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THE HISTORY OF PLANT BREEDING IN THE RUSSIAN FEDERATION

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SUMMARY

The beginning of organized breeding work in Russia concretized at the end of the 19th century in two capitals of the Russian Empire: in 1877 at St. Petersburg and in 1881 in Moscow, where seed quality control stations first opened. The stations' work transfer to scientific-based functions commenced in the first half of the 20th century by N.I. Vavilov. Under his leadership, the People's Commissariat of Agriculture of the RSFSR organized an extensive network of 115 breeding and experimental stations. The 20 to 30 years of the 20th century displayed epoch-making discoveries by Russian scientists in the field of genetics. In 1920, N.I. Vavilov discovered and formulated the law of homological series in hereditary variability. In 1925, pioneering worldwide, Russian scientists, under the influence of ionizing radiation, received mutations in yeast fungi. During the same years, S.S. Chetverikov and his students laid the foundation for evolutionary genetics, which became an impetus for developing the modern genetic breeding theory. Later, in the 1930s of the 20th century, A.A. Serebrovsky and N.P. Dubinin proved the divisibility of the gene and substantiated the theory of its complex structure. Based on this discovery, geneticists globally, studying the patterns of inheritance and variability, have discovered and continue to uncover new breeding means.

Keywords: Russian Federation, selection, breeding, Vavilov

Key findings: At present, recognizing that breeding and seed production in Russia today are in a challenging state against the background of a rapidly growing market of seeds of foreign selection is urgent. It should be a consideration since realizing the biological potential of the variety is the main factor in increasing production volumes, improving product quality, and reducing its cost. As a result, in addition to economic attractiveness, it guarantees the country's food independence.

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INTRODUCTION

Breeding is the science of creating new and, as a rule, improved breeds of domestic animals, varieties of cultivated plants, and strains of microorganisms. Primarily, the breed is an artificially created human population with hereditary features beneficial to humans, high productivity, and optimal morphological and physiological characteristics. Most of the plants in the world practice that humanity uses in writing are products of breeding: wheat, potatoes, tomatoes, and corn. The main directions of modern breeding sought to obtain high yields, early maturity, nutritional value, and stability of crops, depending on geographical conditions. In plant breeding, three methods applied comprised selection, hybridization, and artificial mutagenesis. In recent years, different genetic tools have emerged for correcting any adverse signs in the offspring. The latest breeding methods include artificial mutagenesis, a mutation caused by radioactive radiation or the action of chemicals.

Thus, breeding and seed production form the basis of agricultural productivity, ensuring the state’s food security. Their development level is a direct indicator of the independent functioning of a nation based on reducing the volume of imports and providing the population with its own high-quality products (Collard *et al*., 2018; Kondakov *et al.*, 2020). According to the official definition, food security interlinks with the state of the economy capable of creating conditions for food independence, which guarantees every citizen physical and economic accessibility for food consumption following the norms of the legislation of the Russian Federation in volumes not less than rational consumption standards necessary for an active and healthy lifestyle of the residents of the state (Kovalenko, 2020). Thus, by the Decree of the President of Russia dated January 21, 2020, No. 20, "On the approval of the Food Security Doctrine of the Russian Federation," a new food security indicator surfaced for seeds of the chief cultivated crops of domestic selection. Their share should be at least 75% (Decree of the President of the Russian Federation, 2020). During this period (2019), the indicator was 62.7%.

History of discovery and study of mutations

In Latin, the term “mutatio” (change) appeared and had its first utterance in ancient times when mail delivery occurred by horse and foot messengers who rested and changed horses in roadside inns in the 2nd century AD, during the reign of the Roman emperor Hadrian Mail. In the modern sense, the term "mutation" became a proposed topic in 1890 by Hugo De Vries in the classic work "Mutation Theory" (de Vries, 1901). It is one of the foundations of genetics. This hypothesis originated shortly after the discovery of Gregor Mendel's law at the beginning of the 20th century. Almost simultaneously with Hugo de Vries (1925), the Russian scientist-botanist S.I. Korzhinsky came to similar results before Hugo de Vries (Korzhinsky, 1899). However, the priority in the primacy and the better coincidence of the original provisions belongs to the Russian scientist to a greater extent (Korzhinsky, 1899).

The recognition of the main evolutionary significance of discrete variability and the denial of the role of natural selection in the theories of S.I. Korzhinsky (1899) and Hugo de Vries (1925) attained links with the insolubility at that time of the contradiction in the evolutionary doctrine of Charles Darwin (1858), between the important role of minor deviations and their absorption during crossing. Hugo de Vries (1925) surprisingly correctly formulated the concept of mutation: the phenomenon of a discontinuous change in a hereditary trait. Korzhinsky (1899), having studied a vast amount of archival botanical materials, came to a similar conclusion: ‘The emergence of new forms is a phenomenon common to the whole world of living beings, and hereditary changes always occur in leaps, not gradually.’ The modern definition included the concept of molecular biology, designating a mutation as a qualitative change in the structure of DNA at one locus (gene mutation) or a change in the number or microstructure of chromosomes (chromosomal mutation).

Breeding as an advanced science of our time

Breeding as an advanced science has its formation in Russia in the early 20s of the last century. It was in the 1920s and 1930s of the 20th century that demonstrated immense achievements and discoveries in this science. At this time, Russian scientists have achieved phenomenal results in genetics. Thus, in 1920, N.I. Vavilov discovered and substantiated the law of homological series in hereditary variability (Vavilov, 1920). This law made it possible to establish centers of origin for cultivated plants with a superior variety of inherited forms, which allowed N.I. Vavilov expresses the opinion that selection is an evolution guided by the will of man. He stated that the foundations of forming breeding theory are the doctrine of pure lines and mutation theory. Based on the above, one can conclude that before the discovery of G. Mendel and the establishment of the principle of pure lines, the mutational theory of selection as a science was nonexistent. G. Mendel found that when crossing two pure lines of peas—with yellow and green seeds—all hybrids of the first generation will have yellow seeds, and in the second generation, 3/4 of the offspring will have yellow seeds and 1/4 is green (Chetverikov, 1983). The results led G. Mendel to the idea that the color of seeds has discrete hereditary factors (genes) determining it. Each gene can have several variations (alleles).

The works of N.I. Vavilov, conducted at the end of the 10 years of the 20th century, devoted to studying the immunity of various agricultural plants, deserve attention. Based on an enormous factual material (650 varieties of wheat and 350 varieties of oats or other non-grain crops), a hybridological analysis of the immune properties of selections and their anatomical and physiological features commenced. As a result of this work, the doctrine of anti-infectious immunity of plants surfaced, summarized in the monograph "Immunity of plants to infectious diseases," published in 1919 (Vavilov, 1919). Later, N.I. Vavilov published another fundamental work – "The doctrine of plant immunity to infectious diseases" (Vavilov, 1935).

N.I. Vavilov had a tremendous influence on his contemporaries; his ideas, approaches, and methods concerning the study of plant immunity were the scientific foundation for further research in this direction, where many scientists' research took off and continued (Avrutskaya *et al.*, 2018). However, causing the early tragic death of N.I. Vavilov, in the period of unjustified repression in our country in the 30–40 years of the 20th century, ended the life of a great world-class scientist. Currently, with the earth's increasing population, the issues of studying plants' natural and induced immunity begun by N.I. Vavilov is of exceptional importance for solving the problems of ensuring world food security.

Demonstrating the effect of radiation on heredity first came from the Russian botanist Georgy Nadson (Nadson and Philippov, 1925) and the American geneticist Herman J. Muller (Muller, 1927). In 1925, G.A. Nadson and G.S. Philippov were the first to observe in the world mutations in yeast fungi under the influence of radium rays (Nadson and Philippov, 1968). Describing the effects of radium rays on the structure and development of yeast, G.A. Nadson came to the conclusion that the effect of radium is inherited (Nadson, 1932, 1967a, b). The recorded results led to further investigations of the causes of mutagenesis in microorganisms. In a report at the Third All-Union Congress of Radiologists and Radiologists in 1925, G.A. Nadson and G.S. Philippov announced data on the receipt of hereditary changes in the lower fungi Misog and Zygorhynchus as a result of irradiation (Nadson and Philippov, 1925). The appearance of asporogenic forms was evident, with one also distinguished by fat accumulation. Later, they described mutants in the yeast-like fungi Sporobolomyces and Nadsonia (Philippov, 1934). When studying the induced variability in Nadsonia, it exhibited that irradiation stimulates a change in enzymatic properties that initiate the appearance of a form that does not ferment certain sugars (Nadson, 1967b). The description of such biochemical mutants was more than a decade ahead of the classical works on biochemical mutations by Beadle and Tatum (1941). The work has demonstrated that each link in the chain of biochemical reactions has an enzyme carrying it out and, therefore, has a specific gene in control based on the rule "one gene - one enzyme" (Beadle and Tatum, 1941). According to this rule, Beadle and Tatum tried to substantiate the concept of the pathogenesis of hereditary diseases. The authors have shown that mutation of one gene leads to a change in only one primary biochemical reaction (Beadle and Tatum, 1941). It is how the idea originated that each gene controls the biosynthesis, specificity, and function of only one specific enzyme. The details of this concept later gained clarification. In particular, it was apparent that the products of genes can be both enzymes and other proteins (antibodies and hormones of a protein nature, hemoglobin, and blood transport proteins).

G.A. Nadson found that when irradiated with radium, hereditary changes occur in yeast cells, with the primary source being the cell nucleus (Nadson, 1920). In 1932, G.A. Nadson and E.Ya. Rokhlina described radiation-induced variability in *Saccharomyces cerevisiae* and drew attention to the possible practical use of the obtained radiores. All these helped conclude that hereditary changes occur under the influence of a well-known and precisely dosed factor (Nadson and Rokhlina, 1934). At the same time, it should be noteworthy for G.A. Nadson as rightfully elevated to the category of the founder of the modern school of microbiology in Russia. His disagreements with the Soviet authorities that arose in the 1930s of the last century gave rise to the problem of possible continuing scientific creativity in the absence of political and civil rights. Groundlessly accused of terrorism led to the shooting of G.A. Nadson and for a long time, his name’s oblivion and the silencing of the primacy of his radiation mutagenesis discovery, which, according to scientific literature, began to belong to the American geneticist H.J. Muller (1927). In the Soviet Union, H.J. Muller (from 1934 to 1938) headed the laboratory of gene and mutagenesis problems of the Institute of Genetics of the USSR Academy of Sciences (Bogdanov, 1993), which, among other things, focused on medical genetics. Most of his work centered on radiation genetics. In Moscow, he completed the writing of the eugenic book "Out of the Night: A Biologist's View of the Future" (Muller, 1935). However, by 1936, the policy of I.V. Stalin supported the idea of developing an "agrobiological" direction in Soviet biology under the leadership of T.D. Lysenko led to a deterioration in the living and working conditions of H. J. Muller in the Soviet Union. He and some Soviet scientists tried to resist the so-called "scientific" activities of T.D. Lysenko and his Lamarckian theory of evolution, but the political danger of being in the country forced the scientist to leave the USSR.

After H.J. Muller returned to the United States in 1940, he received a research position at Amherst College. His research on drosophila genetics concerned measuring spontaneous (rather than radiation-induced) mutations. Later, H.J. Muller received the Nobel Prize award in 1946 (for the discovery of the appearance of mutations under the influence of X-ray irradiation) in light of the consequences of the atomic bombing of Hiroshima and Nagasaki, which contributed to increasing the concern of the world community about the possible consequences of nuclear war. This discovery stimulated numerous genetic studies that went hand in hand with developing wave and nuclear physics. Among such studies were works carried out by prominent Russian scientists, including A. Sapegin, who studied radiation-induced mutagenesis in common wheat (Sapegin, 1930), and N. Timofeev-Resovsky, the founder of a new direction in radiation genetics (Timofeev-Resovsky, 1929). At the same time, N. Koltsov and his student, I. Rapoport studied chemical mutagenesis, whose achievements became crucial for applying the chemical method in plant breeding (Rapoport, 1946).

In 1930, A.A. Sapegin (Sapegin, 1934) and L.N. Delaunay (Time in Captivity, 2010) applied radiation mutagenesis for the first time in world practice to produce new wheat varieties with economically beneficial mutations and proposed using it to obtain a base material in breeding. The scientific work of Andrey Afanasyevich himself sought to create new varieties of barley and wheat through artificial crosses. The varieties he bred were distinguishable by their high yields, increased drought resistance, and high immune and baking properties. They organically entered production and occupied the main areas of winter wheat crops in Ukraine. By 1940, the area of crops of wheat varieties obtained by A.A. Sapegin occupied up to one and a half million hectares. In 1934, renaming the institute at the request of T.D. Lysenko to the Ukrainian Breeding and Genetic Institute had the word "genetics," unfortunately, in second place. In the newly renamed institute, they mainly focused on breeding, using traditional methods, gradually pushing genetics, as a science, into the background. Still, the colleague of A.A. Sipiagina, Professor L.N. Delaunay, whose works centered on a genetic nature, founded a new direction: karyosystematics and using radiation in breeding to create new plant varieties. For the first time in global practice in 1922, L.N. Delaunay, in his work "Comparative-karyological study of species," proposed the term "karyotype" (Delaunay, 1922; Battaglia, 1994). The concept of karyotype in the Denver and Paris classification of chromosomes received designation as a set of features of a complete set of chromosomes for a given biological species (specific karyotype), a given organism (individual karyotype), or a line (clone) of cells (The concept of karyotype and idiogram, 2020).

At the same time, S.S. Chetverikov, despite the historical difficulties associated with the political processes taking place in the country, took up the problem of the genetic foundations of populations and evolutionary genetics, which is currently the basis of the modern genetic theory of breeding. S.S. Chetverikov organized the experimental study of hereditary properties in natural animal populations before other scientists (Chetverikov, 1983). These studies allowed him to become the founder of modern evolutionary genetics. In this field of knowledge, Sergey Chetverikov acted as an innovator who determined the ways of developing world biological science for many decades. The works of S.S. Chetverikov, especially his main work "On some moments of the evolutionary process from the point of view of modern genetics" (1926), formed the basis of the synthetic theory of evolution (Chetverikov, 1926). In 1926, S.S. Chetverikov published the results of his research and reflections in a vast article, "On some moments of the evolutionary process from the point of view of modern genetics." In this work, it revealed that there is no contradiction between the data of genetics and the evolutionary theory. On the contrary, the results of genetic research should form the basis of the doctrine of variability and become the key to understanding the process of evolution. S.S. Chetverikov, using simple mathematical methods, proved that mutations (genovariations) in natural animal populations do not disappear and can accumulate in a latent (heterozygous) state and provide material for subsequent variability and natural selection.

In the early 30s, A.A. Serebrovsky and N.P. Dubinin were the first to prove the divisibility of the gene and substantiated the theory of its complex (center) structure. All these works have greatly influenced the development of the theory and practice of genetic research conducted in the world's leading scientific centers (Dubinin, 1992; Serebrovsky, 1933). Later, the chemical equivalent of a genetic locus (or a functional unit of DNA) emerged as a cystron, which contains genetic information about one of the polypeptides that make up DNA. Therefore, it was correct to say that 'one cystron is one polypeptide,' and the development of hereditary traits occurs according to the following scheme: gene - enzyme - metabolites - cells - tissues - organs - organism. G.W. Beadle (1903–1989) and E.L. Tatum (1909–1975), in 1958, received the Nobel Prize in Physiology or Medicine for their work on the relationship between genes and enzymes, which defined the concept of 'one gene-one enzyme.' They showed that single mutations usually affect the production of a single enzyme in the pathway. It led to the idea that genes encode proteins (enzymes). The concept of 'one gene-one enzyme' did not imply the exclusion of the possibility that genes can encode RNA or something else, although this point of view has become widely replicated

(Nozdrachev *et al.*, 2002). However, the prime purpose of G.W. Beadle and E.L. Tatum was to show an immutable correspondence between the gene and the protein (Beadle and Tatum, 1941). It brought a former student of G.W. Beadle, Joshua Lederberg, and E.L. Tatum to receive the Nobel Prize in 1958 (Lederberg, 1961).

The rapid evolutionary development of genetics has radically changed the view on the main problems of plant breeding. Thus, genetic mutations in the genome of crops contributed to their genetic diversity, which made it possible to purposefully exploit it to obtain high-yielding elite varieties (Schlegel, 2021; Engels and Ebert, 2021). It resulted in a loss of genetic diversity, essentially genetic erosion, and prompted a concerted effort by scientists to preserve original genetic material throughout the world (FAO, 1969).

N.I. Vavilov was one of the first to fully appreciate the importance and power of genetic diversity for crop improvement, an outstanding Russian geneticist and director of the All-Union Academy of Agricultural Sciences named after V.I. Lenin in Leningrad (now the Federal State Budgetary Scientific Institution "Federal Research Center All-Russian Institute of Plant Genetic Resources named after N.I. Vavilov - VIR). The first person to support this scientific direction was the head of the government of Soviet Russia, V.I. Lenin, who gave instructions to concentrate their efforts on obtaining new high-yielding plants for effective cultivation in Siberia (Vavilov, 1997). N.I. Vavilov and his collaborators collected and systematized about 50,000 cultivated plant specimens worldwide. The work made it possible to identify and evaluate their characteristics, expand the understanding of genetic diversity, and conclude that areas are limited to the so-called centers of diversity and origin of the studied crops (Vavilov, 1926). N.I. Vavilov was one of the first to note the increase in losses of land plant varieties in the process of obtaining individual highly productive plants (FAO, 1969), especially since the beginning of the "green revolution," which began in the late 1950s to early 1970s, with the success of high-yielding (dwarf) varieties of wheat and rice in combination with new agricultural technologies. It has come with a dramatic loss of traditional varieties of these crops and has raised concerns among organizations, such as, the European Society for Research and Plant Breeding (EUCARPIA) and FAO (Food and Agricultural Organization of the United Nations) (Engels and Ebert, 2021; Scarascia-Mugnozza *et al.*, 2002). Even though systematic plant breeding and crop management have a relatively short history compared with traditional breeding, their combination with advances in technology and strategies increased crop yields by 56% worldwide in 1965-1985, known as the Green Revolution. Later, the first half of the 21st century witnessed a series of rapid discoveries characterized by breakthrough technologies and cost reductions in the field of genomics (Thudi *et al.*, 2021). Simultaneously, analyzing a massive amount of genomic information, predicting the relationship between genes and phenotype, and affecting the adaptation of plants to climatic conditions helped ensure global food security.

The acquired data served as the basis for creating plant introduction centers, which later grew into gene banks to satisfy the growing demand of breeders for the genetic diversity of plants from different regions of the globe. These centers specifically included the All-Union Institute of Plant Growing in St. Petersburg (in 1920), Seeds from the Commonwealth potato collection deposited in the Global Seed Vault (Commonwealth in Cambridge, UK before World War II), collections for research programs of the Rockefeller Foundation in the USA (1943), and National Seed Storage Laboratory in Fort Collins, Colorado, USA (1958) (Scarascia-Mugnozza *et al.*, 2002). In connection with the above, it should be noteworthy that at the beginning of 1928, a specialized union of agricultural cooperation, Semenovodsoyuz, materialized in the USSR, and the journal "Breeding and Seed Growing" became published in October 1929.

During the Soviet period, more than 3,000 varieties and hybrids of various agricultural crops bore cultivation in the country, which had a sufficiently high yield, and, most importantly, showed adaptability to the local soil and climatic conditions of diverse geographical zones. Soviet breeders in all regions created the best winter wheat varieties recognized in the world, such as Mironovskaya 808 and Bezostaya 1, with a yield production of 40–50 kg/ha. However, in the post-Soviet period, breeding and seed production declined due to the shortcomings of the central government (Development of Breeding and Seed Production, 2020; Vorotnikov, *et al.*, 2018). It has significantly slowed down the introduction of advanced scientific achievements of breeding science in the Russian Federation, which are not inferior in quality and productivity to foreign analogs. In the last decade, measures have been taken in Russia to expand the assortment of seeds and plant genetic resources, develop modern biotechnological and breeding methods, create and introduce new hybrids and varietal technologies, and improve the regulatory framework of breeding and seed production (Manukyan and Abieva, 2019).

It is necessary to change the conditions for its stimulation, aimed at increasing the attractiveness of investments in breeding and seed production, ensuring technological modernization of the selection and seed production complex, and supporting for rational innovation dynamics through planned modernization of existing scientific processes to overcome inertial trends. Thus, at the Grain Research Center (GSC), named after P.P. Lukyanenko, introduced technologies of marker-based selection (Davoyan *et al.*, 2019; Bazhenov *et al.*, 2021), chromosome engineering (Davoyan *et al.*, 2019a) and biotechnological approaches (creation of dihaploid forms) (Davoyan *et al.*, 2019b), and testing of the introduction of genomic selection has now begun (Federal Scientific and Technical Program, 2021).

Plant breeding aims to improve crops genetically. Emphasis must center on phenotypic selection remaining as the basis to this day, ensuring phenomenal progress in plant breeding. The use of selection using molecular markers is less due to the complexity of using genomic technology. However, the work currently in progress and aimed at a dense coverage of the genome with molecular markers (Dzyubenko, 2018) should reduce the costs of genomic technology by increasing the speed and selection cycle, with less need for phenotyping (Zanotto *et al.*, 2023).

Sequencing has greatly enhanced genomic resources, such as, genome sequence assemblies, germplasm sequencing data, and gene expression atlases. High-throughput and cost-effective genotyping platforms and faster trait mapping approaches have become available. Currently, molecular markers associated with core traits can be cost-effective, paving the way for promising breeding using a high-throughput genotyping platform (Thudi *et al.*, 2021).

Using chromosome engineering methods and marker-based selection makes it possible to implement a strategy for genetic plant protection, allowing reducing the number of chemical treatments or totally abandoning them. At the same time, to manage and control the phytopathological situation in wheat agrocenoses, the method of varietal mosaic began its introduction: placing varieties that differ in the degree of resistance to diseases, which permits to stay ahead of pathogens through rapid variety change, optimizing the phytopathological situation, and stabilizing the gross harvest of winter wheat grain (Bespalova and Ablova, 2019).

CONCLUSIONS

Thus, to improve work in the breeding field, it is necessary to develop additional measures to preserve and actively use Russian genetic resources in plant and animal husbandry, including establishing a federal fund for elite seed materials. It is necessary to focus efforts on creating and producing competitive Russian varieties by using new high-tech domestic developments and forming modern (molecular biology and biochemistry, genetic engineering, bioinformatics) methods for the accelerated creation of varieties and hybrids of plants with specified economically valuable characteristics. Similarly, founding and implementing a system for assessing the safety of food products produced using genetically engineered organisms of plant, animal, and microbiological origin requires extensive evaluation.

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