonium – 120, 80 of which are promising, 16 are elite; chrysanthemum – 62, 10 of which are promising, 6 are elite.

New subtropical fruit cultivars should have the following parameters: low- and medium-grown, a high rate of productivity and adaptation to growing conditions, resistance to pests and fungal diseases, a stable yield, and fruits of high commercial and taste qualities (Omarov et al., 2018). Concerning flower crops, they should have decorativeness, abundant long-term flowering, high productivity and reproduction rate, as well as resistance to specific environmental conditions (Gutiyeva, 2020; Paschenko, 2020a, b).

In the process of research were used: the methods of State cultivar testing for agricultural and ornamental crops; programs and methods for studying fruit, berry and nut cultivars: “Program of the North-Caucasian Centre for the Breeding of Fruit, Small-fruit, Ornamental Crops and Grapevine for the Period until 2030” (2013); “Modern Methods and Tools for the Assessment and Selection of Breeding Material of Orchard Crops and Grapevine” (2017). Parent pairs were selected according to “Citrus Fruit Breeding. VIR Guidelines” (1989). The primary and competitive study of crown anemone hybrids was carried out according to the “Protocol for Tests for the Distinguishability, Uniformity, and Cultivation Stability of the Poppy Anemone” (2003); for chrysanthemum, crosses were carried out according to I.A. Zabelin’s method (1975).

Results and discussion

Citrus crops (*Citrus* family Rutaceae)

Breeding program for the creation of winter-hardy cultivars is based on remote hybridization, the main donors are *Citrus trifoliata* L. (syn. *Poncirus trifoliata* (L.) Raf.), *Citrus japonica* Thunb. (syn. *Fortunella margarita* (Lour.) Swingle), *Citrus cavaleriei* H. Lév. ex Cavalerie (syn. *Citrus ichangensis* Swingle), *C.* × *insitorum* Mabb., as well as previously obtained interspecific hybrids. Medium-grown, winter-hardy, semi-deciduous genotypes, not exceeding 2.0 m in height at the age of ten, were identified.

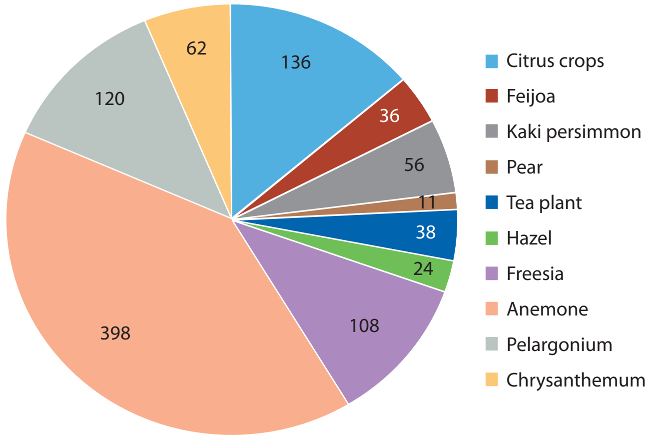

Fig. 3. Crop hybrid fund of FRC SSC of RAS, pcs.

The program for breeding cultivars with high fruit quality (large-fruited, leveled, with high sugar-acid index, seedless, different in ripening terms) is a leading direction in breeding and is based on applying interspecific crosses (*C. reticulata* × *C. sinensis*; *C. reticulata* × *C. paradise*; *C. reticulata* × *C. maxima*). Genotypes with different expressed levels of traits were obtained on the basis of parental forms of different geographical origin, which creates prerequisites for expanding the genetic basis while creating cultivars with high ecological adaptiveness and a complex of other economically valuable traits.

At the moment, the study includes 136 forms of citrus crops, 50 of which are promising and 24 are elite. Forms with high fruit quality occupy the leading place in the hybrid fund collection and represent the main material for breeding (Table 1).

Sugar and acidity levels are the main criteria for the overall fruit quality. Sugar-acid ratio characterizes the degree of fruit sweetness, i.e. a harmonious taste of mandarin fruits is achieved with a certain sugar-acid ratio. The fruits of hybrids 2-5, 99-4, 98-21 and 97-3 have the best taste qualities compared to the control Kowano-Wase (see Table 1).

In many citrus-growing countries, where productivity, early ripening, fruit quality, and immunity to viral diseases are foremost priorities, breeding is carried out on the basis of nucellar polyembryonia (Nesumi et al., 2001; Ben-Hayyim, Moore, 2007; Ali et al., 2013; Combrink et al., 2013; Yasuda et al., 2015).

The FRC SSC of RAS also conducts a breeding program aimed at obtaining high-yielding, early-maturing, medium-grown and variegated forms using nucellar seedlings. 12 promising forms were recorded (Table 2).

Among the nucellar seedlings, the most valuable are low- and medium-grown early-ripening hybrids, which have good fruit quality (Fig. 4, 5).

Variegated forms are becoming very popular among citrus lovers and collectors. We have identified nucellar seedlings MR-97 (Fig. 6) and KI-27 (Fig. 7), which do not lose this trait during vegetative reproduction.

Table 1. Characteristics of the selected mandarin hybrid forms aged 5 years

Hybrid form	Yield, kg/tree	Fruit mass, g			Total sugar, %	Acidity, %	Sugar-acid ratio	Dry matter, %
		general	flesh	skin				
16-1	4.0	90.0	78.0	12.0	13.59	1.74	7.81	11.8
98-21	4.2	120.0	98.4	21.6	8.84	0.96	9.21	11.3
98-22	3.0	90.0	77.7	12.3	7.29	0.96	7.60	8.3
97-3	3.5	75.5	67.7	7.8	10.20	1.16	8.79	11.3
01-12	4.2	85.0	78.5	6.5	13.78	1.69	8.15	10.7
2-5	3.0	85.0	75.5	9.5	12.86	1.13	11.38	11.6
99-2	4.2	150.0	127.8	22.5	7.29	0.96	7.60	8.3
99-4	4.5	120.0	96.0	24.5	8.90	0.96	9.27	10.2
Kowano-Wase (K)	4.2	75.5	67.5	8.0	7.38	1.18	6.25	11.3
Lsd	2.16	0.12	0.14	0.07	0.09	0.02	0.03	0.03

Note. C – control.

Table 2. Characteristics of promising nucellar mandarin seedlings aged 5 years

No. and genealogy of hybrid	Yield, kg/tree	Fruit ripening terms	Plant height, m	Leaf colour
11 (Kowano-Wase × 3252 hybrid)	6.3	Early, mid-October	Average, 3.0–3.5	Green
02 (Kowano-Wase × 3252 hybrid)	3.5	Early, late September	Average, 3.0–3.5	
T-17 (Kowano-Wase × *C. tangerine*)	8.4	Early, mid-October	Short, 2.5–3.0	
V-29 (Miyagawa Wase × *C. sinensis* Valencia)	5.8	Medium, early November	Average, 3.5	
12 (Sochinskiy 23 × *C. tangelo*)	3.8	Early, late September	Average, 3.5	
32-3 (large-fruited × 3252)	4.6	Medium, early November	Average, 3.5	
32-8 (large-fruited × 3252)	5.2	Medium, early November	Average, 3.5	
42 (Miyagawa Wase × *C. tangelo*)	4.8	Early, late September	Average, 3.0–3.5	
MSH-2 (Miyagawa Wase × *C. leiocarpa*)	3.6	Early, late September	Short, 2.5–3.0	
KI-27 (Kowano-Wase × *C. ichangensis*)	2.8	Medium, early November	Short, 2.5–3.0	With yellow brim
MR-97 (Miyagawa Wase × *P. trifoliata*)	2.4	Medium, early November	Average, 3.0–3.5	Silvery ribs

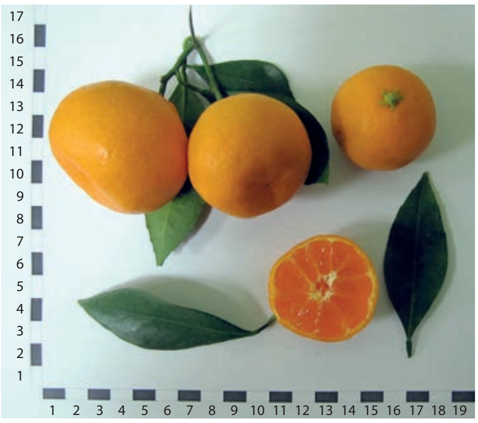

Fig. 4. Seedling 02 (*C. reticulata* × hybrid 3252).

Fig. 5. Seedling T-17 (*C. reticulata* × *C. tangerine*).

A number of bud mutations were recorded on the basis of the mandarin genetic collection of FRC SSC of RAS, the altered traits were fixed in the process of reproduction by budding, and two isolated clones were subjected to State cultivar testing (Fig. 8, 9).

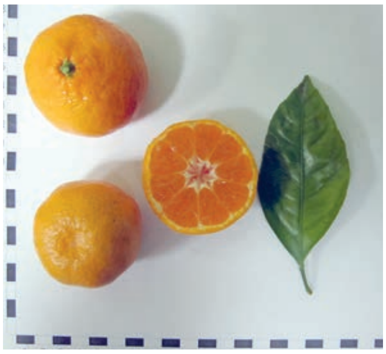

Fig. 8. Mandarin Clone 22.

Fig. 9. Mandarin Clone 33.

Kaki persimmon (*Diospyros kaki* L.) is considered one of the most frost-resistant subtropical crops. Without significant damage, adult plants can withstand prolonged low temperatures up to –12…–15 °C. The main goal of kaki persimmon breeding is to create high-yielding cultivars with fine fruit quality, (fruit weight 150–200 g, sugar amount 15–20) and resistance to extreme environmental factors. Over the past 10 years, 16 intervarietal and 5 interspecific cross combinations have been carried out, the best ones have been determined: Djiro × Geili, Djiro × Zenji-Maru and Hiakume × Fuyu, Djiro × *D. virginiana* L., of which the largest number of promising hybrids was identified (Table 3).

The hybrid fund of kaki persimmon includes 56 forms from intervarietal and interspecific crosses, 18 of which were recorded as promising ones. A new winter-hardy cultivar MVG Omarova with good fruit quality (ascorbic acid 20 mg %, the sum of sugars 22 %) was obtained and in 2021 transferred to the "State Register of Selection Achievements Authorized for Use for Production Purposes" of the Russian Federation, (Fig. 10). Currently, the hybrid form No. 39 is being tested by the State Cultivar Commission (Fig. 11).

Fig. 6. Seedling MR-97 (*C. reticulata* × *P. trifoliata*).

Fig. 7. Seedling KI-27 (*C. reticulata* × *C. ichangensis*).

Table 3. Results of crossing kaki persimmon (average for 4 years)

Cross combination	Pollinated flowers, pcs	Set, %		Germination rate, %	Selected hybrids, %
		fruits	seeds		
Djiro × Zenji Maru	51.75 ± 3.75	49.3 ± 11.95	56.38 ± 14.13	45.68 ± 12.84	37.20 ± 6.10
Djiro × Geili	53.00 ± 2.00	54.75 ± 13.8	61.23 ± 13.88	47.85 ± 15.05	43.15 ± 6.50
Djiro × Fuyu	53.25 ± 4.75	44.95 ± 7.33	53.03 ± 16.51	43.03 ± 11.58	34.35 ± 5.20
Hiakume × Fuyu	51.50 ± 2.50	43.90 ± 8.05	54.78 ± 15.89	43.78 ± 12.43	33.95 ± 6.85
Djiro × *D. virginiana*	21.25 ± 1.88	33.00 ± 8.50	66.88 ± 10.63	42.10 ± 4.60	41.65 ± 8.35

Fig. 10. Kaki persimmon cultivar MVG Omarova.

Fig. 11. Hybrid form No. 39.

Feijoa (*Feijoa sellowiana* Berg)

In recent years, in the subtropical regions of Russia, there has been an intensive expansion of feijoa plantings, but mainly by plants grown from seeds without varietal membership. In order to expand the assortment and develop new adapted cultivars, eight cross combinations were carried out, and a large hybrid fund adapted to local cultivation conditions was created (Table 4).

The best cross combinations, from which seeds with a high germination rate were obtained, are the following: Dachnaya × Superba, Superba × Dagomysskaya and Superba × pollen mixture. From the entire variety of forms, 36 promising ones were recorded, 7 of which are elite with high and stable yields (Table 5).

Of these, the form B-13 was recorded as large-fruited, form 10-22 has active growth, and equals the zoned cultivar Superba in fruit mass.

New feijoa cultivars bred by FRC SSC of RAS Dachnaya (Fig. 12), Dagomysskaya (Fig. 13) and Sentyabrskaya are actively used in the breeding process as donors of such signs as “active growth” and “early maturity”.

Table 4. Results of studying feijoa hybrids (average for 4 years)

Cross combination	Pollinated flowers, pcs	Picked fruits, pcs	Planted seeds, pcs	Germination rate, %
Dachnaya × Superba	37.75 ± 16.75	10.50 ± 8.75	101.50 ± 38.50	77.75 ± 6.25
Dagomysskaya × Superba	30.50 ± 6.50	14.25 ± 6.75	84.00 ± 25.00	75.00 ± 1.50
Sentyabrskaya × Superba	45.50 ± 13.5	26.25 ± 10.75	144.75 ± 48.25	73.25 ± 3.25
Superba × Dachnaya	71.00 ± 10.00	27.00 ± 10.00	113.37 ± 41.09	75.50 ± 3.00
Superba × Dagomysskaya	56.25 ± 14.88	22.00 ± 10.00	81.25 ± 34.25	76.00 ± 4.00
Superba × Sentyabrskaya	61.25 ± 9.25	34.50 ± 8.50	114.43 ± 54.09	78.75 ± 3.63
Superba × Superba	52.25 ± 15.88	21.50 ± 8.00	48.55 ± 14.45	68.25 ± 3.25
Superba × pollen mixture	61.50 ± 18.50	34.50 ± 10.25	109.25 ± 34.38	81.75 ± 5.25

Table 5. Productivity of feijoa forms aged 10 years

Form	Yield, kg	Fruit mass, g		Fruit size, cm		Form	Yield, kg	Fruit mass, g		Fruit size, cm	
		average	max	length	width			average	max	length	width
Superba (control)	9.7	35.7	53.2	4.4	3.9	13-11	11.8	25.6	39.7	4.4	3.5
Dagomysskaya	19.8	91.2	99.9	6.6	5.1	10-22	10.8	42.7	53.4	4.7	4.5
12-5	8.9	39.2	58.1	4.8	3.9	6-24	8.3	27.1	35.2	3.8	3.6
4-10	9.3	38.7	61.4	5.0	4.6	B-13	19.4	74.8	89.3	5.0	4.9
SHV-1	10.6	38.1	62.2	4.6	3.9	Lsd	0.09	0.13	0.03	0.04	0.26

Fig. 12. Feijoa cultivar Dachnaya.

Fig. 13. Feijoa cultivar Dagomysskaya.

Fig. 14. Tea plant, form AF-3.

Fig 15. Tea plant, form AF-5.

Tea plant (*Camellia sinensis* (L.) Kuntze)

Krasnodar Territory is the northernmost region on the globe where tea culture is cultivated on an industrial scale (Ryndin, Tereshkin, 2012). Research on the development of new cultivars is carried out at FRC SSC of RAS in order to improve winter hardiness, yield and quality of raw materials (Vavilova, 2018). As a result of the work carried out, a promising material with high economic and biological characteristics was recorded. The study includes 38 forms, 3 of which (13-09, 13-13, 13-23) were recorded as candidates for cultivars with high yield (799 g/bush). Five more forms, AF-1, AF-2, AF-3 (Fig. 14), AF-4, AF-5 (Fig. 15), with high winter hardiness, resistance to unfavorable growing conditions and stable yield (423 g/bush) were recorded on the basis of Adygei Branch of FRC SSC of RAS.

As a result of the long-term creation and comprehensive study of the flower crops breeding material, highly decorative and resistant forms were recorded for use in industrial and amateur floriculture, as well as in breeding as sources of valuable traits for creating new cultivars.

The common freesia (*Freesia refracta* (Jacq.) Klatt) is one of the most popular early spring cultures grown for cut flowers. Hybrid forms of freesia are characterized by a wide range of colours from white, blue, beige, to dark blue, purple, and dark red (Table 6). Spots, smears, strokes, and throat colour located on the surface of the perianth lobes give special originality to the colour shades (Paschenko, 2020a, b).

The recorded cultivars and selected elite forms have high decorative qualities of the flower. The colour is varied, ranging from bright white, lilac-yellow, pink-purple to red-crimson and dark blue. In cultivars Breeze, Melange (Fig. 16), Svetlana (Fig. 17) and hybrids K-28-1, R-34-3, T-10-1 and T-10-2/1, the number of flowers in the inflorescence exceeds 10 pcs, the longest inflorescences are in the cultivars Melange and Svetlana, respectively, 8.0 ± 2.5 and 8.0 ± 0.8 cm and in the hybrid form K-28-1 (8.0 ± 0.8 cm).

Pelargoniums (*Pelargonium* L'Hér. ex Ait.) are the most valuable decorative and deciduous plants. Their significant variety allows to use them for decorating gardens, parks, terraces, balconies, etc. from spring to late autumn. They differ from many ornamental plants in their abundant flowering, resistance to stress factors, and high reproduction rate (Van der Walt, Boucer, 1986; Van der Walt, Vorster, 1988). FRC SSC of RAS has an extensive collection of pelargoniums (200 cultivar samples), which includes representatives of four clods (A, B, C1 and C2), 4 subgenera and 6 sections (Fig. 18). Most of the

Fig. 16. Freesia cultivar Melange.

Fig. 17. Freesia cultivar Svetlana.

Table 6. Characteristics of new domestic cultivars and elite hybrid forms of freesia

Cultivar, number of hybrid	Inflore-scence length, cm	Flower colour			Flower		Flowers in inflorescence, pcs
		main	throat	spots	Diameter, cm	Height, cm	
Breeze	7.1 ± 1.2	Dark blue	White	No	6.1 ± 0.5	7.0 ± 0.4	9–11
Melange	8.0 ± 2.5	Lilac	Light yellow	Yellow	7.9 ± 0.5	7.3 ± 0.2	8–12
Angel	7.0 ± 1.0	White	White	No	4.5 ± 0.2	7.6 ± 0.5	8–10
Palmira	6.0 ± 1.5	Red-pink	Light yellow	Yellow	5.6 ± 0.5	5.8 ± 0.4	6–8
Ritsa	6.0 ± 0.7	White with dark blue edge	White	White	4.0 ± 0.6	7.0 ± 0.2	9–10
Svetlana	8.0 ± 0.8	Medium blue	White	No	6.5 ± 0.5	8.4 ± 0.2	10–12
Tatyana	7.5 ± 1.1	Bright yellow	Yellow	No	4.5 ± 0.5	5.5 ± 0.2	9–10
Zoloto Ampsalidy	6.5 ± 1.4	Light yellow	Yellow	No	6.0 ± 0.3	5.5 ± 0.4	7–10
Natalya	6.0 ± 1.0	Bright purple	Yellow	Yellow	5.5 ± 0.2	5.8 ± 0.4	8–10
O-10-14	7.6 ± 0.5	White cream	Cream	Yellow	6.2 ± 0.5	5.8 ± 0.3	8–9
K-28-1	8.3 ± 0.4	Dark blue	White and yellow	No	6.4 ± 0.2	6.9 ± 0.4	9–12
P-28-2	6.5 ± 1.0	Purple	White	Dirty purple	5.2 ± 0.1	7.0 ± 0.2	8–10
P-30-1	4.0 ± 1.2	Dark red	Yellow	Yellow	4.9 ± 0.3	5.6 ± 0.4	6–8
R-24-1	5.5 ± 1.2	Cream	Cream	Bright yellow	5.1 ± 0.6	6.5 ± 0.2	9–10
R-28-3	6.0 ± 0.8	Blue	White	Yellow	5.3 ± 0.2	7.5 ± 0.3	8–10
R-34-3	6.8 ± 0.5	Red-crimson	Yellow	No	6.1 ± 0.4	7.0 ± 0.5	9–11
S-34-4	5.5 ± 1.2	Light purple	White	White	5.0 ± 0.2	7.1 ± 0.2	8–10
T-10-1	7.0 ± 1.4	Cream	Cream	Bright yellow	6.1 ± 0.3	6.1 ± 0.4	10–11
T-10-2	4.6 ± 1.3	Dark blue	White	Yellow	4.5 ± 0.5	5.0 ± 0.5	7–10
T-10-2/1	7.6 ± 0.5	Light blue	White	Bright yellow	4.6 ± 0.2	6.5 ± 0.2	9–12

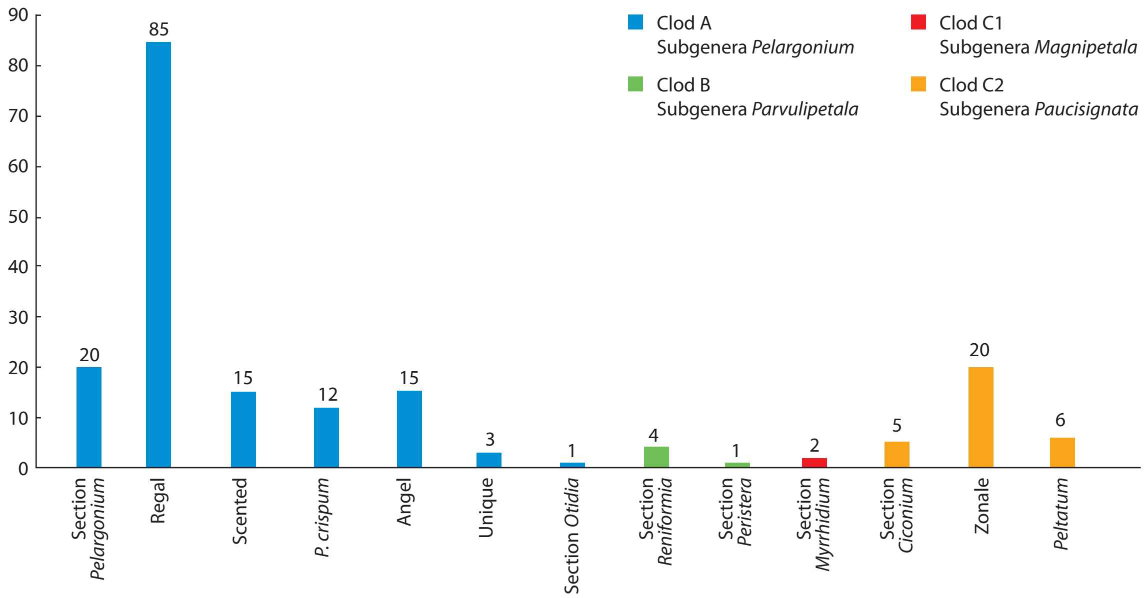

Fig. 18. Composition of *Pelargonium* collection at FRC SSC of RAS.

Table 7. Characteristics of cultivars and elite hybrid forms of pelargonium

Species, cultivar, hybrid	Plant height, cm	The main colour of the corolla	Flowering productivity, pcs	Flower diameter, cm	Duration of flowering, days	Resistance to biotic factors	Total decorativeness
Aristo. Clarina	27.3	Crimson-white	32 ± 2.4	5.0 ± 0.2	72 ± 14	Average	90
Yashma	31.2	Crimson-purple	31 ± 1.6	5.0 ± 0.4	105 ± 13	Good	96
G.K-15-10	16.5	Bright crimson-red	35 ± 2.2	5.5 ± 0.3	88 ± 11	Good	96
P. crispum	40.2	Pink-lilac	145 ± 16.2	2.3 ± 0.2	69 ± 21	Good	87
Sp.16-02	35.3	White	172 ± 10.5	2.8 ± 0.1	85 ± 14	Good	93
Angel. Swedish	26.1	White-dark-crimson	98 ± 11.9	2.1 ± 0.2	66 ± 12	Average	86
Angel. Zagadka	23.2	White-crimson	89 ± 16.4	2.3 ± 0.1	79 ± 10	Good	91
Angel. Tip-top	25.7	Pink-crimson	59 ± 13.5	2.4 ± 02	60 ± 17	Average	85
Surprise	30.1	White-dark-crimson	159 ± 18.0	2.9 ± 0.2	67 ± 15	Good	93
Burgundy Red	18.7	Pink-red	64 ± 13.6	2.5 ± 0.1	65 ± 18	Good	93
A. 15-08 Ocharovaniye	14.4	Pink-crimson	58 ± 15.1	2.6 ± 0.1	72 ± 16	Good	95
Carmen suita	26.5	Purple-crimson	34 ± 2.2	5.5 ± 0.3	88 ± 11	Good	96
P. gemstone	30.2	Red-pink	853 ± 16.2	2.5 ± 0.2	69 ± 21	Average	87
A. 15-08 Luchistaya	35.3	Roze-crimson	114 ± 10.5	3.1 ± 0.1	85 ± 14	Good	93
Pancy	26.1	White-dark-crimson	94 ± 11.9	2.1 ± 0.2	68 ± 10	Average	86
A. 15-03	23.2	White-violet	85 ± 16.4	2.3 ± 0.1	77 ± 12	Good	91
P. cordifolium	29.7	Pink-crimson	57 ± 11.7	2.4 ± 02	59± 16	Average	85
Sp. 15-01	29.8	White-bright-crimson	147 ± 16.8	2.8 ± 0.2	69 ± 14	Good	93
Aristo Violet	26.6	Pink-violet	64 ± 13.3	5.5 ± 0.3	68 ± 16	Average	93
Flamenko	23.4	Bright pink-crimson	88 ± 15.1	6.4 ± 0.2	92 ± 16	Good	95

collection (about 70 %) consists of representatives of the subgenus *Pelargonium* L'Hér. – these are wild-growing species, including those based on which many modern large-flowered and fragrant pelargonium cultivars, angels and unicums have been obtained (Gutiyeva, 2018).

Federal Research Centre the Subtropical Scientific Centre is carrying out breeding work on these groups using interspecific and intervarietal hybridization and intends to create adaptive, highly decorative, productive, and long-flowering cultivars with various flowering periods for universal use. More than 20 cross combinations were carried out. The nature of inheritance of the main decorative features in flower was determined. It was found that 60 % of the seedlings of the studied cross combinations inherited the maternal colour type. Decorative hybrids, carriers of various useful traits, including a fragrance with a high level of adaptability, were isolated from the hybrid offspring (Table 7, Fig. 19, 20).

Crown anemone (*Anemone coronaria* L.) is a perennial herb with an openwork decorative rosette leaves and relatively strong peduncles, 10–40 cm high. Flowers are 6–10 cm in diameter, diverse in shape and colour, with a long (up to 2.5 months) flowering period. Anemone is used in landscaping as a pot culture, in forcing and as a cut flower.

The collection of FRC SSC of RAS includes 25 anemone cultivars, 8 of which are foreign and 17 are domestic. The cultivars selected by the FRC SSC of RAS are distinguished by the diversity and richness in the colour of the perianth lobes, peduncle height and by the productive flowering. The main direction of work with this crop is the creation of cultivars for obtaining cut flower products. The production of new hybrid forms was carried out by intersort hybridization. Criteria for the selection of elite hybrid forms are as follows: a new colour of the corolla or a different combination of colours compared to the original forms; the diameter of the flower more than 6.5 cm; long (more than 25 cm) and stable peduncle; flowering productivity (the number of flowers per plant is more than 8); resistance to abio- and biotic factors (Table 8, Fig. 21).

Fig. 19. Large flower pelargonium cultivars: *a* – Carmen suita, *b* – Flamenko.

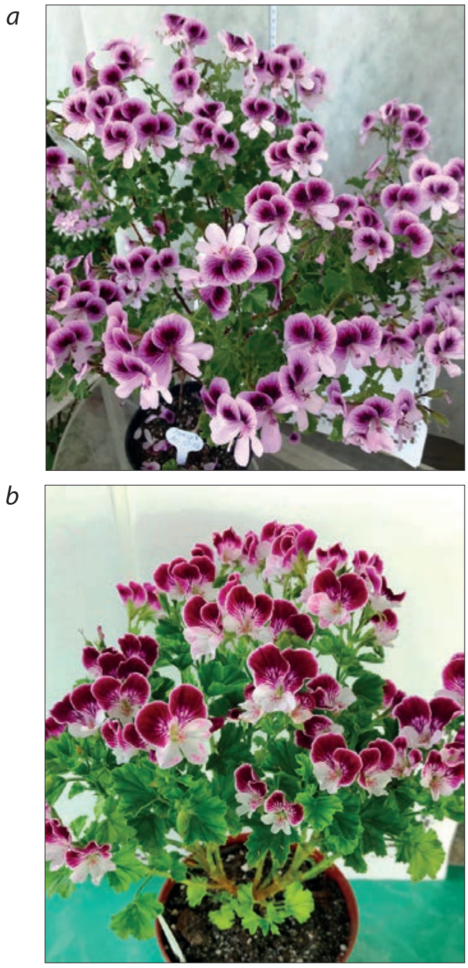

Fig. 20. Crisped-leaf pelargonium cultivars: *a* – Surprise, *b* – Zagadka.

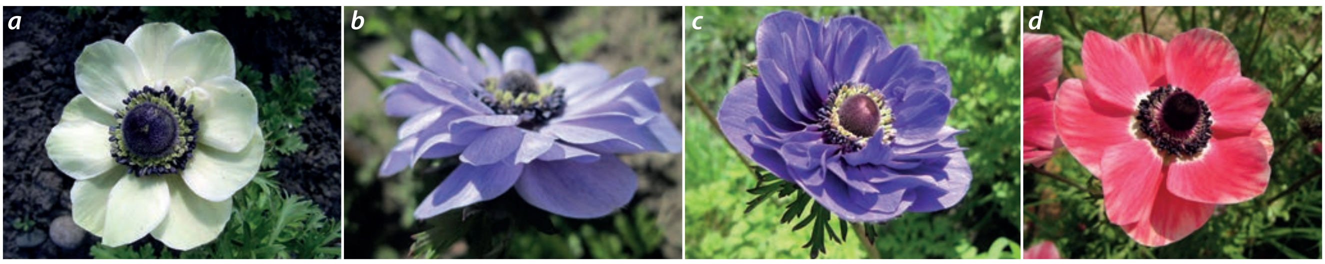

Fig. 21. Crown anemone cultivars: *a* – Polina; *b* – Flora; *c* – Volshebstvo; *d* – Letenitsa.

Garden chrysanthemum (*Chrysanthemum* × *hortorum* Bailey) is a perennial herbaceous crop that ranks second among cut flowers in terms of economic indicators. Modern cultivars differ in the shape, size and color of the inflorescences, in the height of peduncles, the shape of bush, and in flowering terms. Breeding cultivars that meet international standards and are adapted to the conditions of the humid subtropics in Russia is extremely important.

The hybrid fund of the FRC SSC of RAS includes 62 chrysanthemum forms, 10 of which are promising and 6 are elite (R-192-4, I-34-5, R-192-12, R-196-4, R-194-13, R-192-12). Two hybrid forms have been prepared for transfer to the State Cultivar Commission of the Russian Federation: R-196-4 and R-192-4. They have a high productivity of 75–125 pcs/m^2 and a long flowering period (30–35 days).

Conclusion

The analysis of results of using various methods in breeding subtropical and flower crops at FRC SSC of RAS showed that the most effective methods are remote and intervarietal

Table 8. Characteristics of cultivars and hybrid forms of crown anemone

Cultivar	Flower				Peduncle		Flowers from 1 plant, pcs
	Form	Main colour	Colour of the centre	Diameter, cm	Height, cm	Firmness	
Svetlana	Common	White-pink	White-pink	7.0–8.5	24–37	Good	10–12
Krasnaya Shapochka		Red-crimson		6.9–7.8	22–35		7–11
Feya	Semi-double	Rose-red	White-green	8.0–9.5	35.5–40.0	Excellent	12–16
Sineglazka	Common	White-yellow	Dark blue	7.7–9.0	30.2–35.7		10–13
Polina		White-yellow	Green-white	8.9	47.2		10–12
Letnyaya noch		Violet-purple	Dark violet	10.1	38.2		7–10
Eolanta	Semi-double	White-pink	White-pink	7.5–8.2	30.5	Good	10–12
Lesnoy ruchey		Dark blue-lilac	Light violet	7.5–8.9	32.3	Excellent	9–11
Vdokhnoveniye		Lilac-violet	Lilac-violet	8.0–9.0	36.7	Good	9–11
Zaryanitsa	Common	Rose-red, speckled	White-green	8.9–9.5	40.5	Excellent	11–14
Danaya		Red-crimson	White	9.0–11.0	35.3		9–11
Vesenniy ogon		Light red, lines	Light red	7.0–8.5	36.8		10–15
Svirel		Strong purple	Dark blue-violet	8.5–9.0	33.2	Good	8–12
Volshebstvo	Semi-double	Lilac-violet, saturated	Lilac-violet	8.4	36.7	Excellent	9–11
Letenitsa	Common	Rose red, lines	White	9.0	40.5		11–14
P-4-3		Pale red, lines	White-green	6.8–7.5	30.0–38.5	Good	10–12
P-5-4		Violet-lilac	Lilac	7.1–8.8	33.5–41.0	Excellent	11–13
P-5-5		Pink-crimson, white spots	White	7.5–9.0	35.0–42.0		9–11
P-8-17		Tender lilac, mottled	Violet-lilac	7.8–8.9	30.5–38.0	Good	10–12
P-10-18	Semi-double	Purple-violet	Red-black	7.5–8.5	31.0–39.0	Excellent	10–13
P-1-20	Common	Dark purple-violet	Violet	7.8–9.2	38.0–42.0		10–12
P-1-23	Semi-double	Dark blue-violet	Dark blue	8.0–9.5	35.0–40.0	Good	9–11
P-10-29	Common	White	White	9.5–11.0	38.0–45.0	Excellent	11–14
P-2-31		Bluish-violet, lines	Grey-blue	7.5–8.9	33.0–39.5	Good	10–12
P-2-32		Pale-purple	Dark purple	7.8–9.2	34.5–41.5	Excellent	11–13
P-5-80		Crimson	Pink-white	8.5–9.5	38.0–44.0		11–15

hybridization, clonal selection, selection of spontaneous mutations and selection of promising forms from open pollination.

Currently, the FRC SSC of RAS has a rich breeding fund of subtropical, southern fruit and flower plants, from which 989 forms have already been selected for further comprehensive study. Over the past five years, 50 new cultivars have been created and submitted to the State Cultivar Commission, including 26 cultivars of pelargonium, 15 – anemone, 5 – freesia, 2 – chrysanthemum, 1 – kaki persimmon and 1 – apple. In the "State Register of Selection Achievements Authorized for Use for Production Purposes" of the Russian Federation have been included 63 cultivars bred by FRC SSC of RAS, including 26 cultivars of pelargonium, 13 – anemone, 9 – chrysanthemum, 7 – freesia, 4 – hazelnut, 3 – feijoa, 1 – tea plant. 46 patents for breeding achievements were obtained.

Forty-seven sources of economically valuable traits were recorded, including 10 sources for citrus crops, 9 – for pelargonium, 8 – for freesia, 5 – for pear, 4 – for chrysanthemum, 4 – for kaki persimmon, 2 – each for anemone, tulip, kiwi fruit, and 1 – for feijoa.

New cultivars and hybrid forms bred by FRC SSC of RAS show a high adaptation degree to the specific natural and climatic conditions in the region, which distinguishes them from many introduced cultivars and makes it possible to replenish the zoned assortment; furthermore, they present a great interest for further breeding work. Some of them are used in production and landscaping not only in the region, but also in other areas in the south of Russia.

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ORCID ID

A.V. Ryndin orcid.org/0000-0001-9640-4840
R.V. Kulyan orcid.org/0000-0002-8406-8197
N.A. Slepchenko orcid.org/0000-0001-9757-7997

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Breeding of medicinal and essential oil crops in VILAR: achievements and prospects

I.N. Korotkikh ✉, D.N. Baleev, A.I. Morozov, P.G. Mizina, N.I. Sidelnikov

All-Russian Research Institute of Medicinal and Aromatic Plants, Moscow, Russia
✉ slavnica241270@yandex.ru

Abstract. This review discusses the main methods of breeding material development, the current state, problems and prospects for medicinal and essential oil plants breeding. The relevance of this area has especially increased due to the sanctions, the resulting shortage of medicinal plants and their low quality, which does not meet the requirements of the pharmaceutical industry. To produce a stable plant raw material base, it is necessary to actively develop a breeding process to create new highly productive varieties of medicinal plants resistant to biotic and abiotic environments. In breeding with the use of modern molecular biological methods, related species and generic complexes of the All-Russian Research Institute of Medicinal and Aromatic Plants (VILAR) collection can be involved, where there is extensive original genetic material of medicinal, essential oil, rare and endangered species. In the breeding of medicinal and essential oil crops, traditional methods of individual and individual-family selection, polyploidy, chemical mutagenesis and a combination of methods to obtain original breeding material are still promising. VILAR has created more than 90 varieties of medicinal and essential oil crops, most of which have been approved for use throughout the Russian Federation.
Key words: medicinal and essential oil plants; breeding; variety; breeding methods.

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Селекция лекарственных и ароматических растений в ВИЛАР: достижения и перспективы

И.Н. Коротких ✉, Д.Н. Балеев, А.И. Морозов, П.Г. Мизина, Н.И. Сидельников

Всероссийский научно-исследовательский институт лекарственных и ароматических растений, Москва, Россия
✉ slavnica241270@yandex.ru

Аннотация. Рассмотрены методы создания селекционного материала, а также современное состояние, проблемы и перспективы селекции лекарственных и эфирномасличных растений в Российской Федерации. Актуальность данного направления особенно возросла в связи с объявленными санкциями, возникшим дефицитом лекарственного растительного сырья и низким его качеством, не удовлетворяющим требованиям фармацевтической индустрии. Для формирования устойчивой сырьевой базы необходимо создание новых высокопродуктивных, устойчивых к воздействию биотических и абиотических факторов среды сортов лекарственных растений с применением современных молекулярно-биологических методов в селекции. В этой связи большой интерес представляют коллекции Всероссийского научно-исследовательского института лекарственных и ароматических растений, в которых имеется уникальный генетический материал лекарственных и эфирномасличных, в том числе редких и исчезающих видов растений. В селекции лекарственных и эфирномасличных культур все еще перспективны традиционные методы индивидуального и индивидуально-семейного отбора, полиплоидии, химического мутагенеза и сочетание методов для получения оригинального селекционного материала. В институте создано более 90 сортов лекарственных и эфирномасличных культур, большинство которых допущены к использованию на всей территории РФ.
Ключевые слова: лекарственные и эфирномасличные растения; селекция; сорт; методы селекции.

There is no plant that is not medicinal, and there is no disease that cannot be cured by a plant.

Tibetan wise saying

Introduction

Currently, about 350,000 species of flowering plants have been described, but not every one of them is sufficiently studied to be called medicinal. According to the definition of the Great Medical Encyclopedia, medicinal plants are plants used as a source of medicinal plant raw material and medicinal products of natural origin[1]. Medicinal plant raw material is either fresh or dried plants, or their parts (grass, leaves, flowers, fruits, seeds, bark, buds, roots, rhizomes, bulbs, tubers, corms and others) used for the production of herbal medicines. Herbal medicines include fatty oils, essential oils, resins, balms, extracts, tinctures, aqueous extracts, and individual bioactive substances (BS) or their mixtures[2]. These drugs are recommended for the treatment and prevention of almost the entire spectrum of diseases.

The chemical composition of medicinal plants and plant-derived BS is extremely complex. In order to estimate which group of BS has a particular effect, All-Russian Research Institute of Medicinal and Aromatic Plants (VILAR) carries out a complex of chemical and pharmacological studies on extraction, fractionation, purification, isolation of BS from each studied object and determination of their specific activity. It is important that the species of medicinal plants growing in different botanical and geographical zones may contain the same groups of BS allowing in the absence of some necessary species to use alternative medicinal plants and obtain target substances. For example, the flavonoid rutin (vitamin P) which has been shown to strengthen the capillaries is found in varying quantities in the aerial part of the buckwheat (*Fagopyrum esculentum* Moench), the fruits of the chokeberry (*Aronia melanocarpa* (Michx.) Elliott) and black currant (*Ribes nigrum* L.), buds and fruits of Japanese sophora (*Styphnolobium japonicum* (L.) Schott), flowers and fruits of blood-red hawthorn (*Crataegus sanguinea* Pall.), different species of rose hips (*Rosa* L.), in the wood of the lower part trunk of Siberian larch and Gmelin larch (*Larix sibirica* Ledeb., *Larix gmelinii* (Rupr.) Kuzen). Another group of plant-derived BS are tannins, which are contained in the rhizomes of *Bergenia crassifolia* (L.) Fritsch, *Bistorta officinalis* Delarbre, various types of potentilla (*Potentilla* L.), *Sanguisorba officinalis* L., in the bark of various oak species (*Quercus* L.), viburnum (*Viburnum opulus* L.), bird cherry (*Prunus padus* L.), blueberry (*Vaccinium myrtillus* L.), multiple fruits of *Alnus glutinosa* (L.) Gaertn., leaves of *Cotinus coggygria* Scop. and *Rhus coriaria* L. The ability to accumulate cardiac glycosides of cardenolide and bufadienolide nature in tissues has been found in 20 species of medicinal plants belonging to 10 different families (Karpuk, 2011).

The scientific program "From plant biochemistry to human biochemistry", developed by VILAR, allows to study the biosynthesis of plant BS and purposefully use them for the improvement of people's health, which is consistent with the goal of the state drug policy: to provide the population with affordable and high-quality medicines, including plant-derived ones, in a timely manner (Ulumbekova, Kalashnikova, 2018). Currently, their proportion occupies about 30 % of all drugs (Shirokova, 2013). And in this aspect, making a sustainable resource base of medicinal plants for pharmaceutical industry is of current interest. Among the set of tasks to solve this issue, the creation of new high-yielding varieties of medicinal and aromatic plants, resistant to the effects of biotic and abiotic factors, and the development of agricultural technologies for their cultivation is the most important.

Modern approaches for breeding of medicinal plants

Biotechnology and molecular biology are used along with traditional breeding methods to create new varieties of medicinal plants. In such a case, the main goal is to increase both the yield of medicinal plant raw material and the content of certain secondary metabolites. Improved genotypes are important to increase the profitability of the production of high-quality medicinal plant materials.

Information on the genetic diversity and inheritance of the selected traits is one of the conditions for effective plant breeding (Wagner et al., 2005). The development of molecular biology methods opens many new possibilities for plant breeders to solve complex problems they face in traditional breeding process. Most modern research on medicinal plants focuses on the study of their genetic variability using DNA markers (Run et al., 2020). New high-yielding cultivar of *Perilla frutescens* L. was created using data of genome-wide sequencing and SNP analysis (Shen et al., 2017). At the same time, very little is known regarding the approaches to medicinal plants improving based on the molecular mechanisms of metabolite biosynthesis (Máthé, 2015). For example, several structural genes associated with the biosynthesis of flavonoids in gentian were isolated and characterized (Nakatsuka et al., 2008; Shimada et al., 2009). Wagner et al. (2005) showed the phenomenon of monogenic inheritance of the (–)-α-bisabolol and chamazulene content in chamomile. The greatest success has been achieved in *Artemisia annua* L. breeding, which produces the important sesquiterpene lactone called artemisinin (Graham et al., 2010; Townsend et al., 2013).

In vitro tissue cultures are often used in the breeding of medicinal plants (Máthé, 2015). Effective systems for cultivation and regeneration of tissues including the cultivation of callus, anthers, and protoplasts, have been created for some species such as *Echinacea purpurea* (L.) Moench, *Dendrobium candidum* Wall., *Aristolochia contorta* Bunge, *Centella asiatica* L. and *Curcuma wenyujin* Y.H. Chen. (Wang et al., 2020). Biotechnology techniques play an important role in the conservation of some medicinal plants – in particular endangered species. In spite of the number of problems, there are significant prospects for future development of this field of research.

[1] The Great Medical Encyclopedia. Ed. by B.V. Petrovsky. 3rd edn. Vol. 12. Available at: URL: https://xn--90aw5c.xn--c1avg/

[2] Russian State Pharmacopoeia. 14 edn. GMP.1.5.1.0001.15. Medicinal plant raw materials. Available at: URL: https://pharmacopoeia.ru/ofs-1-5-1-0001-15-lekarstvennoe-rastitelnoe-syre/

Varieties of medicinal plants created by VILAR and prospects for their industrial use

The institute has collected and created an original and unique genetic material base of medicinal and aromatic (including rare and endangered) plant species. However, until recently, this material has not been studied properly. Morphotypes, closely related species and generic complexes can be involved in breeding using modern methods. For these purposes, collections of the genera *Digitalis* L., *Echinacea* Moench, *Origanum* [Tourn.] L., *Atropa* L., *Tanacetum* L. and *Mentha* L. have been set up in VILAR in the last decade. The development of modern approaches using cytological and molecular biological methods is very promising for the study of medicinal plants. Studies using various modern methods of chromosomal analysis at the early stages of ontogenesis (seedlings, cotyledons, and the first true leaves) make it possible to establish the cytogenetic characteristics of promising plant lines, which can then be included in the breeding process. Many species of medicinal plants have small chromosomes (up to 3 microns). The methods of selection and application of chromosomal markers were tested on ***Potentilla alba* L.** (Muravenko et al., 2003). In a paper by Samatadze et al. (2018) it was shown that the chromosomes of *P. alba* $2n = 28$ are very small (0.88 to 1.7 μm) and have a similar morphology (based of monochrome staining).

In the breeding of medicinal and essential oil plants success is often achieved by a combination of methods for obtaining original breeding material (for example, exposure to mutagens in order to obtain polyploids for subsequent hybridization). Selection of polyploid forms obtained as a result of 0.2 % colchicine solution exposure has been successfully used on **chamomile** (*Matricaria chamomilla* L.). Among the three varieties recommended for cultivation in the Russian Federation, the variety Podmoskovnaya is an autotetraploid ($2n = 36$), and Nasten'ka and Sibirskaya bisabololnaya (Fig. 1, *a*) are diploids ($2n = 18$) (Khazieva et al., 2017). Polyploid variety Podmoskovnaya is distinguished from others by larger inflorescences, which are 1.5 times bigger than those in the standard (variety Azulena), an elongated peduncle and weak foliage – important factors for mechanized harvesting. At the same time, the effect of the same mutagen on seedlings of ***Datura stramonium* L.** did not cause a change in the ploidy level but led to a unique mutation: the absence of thorns in capsule fruits (see Fig. 1, *b*, *c*), which simplifies the harvesting of seeds and does not injure hands of plant collectors (Konon et al., 2012).

Polyploids were also used at the initial stage of **peppermint** breeding (*Mentha* × *piperita* L.) to obtain fertile plants and their generative offspring: when exposed to 0.025 % colchicine solution, a fertile allopolyploid was obtained ($2n = 144$). In mint breeding, a targeted selection of fertile forms with valuable traits (yield of leaves and above ground mass, content of essential oil and menthol) used for hybridization or to obtain generative offspring from free pollination was carried out. In this case, vegetative propagation and clonal selection were used at the stage of assessment and reproduction of elite plants selected in hybrid offspring. In interspecific hybridization, other species of mint (*Mentha arvensis* L. and *M. sachalinensis* Kudo) were used to increase the winter hardiness of hybrids: this is how the Prilukskaya 6, Yantarnaya, Kubanskaya 6, Lekarstvennaya 1, Lekarstvennaya 4, Moskvichka and Medichka varieties, which are widespread in industry, were created (Fig. 2). Due to winter hardiness and high productivity in various natural climatic conditions, these varieties were zoned for all regions of the Russian Federation and recommended for complex use, including for the

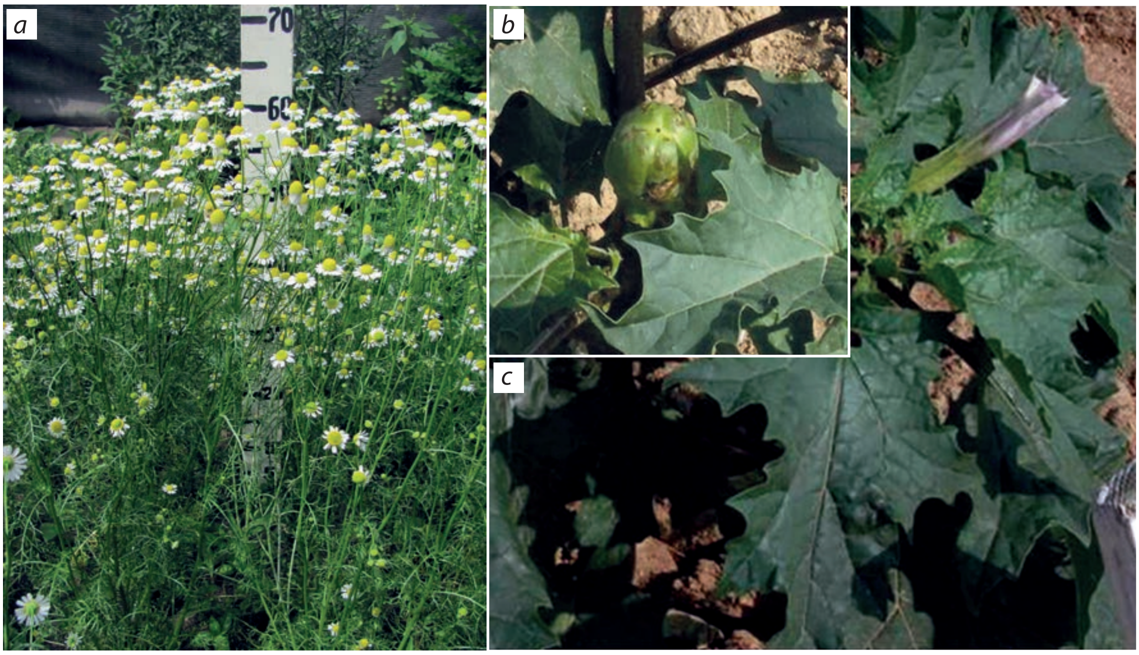

Fig. 1. *Matricaria chamomilla*: variety Sibirskaya bisabololnaya (*a*); *Datura stramonium*: variety Besshipnyi, fruit (*b*), plant in the flowering phase (*c*).

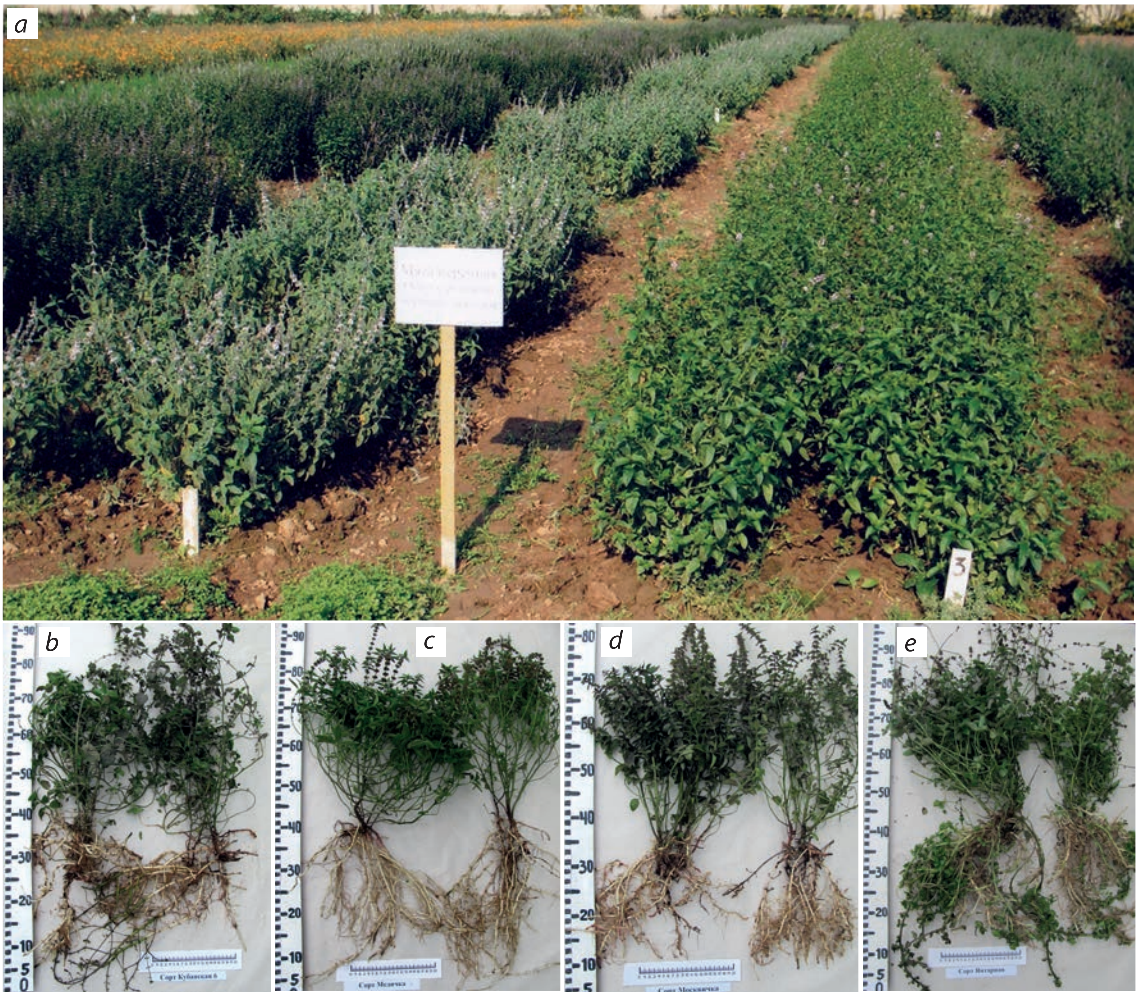

Fig. 2. *Mentha piperita*: collection nursery (*a*); varietal plants: Kubanskaya 6 (*b*), Medichka (*c*), Moskvichka (*d*), Yantarnaya (*e*).

production of essential oil and menthol (Morozov, 2018). The Aromatnaya mint variety was also isolated by clonal selection from a hybrid population; the essential oil of this variety has a mild taste and delicate aroma due to its low menthol content – an order of magnitude lower than that in the most other varieties (Morozov et al., 2012).

In the breeding study carried out by Glazunova et al. (2020), chemical mutagenesis was also used to obtain polyploids (tetraploid, $2n = 4x = 36$) of ***Polemonium coeruleum* L.** On the 2nd year of life polyploids were differed from diploid ones by sight (Fig. 3, *b, c*): tetraploids were undersized compact plants with a large number of peduncles. Moderate growth of the aboveground part contributes to the accumulation of active substances in the aboveground and underground parts; the volume and mass of the rhizome also increased.

The breeding based on the species created by mutagenesis was carried out for ***Calendula officinalis* L.** (Fig. 4, *a*). The most effective mutagens for *C. officinalis* were 0.05 % diethyl sulfate and 0.08 % dimethyl sulfate. By selection for morphological characters, productivity and biologically active substances (in M_1) and assessment for uniformity, distinctness and stability (in M_{2-3}), new marigold varieties Zolotoe more (Fig. 4, *d*) and Rajskij sad (Fig. 4, *c*) were developed. The yield of raw plant materials was 30–39 % higher compared to the standard variety Kal'ta, the content of extractives and total flavonoids content were increased by 13–21 and 29–43 %, respectively (Khazieva et al., 2016). The proportion of fractions suitable for mechanized sowing in the seed yield was increased: the fraction of hook-shaped seeds (up to 86 %), the fraction of ring-shared seeds (almost twofold) (see Fig. 4, *b*).

In the breeding of medicinal and aromatic plants, traditional methods of individual and individual-family selection are still promising, since most of these species were introduced into culture recently and are characterized by a high degree of polymorphism. Revealing the level of phenotypic variability and correlation of morphological and economically useful traits makes it possible to select the most productive morphotypes based on visual traits, easily taken into account. Breeding for productivity is carried out both for increasing the yield of raw plant materials and the content of BS.

It should be noted that for the medicinal plants, the relationship between the yield of raw materials and the content of BS is a negative correlation value – this is because substances useful to humans are secondary metabolites used by plants for growth, development and adaptation to external factors. Therefore, sequential separate selection is mainly performed:

Fig. 3. *Polemonium coeruleum*: variety Lazur' (*a*); leaf and rhizome of diploid form (*b*, *c*, left) and tetraploid form (*b*, *c*, right).

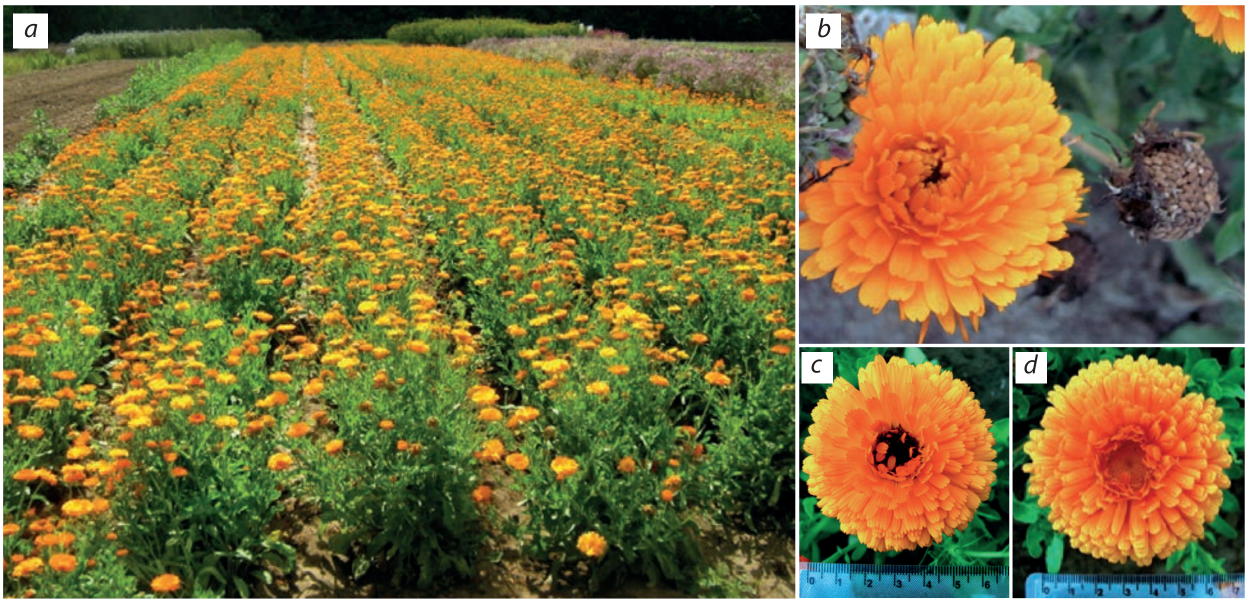

Fig. 4. *Calendula officinalis*: nursery seed of the variety Zolotoe more (*a*); inflorescence and infructescence of the *C. officinalis* double inflorescences form (*b*); inflorescence of the varietal plant Rajskij sad (*c*) and Zolotoe more (*d*).

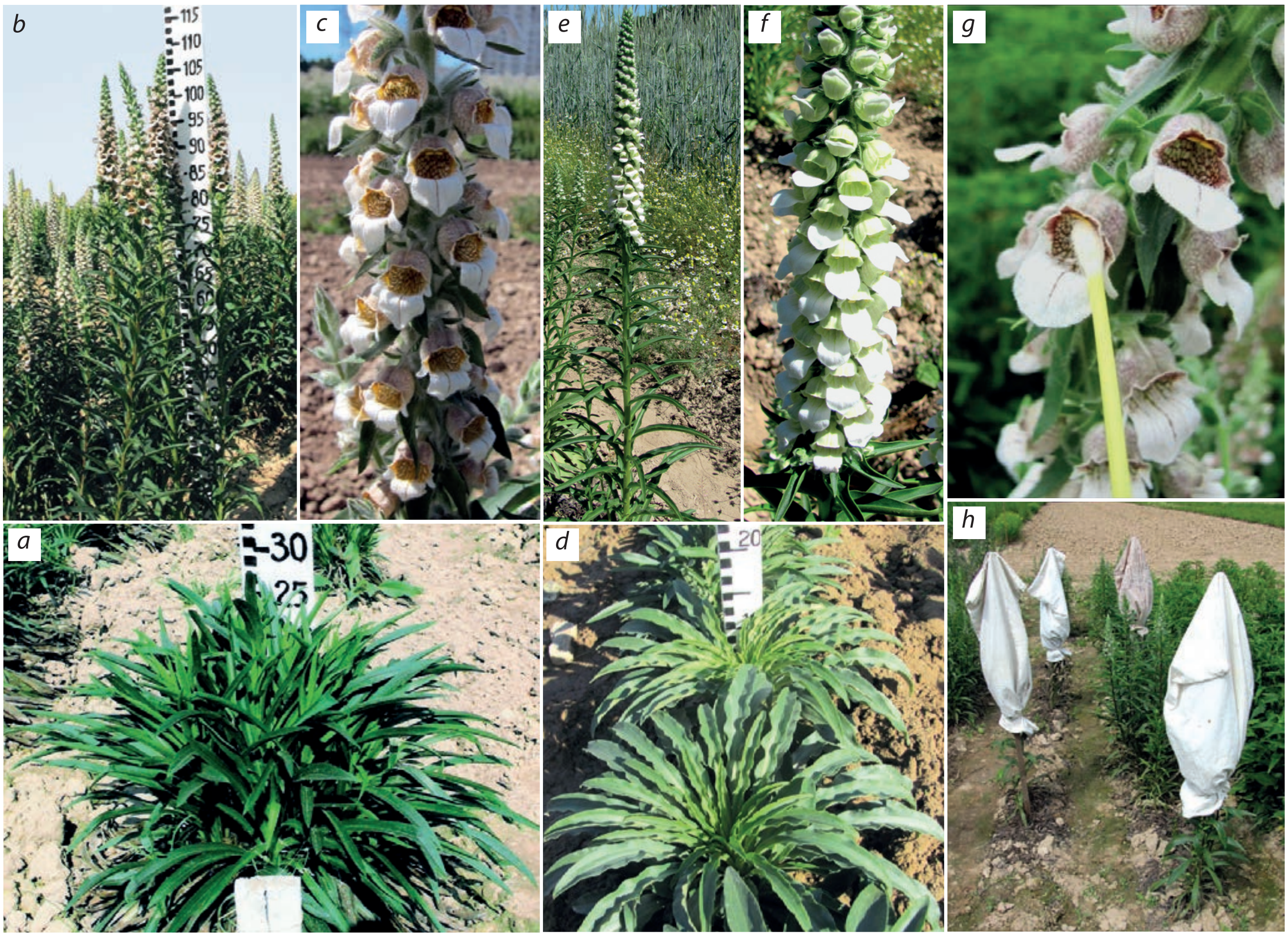

Fig. 5. *Digitalis lanata*: plant variety Ritm, immature rosette of basal leaves of plants 1st year (*a*), generative shoots (*b*) and inflorescence (*c*) of plants 2nd year. *D. lanata* white-flowered form, immature rosette of basal leaves of plants 1st year (*d*), generative shoots (*e*) and inflorescence (*f*) of plants 2nd year. Artificial pollination under the insulator (*g*); individually-insulated plant (*h*).

initially, productive morphotypes are selected according to a complex of external characteristics (usually, the number and size of plant organs); after that, morphotypes with a high content of BS are selected. In accordance with the goals of breeding and the biological characteristics of particular plants, one or another method of selection and reproduction is used. For example, the breeding material of ***Digitalis lanata* Ehrh.** was created using forced self-pollination under the conditions of mechanical isolation (Fig. 5, *g*, *h*) and subsequent multiple systematic individual selection in 1st–3rd self-pollinated offspring (Korotkikh et al., 2013). Based on one of self-pollinated offspring, the variety Ritm was created (see Fig. 5, *a*–*c*). In comparison with the standard variety Spectr, the yield of the raw material (leaves) of the new variety was 25–30 % higher and the adaptability to mechanized harvesting was improved due to the vertical deflection of the rosette leaves. The morphotypes were also differed in lanatoside content ranged from 0.22 to 0.65 %. As a result of repeated self-pollination, the original form of *D. lanata* was obtained. It was characterized by white flowers (see Fig. 5, *d*–*f*) with a decorativeness as good as the widely known decorative varieties of *D. purpurea* L.; it even exceeds these varieties in flowering duration (41–47 days).

For breeding aromatic perennial herb **oregano** (*Origanum vulgare* L.), vegetative propagation by division of the rhizomes was used to select clones. In the development of young plants, two reproductive phases were noted (summer and fall); plants formed seeds in the current growing season and could be used in breeding and for preservation *ex situ* biological collection. Using the method of individual selection, we isolated the samples of oregano clones with high yields of raw materials and the content of essential oil (Korotkikh et al., 2015). The selection was carried out according to the height of the plants and the color of the flowers (Fig. 6, *a*). Tall forms including variety Raduga (see Fig. 6, *b*) were characterized by the maximum yield of raw plant materials. However, the maximum essential oil total harvest was possible from plants of medium height and low-growing plants due to the increased content of essential oil being between 0.8 and 2.4 times higher, which indicates their value for cultivation (see Fig. 6, *c*, *e*).

With repeated successive self-pollination of *O. vulgare*, the original creeping form was obtained (see Fig. 6, *f*, *g*), which does not form a typical rhizome with the aerial part approximately 10–12 cm tall and consists of three hundred or more thin succulent shoots. The content of essential oils cor-

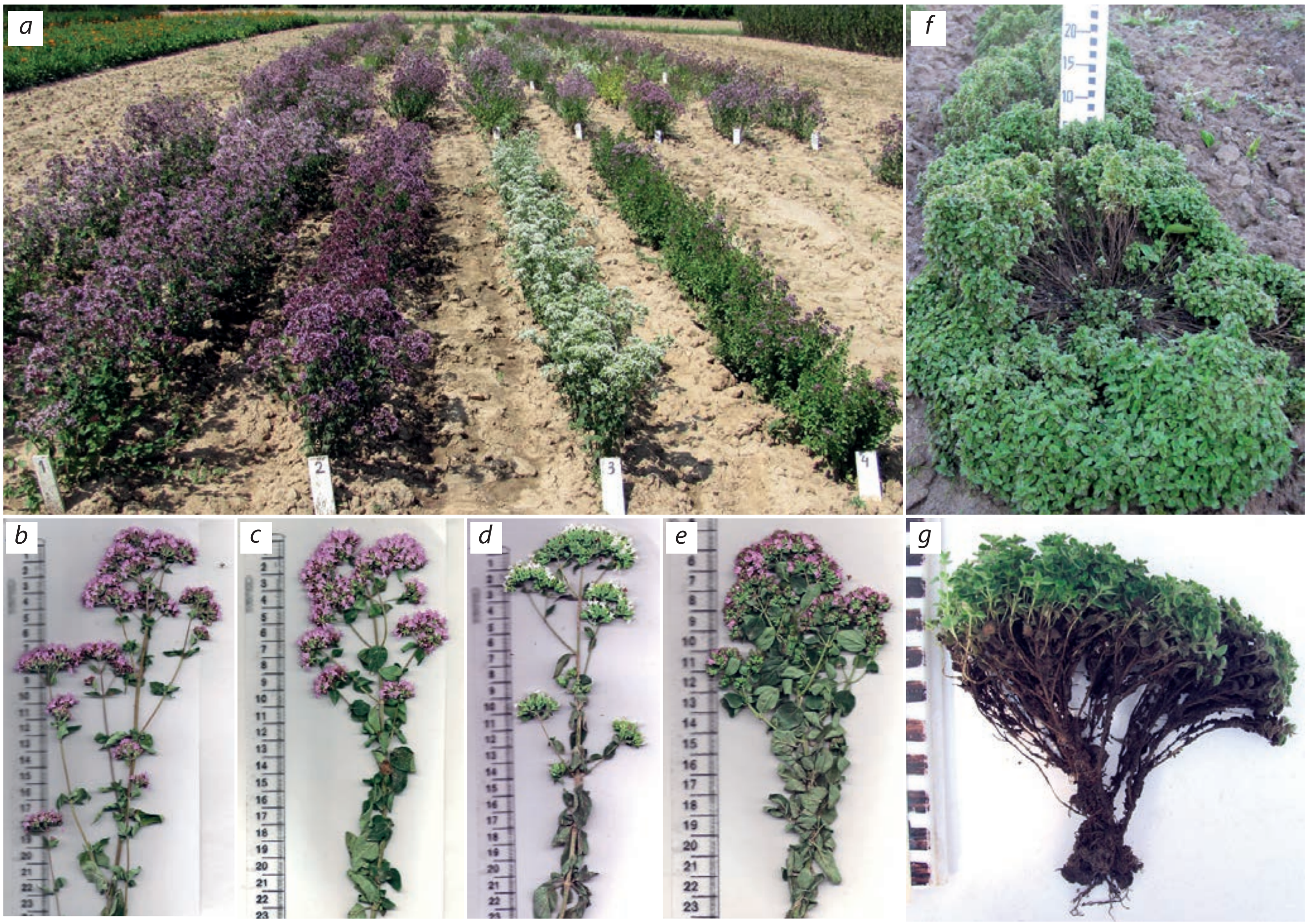

Fig. 6. *Origanum vulgare*: collection nursery (*a*) and generative shoots of varieties Raduga (*b*), Slavnitsa (*c*), Zima (*d*), No. 12-06 (*e*); creeping form *O. vulgare* (*f*, *g*).

responded to that in the initial form. Overall, this form could be recommended for food or decorative purposes.

The phytochemical study of essential oil samples of oregano (*O. vulgare*) varieties revealed that sesquiterpenes (β-elemene, α-copaen, β-caryophyllene, germacrene D, β-bisabolene, etc.) predominated in all varieties and their maximum content was found in the variety Zima (51 % in essential oil). The identification (or creation) of intraspecific chemotypes by the composition of the essential oil is relevant in connection with their specific pharmacological activity (antimicrobial, cytotoxic, analgesic, anti-inflammatory, antibacterial). The content of monoterpenes (α-thujene, α-pinene, sabinene, β-myrcene, α-terpinene, γ-terpinene, β-linalool, β-terpineol, borneol, etc.) in the variety Slavnitsa was 6 and 15 times higher than that in varieties Raduga and Zima, respectively. The highest content of phenolic compounds (thymol, methyl ether, thymol carvacrol) was found in the variety Raduga (Khazieva et al., 2019).

Supportive selection. Traditional breeding methods used in VILAR help in continuous breeding improvement with the involvement of already created varieties and primary seed production. However, multiple reproductions of the cultivated variety lead to accumulation of the low-value morphotypes resulting in decreased or lost stability of varietal indicators. Due to the instability of meteorological indicators, the frequency of drought, freezing, and soaking increases. Older varieties may not be adapted to such non-typical growing conditions.

Breeding of introduced species. With regard to introduced species, the aim of breeding is to increase not only valuable agronomic indicators (yield and quality of raw plant materials), but also indicators showing adaptation to regional conditions (seed productivity, duration of the growing season and winter hardiness). For example, only long-term acclimatization and mass selection in a cultivated population of ***Echinacea purpurea* (L.) Moench** made it possible to obtain high-quality seeds of local reproduction and subsequently to create national varieties, distribute and cultivate a new crop in Russia. Breeding of *E. purpurea* has been carried out in VILAR since 1996 and resulted in the first national variety Tanyusha (Fig. 7, *a*); in specific regional conditions of the North Caucasian branch of VILAR, the variety Yuzhanka was created (see Fig. 7, *b*). By individual selection using vegetative reproduction (initial form) and self-pollination (within the family), we obtained breeding material with stable productivity and adaptability which became the basis for a new variety Severyanka developed for the Non-Chernozem zone (see Fig. 7, *c*) (Korotkikh et al., 2019).

Fig. 7. *Echinacea purpurea*: varietal plants Tanyusha (*a*), Yuzhanka (*b*), Severyanka (*c*).

Conclusion

Plant breeders of the VILAR and its branches have created more than 90 varieties of medicinal and aromatic plants using selection methods, intraspecific and interspecific hybridization, experimental polyploidy and mutagenesis for more than 70 years. A total 62 varieties, of which 17 varieties are protected by patents of the Russian Federation, were included in the "State Register of Breeding Achievements" in 2020 and approved for use on the territory of Russia. Collections of seeds and vegetative plants have been created and maintained to preserve varietal material.

Long-term studies have shown that in the breeding of medicinal and aromatic plants, the most promising is the complex study and use of the natural intraspecific variability of the crops. In recent years, there have been large-scale changes in molecular biology and information technology related to the study of genomes, transcriptomes, proteomes, small RNAs, epigenetics, gene editing and synthetic biology. Modern methods of breeding can involve morphotypes, closely related species and generic complexes. Collections of species promising for breeding and introduction are currently being formed at VILAR for these purposes. Therefore, the duration of the breeding cycle – which traditionally required 5–6 years for annual and biennial medicinal and aromatic crops, and 7–10 years for perennial crops – can be reduced if the studies are carried out year-round in laboratory and in greenhouses, making it less dependent on the duration of the growing season.

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ORCID ID
I.N. Korotkikh orcid.org/0000-0002-0954-9353
D.N. Baleev orcid.org/0000-0002-1228-0594
A.I. Morozov orcid.org/0000-0002-4293-8457
P.G. Mizina orcid.org/0000-0001-6510-9603
N.I. Sidelnikov orcid.org/0000-0002-0132-1530

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Genetic resources of vegetable crops: from breeding non-traditional crops to functional food

Yu.V. Fotev[1, 2] ✉, A.M. Artemyeva[3], O.A. Zvereva[3]

[1] Central Siberian Botanical Garden of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia
[2] Novosibirsk State Agrarian University, Novosibirsk, Russia
[3] Federal Research Center the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR), St. Petersburg, Russia
✉ fotev_2009@mail.ru

Abstract. In this review, the authors considered the promising species of vegetable crops for introduction and breeding in the Russian Federation. An attempt was made to assess the possibilities of their breeding improvement from the standpoint of the presence of traits that limit large-scale production. Species that could potentially serve as sources of a high content of functional food ingredients (FFI) have been identified and characterized. For the successful introgression of these species in the Russian Federation, we proposed the methodological approaches including the assessment of the potential cold resistance of thermophilic crops in the mature male gametophyte *in vitro* (e.g., asparagus bean). The increase in the biodiversity of vegetable plants and improving of their nutritional value should be recognized as one of the main tasks, along with the growth of crop productivity. It is proposed to use the ratio of the total number of the registered cultivars of a particular crop to the number of years since the first cultivar of that crop has been included in the State Register of Breeding Achievements Admitted for Use as a measure of demand. It is advisable to formalize the trait "high content of FFI" in crops, taking as a basis, for example, a 2–4-fold excess of the content of any FFI or their complex in a cultivar over the crop's standard (reference) value. Such varieties should be included in the State Register of Breeding Achievements Approved for Use as a separate list. The purpose of their separation in the State Register is to ensure the potential interest of investors and business structures in the sale of functional food on the market. The paper discusses in detail the most promising species of introduced vegetable crops from five families (Brassicaceae, Amaranthaceae, Solanaceae, Leguminosae, Cucurbitaceae). The following species are proposed as potential sources of high FPI content: *Brassica oleracea* ssp. *oleracea*, *B. oleraceae* var. *alboglabra*, *B. rapa* ssp. *chinensis*, *B. rapa* ssp. *narinosa*, *B. rapa* ssp. *nipposinica*, *B. rapa* ssp. *rapa*, *B. juncea*, *Cochlearia officinalis*, *Lepidium sativum*, *Amaranthus caudatus*, *A. cruentus*, *A. hypochondriacus*, *A. dubius*, *A. tricolor*, *A. lividus*, species in the genus *Physalis* L., *Momordica charantia*, *Benincasa hispida*, *Cucumis metuliferus*, *Vigna unguiculata*.
Key words: introduction; breeding; underutilized vegetable crops; functional food; functional food ingredients.

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Генетические ресурсы овощных растений: от селекции нетрадиционных культур к функциональным продуктам питания

Ю.В. Фотев[1, 2] ✉, А.М. Артемьева[3], О.А. Зверева[3]

[1] Центральный сибирский ботанический сад Сибирского отделения Российской академии наук, Новосибирск, Россия
[2] Новосибирский государственный аграрный университет, Новосибирск, Россия
[3] Федеральный исследовательский центр Всероссийский институт генетических ресурсов растений им. Н.И. Вавилова (ВИР), Санкт-Петербург, Россия
✉ fotev_2009@mail.ru

Аннотация. Рассмотрены перспективные для интродукции в России виды овощных культур и сделана попытка оценить возможности их селекционного улучшения по признакам, ограничивающим масштабное производство этих культур. Обсуждаются методические подходы, которые включают в себя признаки, способствующие успешной интрогрессии данных видов в РФ, и направлены на преодоление барьеров на пути расширения сортимента выращиваемых культур. На примере вигны предлагается проводить оценку потенциальной холодостойкости теплолюбивых культур в фазе зрелого мужского гаметофита *in vitro*. Одной из главных задач, наравне с ростом продуктивности культур, следует признать расширение сортимента рекомендуемых для широкого выращивания овощных растений. В качестве характеристики «степени востребованности культуры» предложено использовать показатель отношения общего числа зарегистрированных

сортов по культуре к количеству лет с года включения в «Государственный реестр селекционных достижений, допущенных к использованию» первого сорта. Намечены возможные виды-источники высокого содержания функциональных пищевых ингредиентов (ФПИ) и охарактеризованы потенциальные доноры ФПИ. Целесообразно формализовать признак «высокое содержание ФПИ», приняв за основу двух-четырехкратное превышение содержания конкретных ФПИ или их комплекса в новом сорте по сравнению со стандартными сортообразцами или видами по селектируемой (интродуцируемой) культуре. Эти сорта целесообразно включать в «Госреестр…» отдельным списком. Цель такого выделения – обеспечить потенциальную заинтересованность производственников, инвесторов и бизнес-структур в реализации новых товарных позиций на рынке функциональных продуктов питания. Рассмотрены наиболее перспективные виды-интродуценты овощных культур из пяти семейств (Brassicaceae, Amaranthaceae, Solanaceae, Leguminosae, Cucurbitaceae). В качестве потенциальных источников высокого содержания ФПИ рекомендованы следующие виды: *Brassica oleracea* ssp. *oleracea*, *B. oleraceae* var. *alboglabra*, *B. rapa* ssp. *chinensis*, *B. rapa* ssp. *narinosa*, *B. rapa* ssp. *nipposinica*, *B. rapa* ssp. *rapa*, *B. juncea*, *Cochlearia officinalis*, *Lepidium sativum*, *Amaranthus caudatus*, *A. cruentus*, *A. hypochondriacus*, *A. dubius*, *A. tricolor*, *A. lividus*, виды рода *Physalis* L., *Momordica charantia*, *Benincasa hispida*, *Cucumis metuliferus*, *Vigna unguiculata*.
Ключевые слова: интродукция; селекция; нетрадиционные овощные культуры; функциональные продукты питания; функциональные пищевые ингредиенты.

Introduction

The domestication of many cultivated plants, including vegetable crops, often took place around the world in the form of introduction (Bazilevskaya, 1964). Some new species began to occupy leading positions in peasant farms, displacing the previous “favorites”, while others remained unclaimed. They are called “non-traditional crops” in the scientific agricultural literature.

The lack of planting material, insufficient awareness of the population (potential consumers) about nutritional and medicinal value of non-traditional crops and the lack of information about specific cultivation technology of these crops are considered to be possible reasons for insufficient use of non-traditional crops (Jena et al., 2018). In addition to these three reasons, another important factor in Russia is the presence of agrobiological traits and/or their expression, which limits the possibility of effective cultivation of such crops in the conditions of real agrocenosis in many regions of the country. A long growing season exceeding the duration of the frost-free period of many territories of the Russian Federation, poor resistance to low temperatures, high sensitivity of the generative sphere to environmental factors, susceptibility to diseases and pests, inadequacy of the quality of marketable products to consumer expectations also limit the potential of new crops and the possibility of their positioning as food products, including functional ones.

The problem of expanding production and the demand for new crops

The All-Union Institute of Plant Industry (now the All-Russian Institute of Plant Genetic Resources (VIR)), headed by N.I. Vavilov, played an outstanding role in the collecting and studying of the collection of vegetable plants which were new for Russia. A lot of new species were first included in the collection of the Institute with Vavilov’s active participation (Vavilov, 1987).

At present time the world collection of vegetable and melon crops of the Russian Federation, stored in the VIR, has more than 50 thousand samples belonging to 29 families, 145 genera, and 610 species. The status of the collection samples is as follows: 5.5 % are wild species and primitive forms; 34 % are landraces; 49 % – breeding (commercial) varieties; 11.5 % – different types of breeding lines and hybrids, including hybrid populations. The uniqueness of the collections of some vegetable crops reaches 80 %.Vegetable crops presented in the VIR collection belong mainly to 9 families:

– Brassicaceae Burn.;
– Solanaceae Juss.;
– Leguminosae Juss.;
– Cucurbitaceae Juss.;
– Alliaceae Borkh.;
– Apiaceae Lindl.;
– Amaranthaceae Juss.;
– Asteraceae Bercht. et J. Presl;
– Lamiaceae Martinov.

The diversity of these large taxonomic groups is exceptionally great in terms of the biochemical characteristics of the representatives of these families. Some of the species and crops that deserve priority inclusion in the introduction programs from the standpoint of their biochemical value and the possibility of use as functional foods (FF) are listed below. At the same time, the problem of expanding production of cold-resistant crops used as leafy vegetables (species from the Brassicaceae family and, partly, Amaranthaceae) in agricultural enterprises is largely associated with the lack of agricultural technologies and the availability (supply) of high-quality seed material and, to a lesser extent, with their adaptive potential (e. g., preference of short-day and/or resistance to pathogens and pests), compared with traditional heat-loving vegetable crops. On the contrary, many introduced species of heat-loving vegetable plants from the Solanaceae, Cucurbitaceae, and Leguminosae families with narrow ecological plasticity are carriers of traits that prevent the scaling up their production in the regions of Russia (sensitivity to low temperatures and response to the day length, susceptibility to certain diseases, etc.) (Supplementary Material)[1]. Such species require significant breeding and genetic improvement for cultivation in a real agrocenosis.

The Table provides basic information about the range of non-traditional vegetable crops presented in the State Register. The number of registered cultivars varies from 1 (naranjilla, kiwano) to 61 (Chinese cabbage), while the period of stay

[1] Supplementary Material is available in the online version of the paper: http://vavilov.elpub.ru/jour/manager/files/Suppl_Fotev_Engl.pdf

Assortment of non-traditional vegetable crops in the "State Register of Selection Achievements Authorized for Use" [National List]

Crop	The number of cultivars in the State Register of the Russian Federation in 2020	Year of inclusion of the 1st cultivar in the State Register	Number of years from the year of inclusion of the 1st cultivar in the State Register (up to 01.01.2021)	Median year of inclusion of cultivars in the State Register	Skewness	Kurtosis	Coefficient of demand for the crop*
Kale (Collard greens) *Brassica oleracea* ssp. *oleracea* L.	5	2000	20	2020	–0.6	–3.3	25
Pakchoi *B. rapa* ssp. *chinensis* (L.) Hanelt	19	2000	20	2010	–0.1	–1.3	95
Chinese cabbage *B. rapa* ssp. *pekinensis* (Lour.) Hanelt	61	1962	58	2008	–2.4	10.3	107
Mizuna or Japanese mustard greens *B. rapa* ssp. *nipposinica* (L.H. Bailey) Hanelt	5	2002	18	2011	–0.7	–0.9	28
Leaf mustard *B. juncea* Czern.	21	1942	78	2008	–2.8	9.9	27
Cress *Lepidium sativum* L.	17	1995	25	2010	–0.9	0.03	70
Amaranth, species of *Amaranthus* L.: *A. dubius* Mart. ex Thell., *A. tricolor* L., *A. caudatus* L., *A. cruentus* L., *A. lividus* L., *A. hypochondriacus* L.	6	2004	16	2008	1.1	–0.4	50
Common chicory *Cichorium intybus* L. var. *foliosum* Hegi	10	2008	12	2015	–0.6	–1.1	83
Pepino *Solanum muricatum* Aiton	2	1999	21	–	–	–	10
Naranjilla *S. quitoense* Lam.	1	2001	19	–	–	–	5
Physalis (*Physalis* L.) *Ph. ixocarpa* Brot., *Ph. pubescens* L., *Ph. peruviana* L., *Ph. philadelphica* Lam.	13	1990	30	2006	–0.2	0.4	43
Bitter melon *Momordica charantia* L.	5	2006	14	2018	–2.0	4.0	36
Wax gourd *Benincasa hispida* (Thunb.) Cogn.	2	2008	12	–	–	–	17
Kiwano *Cucumis metuliferus* E. Mey. ex Naudin	1	2006	14	–	–	–	7
Asparagus vigna *Vigna unguiculata* (L.) Walp.	25	2006	14	2015	–0.5	–1.1	179

$$^{*}\text{ Coefficient of demand for a crop} = \frac{\text{Total cultivars of crop in the State Register}}{\text{The number of years since the year of inclusion of the first cultivar in the State Register}} \times 100.$$

in it from the year of registration of the first cultivarup to 01.01.2021 varies from 12 (wax gourd, common chicory) to 78 years (leaf mustard). Most of the cultivars have been relatively recently bred and included in the State Register: the median of the year of inclusion falls on 2006–2020. The largest minus values of the coefficient of asymmetry by a year: –2.8, –2.4, –2, respectively, for mustard, Chinese cabbage, and bitter melon, illustrate a sharper increase in the number of inclusions in the State Register in recent years (which means an interest for them from consumers and breeders), compared with an earlier period – the year of registration of the first cultivar. On the contrary, the interest of breeders in the registration of amaranth cultivars has decreased in comparison with the previous period – the coefficient of skewness is 1.1. Leptokurtic (peaked) distribution by years of inclusion in the State Register cultivars of Chinese cabbage, mustard, and bitter melon with kurtosis indices, respectively, 10.3, 9.9, and 4.0 shows a significant increase in the number of registrations of breeding achievements for these species around the median indicator (year). The ratio of the total number of registered cultivars by crop to the number of years since the year of inclusion in the State Register of the first cultivar shows the relative degree of demand for the crop, although this may also indicate the lack of available intraspecific genetic diversity (biodiversity) necessary for its breeding improvement. The calculated "coefficient of demand for the crop" turned out to be the maximum for asparagus vigna (179), Chinese cabbage (107), and pakchoi (95).

Below, as an example of the choice of the object of introduction and selection, we will consider information about the three most promising, from our point of view, crops.

Asparagus vigna (*Vigna unguiculata* (L.) Walp.) is a valuable vegetable crop that could be used as a functional food (Fotev et al., 2019). Its cultivation in Russia is limited due to high heat demand, negative reaction of many cultivars for a long day, and susceptibility to some pathogens. The collection of cowpea VIR includes 4092 specimens of 9 species of the genus *Vigna* Savi (Vishnyakova et al., 2019). As of 01.01.2021, 25 Russian cultivars of *V. unguiculata* are included in the State Register.

Fig. 1. Asparagus vigna, cultivar Sibirskiy razmer. Photo by Yu.V. Fotev.

Cold hardiness is a complex trait in many crops. There are different methods of evaluating cold resistance. For example, a close positive correlation was found between the resistance to low temperatures of microgametophyte and sporophyte in tomato cultivars (Kilchevsky, Pugacheva, 2002). According to V.V. Vinogradova (1988) "when adapting tomato to low temperatures, the most effective assessment of cold resistance is the method of pollen germination in the solution of 15 % sucrose and H_3BO_3 (100 mg/l) at 6–10 °C" (p. 78). On a solution of a synthetic osmotically active substance – polyethylene glycol with a molecular weight of 6000 (PEG 6000), which does not participate in the metabolism of plant cells (Steuter et al., 1981), species, varieties, and interspecific hybrid forms of tomato combining resistance to low and high temperatures for stages of pollen germination *in vitro* were selected (Fotev, 2013). To assess the resistance of different samples of cowpea to low temperatures, it is advisable to evaluate the growth response of pollen *in vitro* also on a PEG 6000 solution at a concentration of 20 % with boric acid 0.006 % (Fotev, Belousova, 2013). In the Central Siberian Botanical Garden (hereinafter CSBG), the highest indices of cold resistance in the form of the ratio of pollen germination at low (10 °C – 24 h) temperature to the same index at 25 °C for 3 h were observed in *V. unguiculata* samples: Lulin (87 %), Zinder (65 %) and Sibirskiy razmer (46 %) (Fig. 1).

Fig. 2. Wax gourd, cultivar Akulina. Photo by Yu.V. Fotev.

In addition, the cultivars of asparagus cowpea, Sibirskiy razmer (see Fig. 1), and Yunnanskaya, bred in Russia have a neutral reaction to day length.

Selected forms that showed a high level of resistance to *Botrytis cinerea* Pers. and *Sclerotinia sclerotiorum* (Lib.) de Barywere selected in the CSBG: forma 901, forma No. 323 [striped], Early Prolificacy Xiao Bao #2, F_1 (Early Prolificacy Xiao Bao #2 × Sibirskiy razmer) and F_3 (Early Prolificacy Xiao Bao #2 × Sibirskiy razmer) (Fotev, Kazakova, 2019).

Wax gourd (*Benincasa hispida* (Thunb.) Cogn.) originates from Indochina and is widely cultivated in India, Japan, China, and many other tropical countries. Wild wax gourds have small fruits (<10 cm in length), while most cultivars produce giant fruits (up to 80 cm in length and weighing over 20 kg).

Wax gourd fruits contain vitamins, flavonoids, triterpenoids, and metabolites that can be used in the treatment of various diseases. The plant is used as a tonic for the brain, heart disease, and nosebleeds (Biradar et al., 2016). This crop can be seen as avaluable FF.

The first cultivar in Russia of wax gourd – Akulina (Fig. 2) was created in the CSBG. The direction for the improvement of the crop can be the breeding of more cold-resistant cultivars, gynoecious forms, and F_1 hybrids based on them.

Kiwano (*Cucumis metuliferus* E. Mey. ex Naudin) is a vegetable crop, the fruits of which can be stored for up to six months under normal ("room") conditions. Only one cultivar – Zeleniy drakon (Green Dragon) (Fig. 3) – included in the State Register is bred in the CSBG and characterized by a short period from germination to fruiting and high productivity in the outdoor conditions in the south of Western Siberia and greenhouses.

Fig. 3. Kiwano, cultivar Zeleniy drakon. Photo by Yu.V. Fotev.

Kiwano alkaloids have a protective effect on both the liver and kidney tissue (Anyanwu et al., 2014) and antiviral properties against Newcastle disease caused by a virus from the family Paramyxoviridae, a dangerous pathogen for birds (Anyanwu et al., 2016).

Kiwano fruit tastes good but contains a lot of seeds. The use of parthenocarpy can solve this problem. It is known that a short day (Lim, 2012) and low temperatures (Benzioni, 1997) results in the formation of parthenocarpic fruits in this crop.

In addition, kiwano plants can serve as good rootstocks for watermelon against rootworm nematode from the genus *Melodogyne* Goeldi (Kyriacou et al., 2018) and for melon (*Cucumis melo*), due to resistance to nematodes and fusarium (Guan et al., 2014).

Conclusion

As discussed above, the species and forms of vegetable crops that are promising for the Russian Federation were considered for introduction and subsequent breeding. Particular attention is paid to the species – potential sources of high functional food ingredients (FFI) content. These primarily include species of the Brassicaceae family: *B. oleracea* ssp. *oleracea*, *B. oleraceae* var. *alboglabra*, *B. rapa* ssp. *chinensis*, *B. rapa* ssp. *narinosa*, *B. rapa* ssp. *nipposinica*, *B. rapa* ssp. *rapa*, *B. juncea*, *Cochlearia officinalis* ssp. *arctica*, *Lepidium sativum*; Amaranthaceae: *A. caudatus*, *A. cruentus*, *A. hypochondriacus*, *A. dubius*, *A. tricolor*, *A. lividus*; Solanaceae: species *Physalis* L.; Cucurbitaceae: *Momordica charantia*, *Benincasa hispida*, *Cucumis metuliferus*; Leguminosae: *Vigna unguiculata*. The biological characteristics of introduced species limiting the scale of production of specific introduced crops in Russia are indicated. It is proposed the methodological approach for evaluation of resistance to low temperatures with the use of its assessment in the phase of a mature male gametophyte of *Vigna unguiculata in vitro* as an example.

The trait "high content of FFI" in a crop must be specified taking a 2–4 times excess of the content of individual FFI or their complex in the cultivar transferred to the State variety testing over the crop standard (reference) values as a basis. Such cultivars should be included in the State Register of Selection Achievements Authorized for Use in a separate list. The purpose of such allocation is to ensure the future interest of producers, investors, and business structures in the sale of FF vegetable products on the poor market of vegetables of the Russian Federation.

To increase the efficiency of introduction and breeding, it is proposed to use the index of the ratio of the total number of registered cultivars by a crop to the number of years since the year of inclusion to the State Register of the first cultivar as a characteristic of the degree of demand for the crop.

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ORCID ID

Y.V. Fotev orcid.org/0000-0002-0299-3689
A.M. Artemyeva orcid.org/0000-0002-6551-5203

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Scientific support to plant breeding and seed production in Siberia in the XXI century

N.P. Goncharov

Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia
gonch@bionet.nsc.ru

Abstract. Agriculture in the Russian Federation is fundamental to the country's economic performance, living standards, the wellbeing of people and state safety. Considerations relating to food security, prospects of and challenges before plant breeding in the Siberian Federal District (SFD), the largest agricultural area of the Russian Federation, are provided in the article. The agricultural area used in the SFD is about 50 million hectares and accounts for 13 % of the country's gross grain production. The need for the introduction of modern molecular biological methods, bioengineering and IT technology is demonstrated and discussed. As Russia as a whole, Siberia is largely engaged in unpromising extensive farming practices, which rely on natural soil fertility, and this factor should be taken into account. Another issue is noncompliance with intensive farming technologies used for cultivating new-generation commercial cultivars. Although capital investments in plant breeding are the most cost effective investments in crop production, breeders' efforts remain underfunded. The article explains the need for fundamental reform in this economic sector: the recognition of plant breeding as being a fundamental science; a fair increase in its funding; the development of a breeding strategy, nationally and regionally; the further expansion of the network of the Breeding Centers; the re-establishment and improvement of the universities' departments specialized in plant breeding and seed production; having more state-funded places in the universities for training plant breeders to be able to maintain and cement the country's advanced position in plant breeding and to develop new globally competitive next-generation cultivars of main crops. Should these issues be ignored, all the problems that have accumulated to date will lead to risks of long-term instability in this economic sector. The need for the careful preservation of continuity in plant breeders and plants being bred is stated. The regulatory functions of the state and agricultural science in plant breeding, plant industry and seed production are considered.

Key words: breeding; Siberian Federal District; traditional and modern methods; next-generation cultivars; seed production.

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Научное обеспечение селекции и семеноводства Сибири в XXI в.

Н.П. Гончаров

Федеральный исследовательский центр Институт цитологии и генетики Сибирского отделения Российской академии наук, Новосибирск, Россия
gonch@bionet.nsc.ru

Аннотация. Аграрное производство Российской Федерации представляет собой стержень экономической системы государства, от развития которого во многом зависит уровень жизни и благосостояния населения. Оно обеспечивает основу безопасности страны. В статье рассматриваются вопросы продовольственной безопасности Сибири, перспективы и проблемы селекции растений в Сибирском федеральном округе – самой крупной аграрной территории РФ. Площадь сельскохозяйственных угодий в Сибирском федеральном округе около 50 млн га, здесь производится 13 % валового объема зерна страны. В Сибири, как и во всей России, преобладает бесперспективное экстенсивное земледелие, основанное на эксплуатации естественного плодородия почв, поэтому селекция должна учитывать не только несоблюдение технологий возделывания новых сортов интенсивного типа, но и этот немаловажный фактор. Несмотря на то что капитальные вложения в селекцию являются наиболее окупаемыми в растениеводстве, селекционеры до сих пор работают в сложных экономических условиях. Обсуждается использование в селекции современных молекулярно-биологических методов, биоинженерии и IT технологий. Обосновывается необходимость проведения кардинальной реформы отрасли, включая признание селекции фундаментальной наукой, существенное увеличение ее бюджетного финансирования, определение стратегии ее развития на федеральном и региональном уровнях, дальнейшее целенаправленное расширение сети селекционных центров, восстановление и укрепление в аграрных университетах профильных для отрасли кафедр селекции и семеноводства, выделение бюджетных мест в вузах региона для подготовки селекционеров, способных сохранить и упрочить передовые позиции страны в селекции растений и создавать конкурентоспособные на мировом аграрном рынке сорта нового поколения основных сельскохозяйственных культур. В противном случае накопившиеся к настоящему времени проблемы могут привести к возникновению новых долгосрочных рисков нестабильности в отрасли. Делается вывод о необходимости бережного сохранения преемственности, как специалистов, так и селекционного (селектируемого) материала. Рассматриваются особенности регулирующих функций государства и аграрной науки в селекции растений и в отрасли в целом.

Ключевые слова: селекция; Сибирский федеральный округ, традиционные и современные методы; сорта нового поколения; семеноводство.

Introduction

The food sovereignty of the Russian Federation is the basis of the country's safety. This strategically important point is documented in normative acts. Challenges of the 21st century in Russia's and its Siberian Federal District's agricultural sector are well known: global and local climate changes (Gurova, Osipova, 2018) entailing the drying out of soils in the southern areas, which are most favorable for farming, a continued decline in soil fertility (Syso, 2017) and a reduction in the working rural population (Shabanov et al., 2019). All these factors lead to new long-term risks to the stability of the agricultural market. Recently, the concept of smart agriculture has become more and more popular worldwide (Anischenko, 2019). In the Russia of today, it means that agriculture is supposed to proceed on its own. This is a good old national tradition: the Ministry of State Property of the Russian Empire, together with the Department of Agriculture as its part, did not seem to think too much about how scientific achievements could be applied to agriculture, nor did they seem to think about agriculture itself (Elina, 1995, p. 45). According to Elina, that negligence stemmed from a popular belief in the Russia of the 19th century that farming was Russian peasants' natural occupation, and so it was supposed to evolve by itself, without governmental or scientific involvement (p. 45).

The agricultural area used in the Siberian Federal District (SFD) is about 50 million hectares and accounts, according to the Federal State Statistics Service (rosstat.gov.ru), for 13 % of the country's gross grain production. Before 2013, scientific support to regional agriculture was provided by the Siberian Branch of the Russian Academy of Agricultural Sciences. The regional responsibility for the development of agricultural science has since been delegated by the Department of Agricultural Sciences of the Russian Academy of Sciences and the Ministry of Science and Higher Education of the Russian Federation to the Siberian Federal Scientific Center for Agrobiotechnology (Krasnoobsk, Novosibirsk region) created out of the former Presidium of the Siberian Branch of the Russian Academy of Agricultural Sciences and several agricultural research institutes in Novosibirsk region, Tomsk region, Kemerovo region and Zabaykalsky Krai, to the Omsk Agrarian Scientific Center and to the Federal Altai Scientific Center for Agrobiotechnology (Barnaul). With that done, the entire agrarian area of Eastern Siberia and the Extreme North has virtually been left without scientific support. The Joint Academic Council of Agricultural Sciences of the Siberian Branch of the Russian Academy of Sciences (with Full Member of the Russian Academy of Sciences N.I. Kashevarov as Chair and Prof. I.M. Gorobey as Academic Secretary) is the only entity that is doing its best to keep running scientific support. The Joint Academic Council has the Joint Academic and Topical Council of Plant Industry, Breeding, Biotechnology and Seed Production (now with Full Member of the Russian Academy of Sciences N.P. Goncharov as Chair), which was created in 1972 at the Presidium of the Siberian Branch of the V.I. Lenin All-Union Academy of Agricultural Sciences and has since 1992 been operating at the Presidium of the Siberian Branch of the Russian Academy of Agricultural Sciences. The Council provided scientific and methodological guidance to the Siberian Breeding Centers and coordinated their cooperation (Shumny et al., 2016). Before the COVID-19 pandemic, the Council had held 46 annual retreat sessions, with the last event having taken place in Krasnoyarsk, July 23–26, 2019[1]. The sessions were traditionally timed to coincide with plant breeding conferences: originally with national only and later with national and international; and the participating organizations were supposed to display their newest commercial regional cultivars for comparison. The venues for the sessions alternated be-

[1] Theses of the International Scientific Conference "Optimization of the Breeding Process – a Factor of Stabilization and Growth of Crop Production in Siberia" ОВР–2019. Krasnoyarsk, 2019.

Fig. 1. The network of research agrarian institutions in Siberia at the beginning of the 20th century.

Experimental Fields were organized in 1907 in Tulun and Temir, in 1908–1910 in Yalutor, Shadrinsk, Kupino, Krasnoyarsk, Minusinsk, Kazachinsk, Bayandai, and Onokhoy and in 1911 in Semipalatinsk and in other places.

tween different Siberian agricultural plant production institutions.

Before 'reorganized' (eliminated) in 2013 and losing its institutes to the Federal Agency for Scientific Organizations of the Russian Federation, the Russian Academy of Agricultural Sciences had had eight specialized Breeding Centers in the Siberian Federal District:

- Siberian Research Institute of Agriculture (B.I. Gerasenkov, K.G. Aziev, R.I. Rutz)[2];
- Altai Research Institute of Agriculture (V.I. Kandaurov, V.I. Yanchenko, N.I. Korobeinikov);
- Krasnoyarsk Research Institute of Agriculture (N.A. Surin);
- Siberian Research Institute of Plant Production and Breeding (P.L. Goncharov, I.E. Likhenko);
- Siberian Research Institute of Fodder Crops (A.V. Zheleznov, R.I. Polyudina);
- Lisavenko Research Institute of Horticulture for Siberia (I.P. Kalinina, I.A. Puchkin, T.N. Nelyubova);
- Research Institute of Agriculture of Northern Trans-Urals (V.V. Novokhatin);
- Kemerovo Research Institute of Agriculture (V.N. Pakul').

All these institutes, except the Altai Research Institute of Agriculture (now the Federal Altai Scientific Center for Agrobiotechnology) and the Siberian Research Institute of Agriculture (now the Omsk Agrarian Scientific Center), are now the branches of other organizations.

These Breeding Centers worked according to two 20-year programs: 1971–1990 and 1991–2010 (Program…, 1978, 1989). A third 20-year program, 2011–2030, has been elaborated for each of these eight breeding centers (see, for example, Program…, 2011a, b). In addition, there were Siberian regional scientific programs ('Diallel Analysis' (Dragavtsev et al., 1984) and 'Siberian Wheat' (Goncharov P.L. et al., 1989)) as well as All-Union and All-Russian goal-oriented programs (Goncharov N.P., Shumny, 2006), including the All-Union program "Lucerne" (Goncharov P.L., 2009). Information on cultivars zoned for Siberia is provided in a systematized manner in a four-volume set, *Catalogues*… (see, for example, Catalog…, 2009).

In 2020–2021, the Ministry of Science and Higher Education of the Russian Federation organized 36 narrowly specialized Breeding and Seed Production Centers, of which only four are in Siberia: three in Western Siberia (Omsk region, Kemerovo region and Altai Krai) and one in Eastern Siberia (Krasnoyarsk Krai). Of note, this was the third attempt to organize Breeding Centers in the country. Of the two previous attempts, one had been made by Nikolai I. Vavilov in 1929 (Goncharov N.P., 2017) and one, by A.V. Pukhalsky in 1972 (Shumny, Goncharov P.L., 2008).

Although investments in breeding are the most rewarding in crop production, breeders are still struggling:

- they are permanently short of material and human resources;
- the system that used to ensure seed production and the introduction of new commercial cultivars has now been destroyed;
- the sector has been suffering chronic underfunding ever since Mikhail Gorbachev's rule. As a result, there is a continuous search for funding to ensure the country's food security.

At the moment, the amount of scientific patronage over crop production in Siberia is short of that taken at the beginning of the last century (Fig. 1). In the Siberian Federal District, breeding activity has been discontinued for many crops for the lack of high-quality human resources. In Eastern Siberia, only two regional agricultural research institutes, branches of the Krasnoyarsk and Irkutsk Scientific Centers of the Siberian Branch of the Russian Academy of Sciences, are still active in plant breeding. Agrarian science has always been much less developed and much less sustainable in Siberia than in the European part of the country.

Shortly after elimination of the Russian Academy of Agricultural Sciences and "withdrawal" of the responsibility for scientific support to agricultural science in the Siberian Federal District from its former institutes, the annual release of recommendations for field work was discontinued (Alkhimenko et al., 2015; Donchenko et al., 2015), as they do not count as performance indicators as per the Ministry of Science and Higher Education of

[2] Heads of the Breeding Centers appear in parentheses in chronological order.

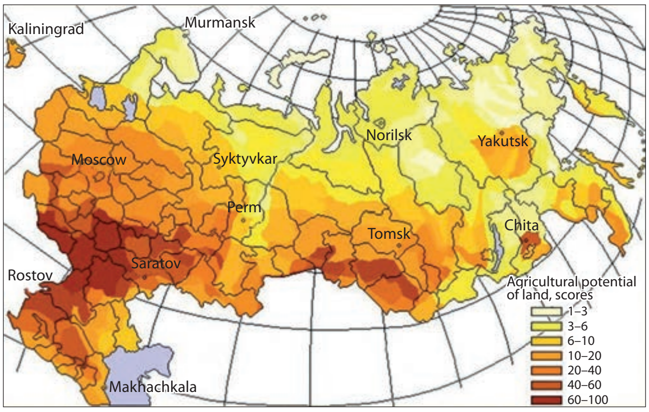

Fig. 2. Soil resources of the Russian Federation (agricultural potential of land).

URL: https://studfile.net/preview/1758647/page:3 (Acccessed Nov. 10, 2019).

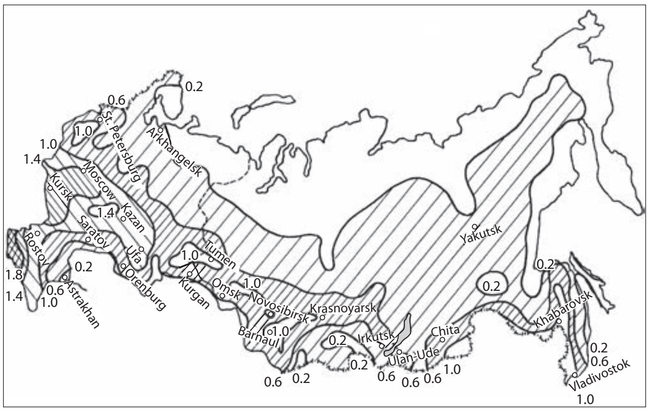

Fig. 3. Agro-climatic potential of the Russian Federation (from: Siberia…, 1993).

"1" stands for the country-average.

the Russian Federation. Stable yield and grain harvest in the SFD is now the responsibility of this ministry.

Pre-breeding

Soils. Although soils represent the most important resource for humankind, the attitude towards them in Siberia and throughout the Russian Federation is not consistent with their importance for ensuring the country's food security (Chekmarev, 2018). Companies and farmers seek to secure their right to land through state registration; however, they are unaware of the fertility status of the soils to become theirs, nor are they responsible for maintaining and enhancing soil fertility (Rassypnov, Ushakova, 2017). Additionally, neither the powers that be nor the Ministry of Science and Higher Education of the Russian Federation recognize the experimental fields of the research institutes as being a unique expensive research tool.

Nowadays, the depletion of soil fertility largely determines possible uses for the soils in the future and the vectors of development of breeding and seed production. Soils have been "watered with our tears and fertilized with our inactivity" for more than three decades. Farms and joint-stock companies in the region have shifted to an extensive three-field crop rotation system everywhere. It should be noted that some modern technologies, such as no-till cultivation, interfere with the process of mineralization of organic matter, which leads to a decrease in the accumulation of nitrogen in the soil (Korchagina, Yushkevich, 2017). Ridge tillage, too, is not universal (Elina, 2017) and does not promote soil fertility in agricultural lands.

There is an urgent need to expand arable land for the further development of the sector in a number of regions (Renev et al., 2017). At the same time, the problem with increasing crop production in the SFD is being addressed extensively, that is it is unlikely that someone in the Russian Federation, not to say in Siberia, may have the will to invest in agricultural science, looking at the spaces of abandoned farmland. Inferior to the European part of the Russian Federation in terms of soil quality (Fig. 2) and agro-climatic potential (Fig. 3), Siberia can only rely on breeders. Incidentally, the introduction of scientific developments is perhaps the only successful part there, as the other resources for maintaining the existing volume of crop production in Siberia are scarce. It is sad to observe that the SFD authorities are not fully aware of their responsibility before the future generations of Siberians for an uninterrupted food supply and that said authorities allow the Ministry of Science and Higher Education of the Russian Federation to bull-headedly "reorganize" experimental agricultural institutions in Siberia. It should be mentioned that over the past hundred years this has been the country's first reform in agricultural science with neither local authorities not Ministry of Agriculture involved (Chernoivanov, 2006). Too bad, there are no such entities in the Siberian Federal District as agricultural holdings that would at least keep local seed production running; while the reformers say plant breeding should be competitive at all stages and get quick profits. Came up with a cultivar? Get it sold! At the same time, the state is not a regulator of the agricultural market.

Gone are the days when the average grain yield was substantially higher in Siberia than in the European part of the Russian Empire and the tsarist government had to set up the Chelyabinsk customs with a duty to tax outbound crops so that the Siberian peasant would not flood the rest of Russia with cheap grain (Goncharov N.P., Goncharov P.L., 2018). In response, the

Siberian peasants organized themselves in production cooperatives and began to export to Western Europe and the exported products were not grain or flour, but oil and cheese. It is estimated that the production of 1 kg of butter requires 25 liters of 3.5 % milk or 25 kg of grain, because to produce 1 liter milk, about 1 kg of grain is needed. To produce 1 kg of milk powder, 11 liters of milk is needed. To produce 1 kg of meat, 15 kg of grain is needed. On average, 1 ton of class 3 wheat can yield about 600 kg of premium flour and 100 kg of grade 1 flour, with the remaining product being bran. Deep processing can further reduce cargo carriage volumes.

In the near future, crop production in the Siberian Federal District and, therefore, the main breeding priorities will become dependent on a grain terminal to be constructed in the Bay Troitsy (Primorsky Krai), with a total capacity of 10 million tons of grain per year. This link in the logistics chain for exporting from Siberia to the countries of the Asia-Pacific region will further increase the imbalance in the plant production.

Breeding strategy. To develop a good strategy for future breeding process, awareness of the current and past experience should be raised. N.I. Vavilov (1935) noted that breeding is made up of knowledge about the initial material, about variability and heredity, and about the role of the environment; from hybridization theory and plant breeding theory; from knowledge about immunity, resistance to adverse abiotic factors and breeding for quality. Recently, high-tech technologies have become yet another part of it.

Time taken to develop a new cultivar. A long-term plan for a new cultivar is going through a series of successive stages and is expected to be a solid achievement success on completion. The cultivars that the State Variety Testing System includes in the State Register of Breeding Achievements of the Russian Federation will occupy vast areas not sooner than in the next few years. The best cultivars that the breeders will submit to the State Variety Testing System today will be included in the "State Register…" only three years later and, therefore, will occupy large areas only five or ten years after. The cultivars that are being created today will go into production only after 20 years (it takes them 15 years to be developed and passed competitive or ecological tests, 3 years to be considered by the State Variety Testing System and 3–4 years to occupy substantial areas) (Goncharov N.P., Goncharov P.L., 2018). Thus, before proceeding to developing a new cultivar, the breeder should set strategic objectives and outline ways to achieve them, not forgetting that in 20 years cultivar requirements may become quite different due to possible changes in criteria, economic situation, cultivation and processing technologies.

However, the development duration that long does not represent a problem with any ongoing breeding process, because the variety development "conveyer" keeps running and new cultivars are being permanently submitted to the State Variety Testing System. The problem is only how to ensure an inflow of professionals and breeding material – and that should be the concern of the state and agricultural science.

Cultivar model. Because the development of a cultivar should be thoroughly planned, and the plan should be clearly defined, the model or the idiotype of the cultivar should be identified first. The cultivar model for individual traits (the cultivar idiotype) has existed for a long time (Donald, 1968). The first models were local cultivars cultivated by peasants. It is reasonably believed that breeding for a particular idiotype is largely breeding for elimination of deficiencies (Davies, 1977), that is, a plan for improving one or more characters of the plant being worked on. However, because "critical characters" can be revealed only after the cultivar model has been described, the role of its specification becomes unclear (Kazak, Loginov, 2019).

Expending and conservation biodiversity. Although rich collections of cultivated species have been taken up, most of accessions have lost their former genetic potential. The problem is not that the world VIR collection is currently only the fourth largest collection in the world, but that it has been left unsupplied with the accessions of the best foreign commercial cultivars for the past 30 years. This has already alerted VIR competitors. Thus, the plant gene collections – Siberian (see the Table) and others (Goncharov N.P., Shumny, 2008; Kershengolts et al., 2012; Levitskaya, 2017; Kosolapov et al., 2021) – will sooner or later obtain accreditation and turn into regional and national highly specialized genebanks. To date, dozens of institutions have been included in the National Plant Germplasm System of the USDA. And what we have got on our side? It has taken us 10 years… not to have yet commissioned the Federal Permafrost Seed Repository in Yakutsk (Kershengolts et al., 2012).

The problem of conservation and effective use of biodiversity is closely related to **plant variety right**. As soon as a cultivar enters the genepools' collections, it automatically becomes their property (see, for example, the website of VIR).

Another way to deal with the dissipation of "gene bank assets" is through **international cooperation**. In 2000, CIMMYT people organized the Kazakhstan-Siberia Network on Spring Wheat Improvement (KASIB). The goals are: (1) to screen modern breeding materials (in-

Collections of crops kept as living accessions in the Siberian Research Institute of Plant Production and Breeding, a branch of the Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences (Likhenko I.E., p.c.)

Collection	Number of accessions*	Storage method
Cereal and legume crops (wheat, barley, oat, pea, spring vetch, *Triticale*)	9286	Seeds
including those resistant to leaf and smut fungi	1285	
Vegetable crops (tomato, pepper, cucumber, pumpkin, beans, greens, onion, garlic)	3200	Seeds
Potato	294	*in vitro*
Perennial onion crops	53	*in situ*
Miscanthus	28	*in situ*
In total:	12 861	

* There is collection of 387 arboreal taxon.

cluding those provided by CIMMYT) through environmental testing; (2) to increase genotypic diversity and to accelerate the breeding process; (3) to exchange the experience and professional development of breeders of the Russian Federation and the Republic of Kazakhstan, including participation in conferences, seminars and internships in CIMMYT divisions. In addition, a number of foreign breeding and seed production companies have come to Siberia on easy terms. The German breeding company "Strube" is successfully operating in Altai, together with local breeders (Korobeinikov et al., 2020). Admittedly, the Siberian Federal District cannot boast having created subdivisions of KWS or other breeding and seed production giants, which the European part of the Russian Federation can.

Traditional breeding

The use of traditional methods has already been reviewed in detail (see, for example, Goncharov N.P., Goncharov P.L., 2018). Let us briefly consider the main of them.

Distant hybridization. Uses of distant hybridization in breeding in Siberia were suggested in the 1930s by N.V. Tsitsin and have since given real results. The first winter cultivars of *Triticale* in the Siberia were produced on the basis of V.E. Pisarev's amphidiploids (AD), and the world's first commercial *Triticale* cultivar 'Rosner', on the basis of spring accession 'AD-20'. Distant hybridization as a breeding method has again become popular in Siberia (Stepochkin et al., 2012). It can be considered an alternative to GMOs, because it allows the transfer of the desired genes between plant species without the use of vectors (genetically engineered constructs).

Polyploid forms. Polyploid cultivars of rye (Likhenko et al., 2014) and clover (Polyudina, 2016) have the highest yield and high level of winter hardiness in Siberia. Unfortunately, triploid beet cultivars and polyploid cultivars of a number of vegetable crops can no longer be found in Siberian fields.

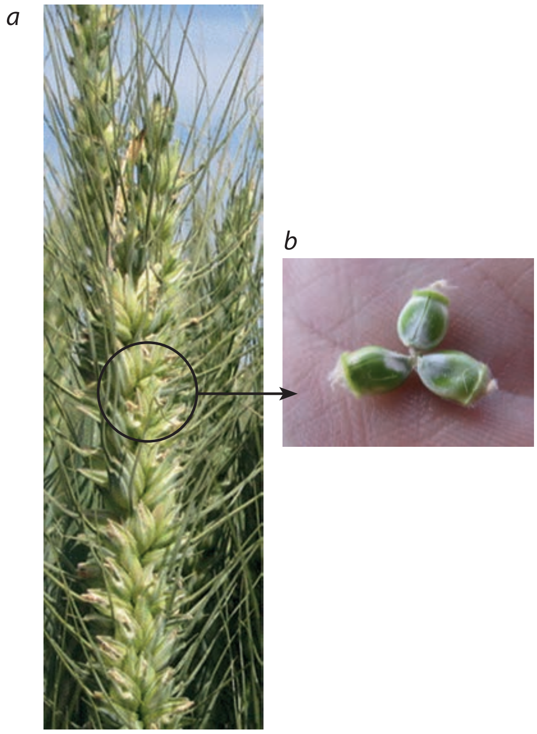

Fig. 4. A common wheat mutant with three grains per flower: *a*, spike; *b*, grains (from: Manual Book…, 2009).

Photo by V.P. Shamanin, Omsk State Agrarian University.

Breeding for productivity and grain quality. The yield of common spring wheat cultivars in Western Siberia depends on the number of plants preserved for harvesting and kernel weight per spike (Kazak, Loginov, 2019). Productive tillering is 1.2 stems per plant. In this case, breeding for the optimization of ear architectonics is possible (Konopatskaia et al., 2016), and so is breeding for branch spike (Dobrovolskaya et al., 2017), for other characters of ear architectonics (Fig. 4) and for close (heavy) seedlings by using mutes with erected leaves (Dresvyannikova et al., 2019), as is the case with some corn cultivars.

Duration of vegetation period. Early maturation is an important breeding character throughout our country (Vavilov, 1935). Most spring wheat varieties in Russia carry two dominant *Vrn* genes, which control the expression of this character. New alleles of these genes have promise for changing vegetative duration in common wheat by breeding (Chumanova et al., 2020). For most cultures, the genetics of this character is poorly studied, which prevents an extensive use of molecular biological methods.

Disease resistance. A phytopathological assessment of the collection of local and commercial Siberian common spring wheat cultivars showed that only 10–15 % of the accessions had low susceptibility to leaf (brown) and stem rust and powdery mildew (Leonova et al., 2017). To increase the diversity of new genes that control resistance to these pathogens, it is efficient to perform their introgression from wheat relatives (Orlovskaya et al., 2020; Adonina et al., 2021), including artificial amphiploids (Goncharov N.P. et al., 2020). The common spring wheat cultivar Grenada with horizontal resistance to stem rust has been developed as an alternative using of effective resistance genes in breeding by the Research Institute of Agriculture of Northern Trans-Urals – a branch of the Tyumen Scientific Center (Novokhatin et al., 2019).

Non-conventional breeding

Breeding and improving soil fertility. Crop rotation was a former practice in Siberia to improve soils with, including the obligatory cultivation of legumes and perennial forage grasses (Ilinykh, 2016). Currently, a new direction in breeding has come to the scene: the commercial grain wheatgrass cultivar 'Sova' was developed for regenerative agriculture with the accumulation of carbon in the soil (Shamanin et al., 2021). It has been included in the "State Register…" since 2020 as an alternative to perennial wheat. It is simultaneously cultivated for grain, which is harvested before the green mass dies, and for hay. Its grain yield is 9–10 tons per ha/year and hay yield is 7–7.5 tons per ha/year. Sowing is used without replanting for up to 7 years. It is drought- and disease-resistant. 'Sova' is extremely interesting in view of the Russian Federation's ratification of the Paris climate agreement, because this variety is capable of accumulating up to 3.7 tons per ha carbon annually in the soil.

Functional nutrition is directly related to the longevity of a person. For this reason, it is believed outside Russia that it is cheaper and more profitable to properly feed people than treat them (Fotev et al., 2018). However, this requires that plants be bred for specific nutrients. In Russia, about 80 % of commercial vegetable production accounts for the so-called "borscht set": white cabbage, tomato, cucumber, carrot, table beet and onion[3]. The assortment can be significantly expanded both by new vegetable crops and new grain crops. For example, it is possible to bake "healthy bread" from wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey) grain, which contains five times as much calcium and 10 times as much folic acid than bread from common wheat (Shamanin et al., 2021). Cereal varieties with increased contents of trace elements can be used (Abugalieva et al., 2021).

Molecular biological methods in plant breeding

Breeders have received new tools to improve the genotypes of cultivated plants. The Institute of Cytology and Genetics of the Siberian Branch of the Russian Academy of Sciences took part in the assembly of the wheat genome (IWGSC…, 2018). The next stage of breeding in the future is working with the pan-genome of economically important plants (Pronozin et al., 2021a).

Breeding for resistance to adverse abiotic factors. A variant of breeding for drought resistance using methods in molecular biology is shown in Fig. 5.

Plant height and architectonics. Breeding for short stems is once again among the priorities of Siberian breeders (Korobeynikov et al., 2020). Selection for genes that control the optimal plant height can now be effectively carried out by molecular markers (Sukhikh et al., 2021).

Genetic modifications to improve cultivated plants. Breeders widely use genomic modeling and editing technologies to address plant breeding problems (Salina, 2016). Modern systems demonstrate the possibility of obtaining non-transgenic plants with specified mutations (Borisuyk et al., 2019), for example editing the genes that control the optimal flowering time of the most important crops (Kishchenko et al., 2020).

Bioinformatics

New challenge for bioinformatics is the development of IT, providing a quick, accurate, massive and at the same time detailed description of plant phenotypes both in the field and in laboratory settings (Kolchanov et al., 2017; Genaev et al., 2019). At the same time, it is necessary to substantially reduce the cost and time of obtaining relevant data with the maximum coverage, resolution

[3] Chekmarev P. A. The state, prospects of development and measures of state support for vegetable growing. URL: https://agrotip.ru/wp-content/uploads/2018/11/Presentatsia_Petra_Chekmareva.pdf (Accepted 14.01.2021).

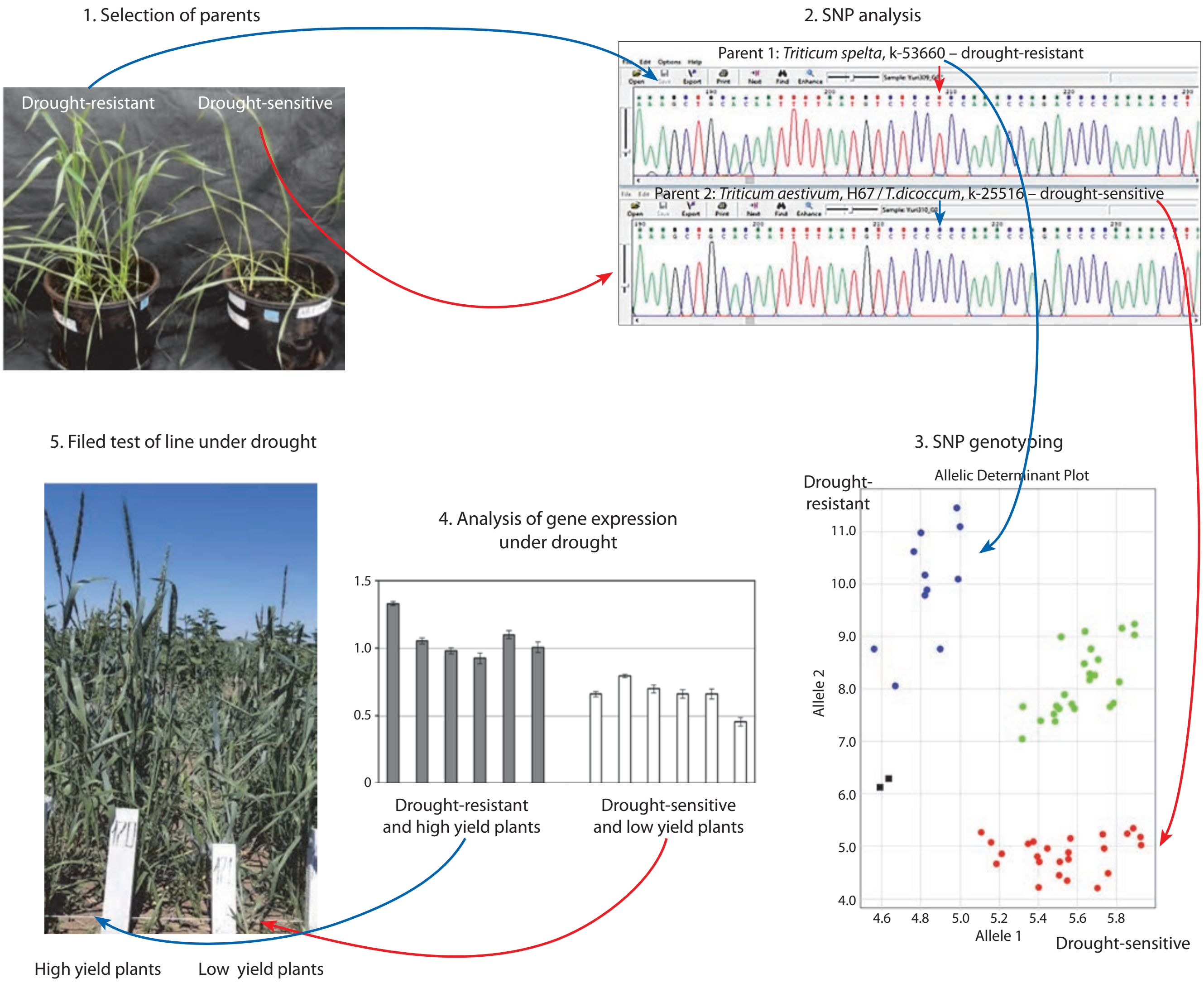

Fig. 5. Production of drought-resistant spring wheat cultivars with high yield and grain quality for the southern part of Western Siberia and Northern Kazakhstan using modern molecular biological methods (Jatayev et al., 2020).

and dynamics. For the diagnosis of the state of crops, it is promising to use drones (Alt et al., 2019); for the diagnosis of plants, automatic morphology phenotyping (Pronozin et al., 2021b); for a risk assessment of edited plant organisms, dynamic programming (Korotkov et al., 2021).

Varietal seed production and varietal authenticity control

Cultivar authenticity control. Identification of cultivars grown from seeds delivered by non-Russia's companies is often not possible due to the lack of standard accessions from originator (Lobach, Samus, 2018); it is only possible to assess how cultivar's seed dockage has.

Foreign cultivars. Foreign and non-local commercial cultivars of grain crops have been successfully displaced from the Siberian Federal District by local breeding cultivars (Loginov et al., 2016; Surin, 2019). At the same time, the seeds of foreign vegetable cultivars just have no rivals. The same goes to many other crops, for example, leguminous ones (Kazydub et al., 2020): for a list of reasons, their import substitution does not occur.

Cultivar change is important for the dynamic development of crop production in the Siberian Federal District. There is no doubt that the so-called "varietal mosaic" helps control diseases in the fields (Bespalova, 2016). At the same time, the cultivar should be cultivated for as long as it can provide a stable, high-quality yield. For example, the potato cultivar Russet Burbank developed at the end of the 19th century, is still grown in the United States and Australia for the production of chips. It should be kept in mind that F_1 hybrid varieties substantially distort the statistics of the dynamics of variety substitution in the country.

Conclusion

Agriculture in the Russian Federation is the backbone of the country's economic system and is fundamental to the living standards and wellbeing of people. This sector sets the pattern of the future development of the Russian state (Belyaev, 2018) and, therefore, addressing its issues, including those with breeding and seed production, should be one of the primary tasks of state authorities. Plant breeding is a lasting process, and so it is extremely important to be sure that we have now chosen the right way to go.

To the Government of the Russian Federation. Breeding should be given the status of a fundamental science, as there is nothing more fundamental in the world than feeding people and defeat hunger. Not only does breeding deserve a conspicuous place in the national program "Science", but it also should be funded from the state budget through dedicated funds. Neither self-financing nor self-supporting should be an option.

Teaching future breeders is an important factor in ensuring the country's food security. For the breeders to be duly taught, it is required that (1) the breeding and seed production chairs be fully restored in all universities of the Ministry of Agriculture; (2) more state-funded places be allocated to breeder students; (3) the state agricultural universities of the Ministry of Agriculture, which, for a reason unknown, live up to the educational standards set up by the Ministry of Science and Higher Education of the Russian Federation, become relevant.

To the RAS Department of Agricultural Sciences and the SFD Ministries of Agriculture. There is an urgent need for the adoption of a regional resolution with a title "On the normalization of genetic-based breeding research and launching original seed production in the Siberian Federal District" – unless we want to live up to Project "Breeding 2.0" by the National Research University Higher School of Economics and the Federal Antimonopoly Service of the Russian Federation.

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Сибирского отделения Российской академии наук»,
проспект Академика Лаврентьева, 10, Новосибирск, 630090.
Адрес редакции: проспект Академика Лаврентьева, 10, Новосибирск, 630090.
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