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Vavilov Institute of Plant Genetic Resources: Historical Legacy, Collections, and Contributions to Global Seed Conservation

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ABSTRACT: The conservation of plant genetic resources (PGR) forms the cornerstone of sustainable agriculture, food, and nutritional security. Seed, being a compact, stable, and easily storable biological entity, provides the most cost-effective means for *ex situ* conservation. Early in the 20th century, N.I. Vavilov emphasized the systematic collection and preservation of crop diversity, laying the foundation of global genebank systems. This article reviews the legacy, infrastructure, collections, and contributions of the Vavilov Institute of Plant Genetic Resources (VIR), St. Petersburg, one of the world's oldest and most comprehensive repositories of cultivated plants and their wild relatives. Its scientific frameworks, operational scale, and continuing role in breeding and policy are discussed, with emphasis on its enduring relevance for contemporary seed science and conservation.

Keywords: Biocollections, Genebanks, Plant genetic resources, Nicolay Vavilov, VIR

INTRODUCTION

The seed is the fundamental unit of plant reproduction, survival, and evolution. It embodies resilience, enabling species to persist across seasons and under adverse conditions, and functions as the natural carrier of genetic diversity through time and space. Because of its compact structure, physiological dormancy, and adaptability to controlled storage, the seed also serves as the most practical and cost-effective unit of *ex situ* conservation [1]. Conservation of plant genetic resources of cultivated crops and their wild relatives not only safeguards crop biodiversity but also secures a reservoir of traits essential for future breeding, adaptation, and global food security [2].

The scientific foundations of systematic seed conservation were laid in the early 20th century by Nikolai I. Vavilov, who envisioned a global effort to explore, collect, and preserve crop genetic diversity. His seminal theories on the centres of origin of cultivated plants [3]. the law of homologous series in hereditary variability [4]. and the geographic distribution of genes provided the conceptual underpinnings of modern plant genetic resource (PGR) science [5, 6, 7, 8, 9]. Vavilov's pioneering advocacy of *ex situ* conservation, particularly through seed storage, directly influenced the establishment of national and international genebanks and inspired global initiatives such as the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and FAO's Global Plan of Action [10, 11].

The Vavilov Institute of Plant Genetic Resources (VIR), established in 1894 as a small Bureau of Applied Botany in St. Petersburg, represents the materialization of this vision. Beginning with just ca.300 accessions, it has expanded into one of the largest and most diverse collections in the world, encompassing hundreds of thousands of seed samples along with herbarium, cryopreserved, and *in vitro* materials. VIR not only conserves but also actively utilizes its germplasm in crop improvement, serving as a cornerstone of Russian agriculture and an influential institution in global conservation policy [3, 5, 6, 7, 8, 12, 13].

Historical Foundations and Scientific Framework

The VIR is among the world's oldest and most comprehensive repositories of cultivated plants and their wild relatives. From its modest beginnings more than one hundred years ago with ca. 300 accessions, the collection expanded to more than 320,000 accessions by 2025, spanning 64 botanical families, 376 genera, and 2,169 species [8, 12]. These accessions were carefully chosen for their adaptability to Russia's diverse agro-climatic zones, reflecting Vavilov's meticulous strategy for systematic collection.

Between 1916 and 1933, Vavilov personally led or supervised over 180 expeditions to regions as diverse as the Mediterranean, Middle East, Central Asia, Ethiopia, Afghanistan, China, and Latin America [5, 6, 8]. Studying the collected material allowed Vavilov to make two fundamental discoveries, which he used to maximize the effectiveness of his subsequent collecting missions. In a rather short time he assembled a rich collection of plant genetic resources. First, he formulated the law of homologous series in hereditary variability [4]. which suggested that related species or genera exhibit parallel patterns of variation. Thus, the law has found application in breeding practice in the targeted search for predicted variability and the search for its sources. Furthermore, the law has played an important role in the development of the collection of world plant genetic resources, because Vavilov and his colleagues now knew exactly *what* to look for when setting out on expeditions [9]. Then, with the theory of the centres of origin of cultivated plants [14]. Vavilov knew exactly *where* to look for the most valuable plant genetic resources. It's safe to assume that without these two brilliant theories, assembling an equivalent collection would have taken much longer. Moreover, without the theories underlying intensive and successful collection missions, the World War II would have prevented the missions from being completed. Thanks to Vavilov's genius, the unique collection was assembled in a timely manner — before the war, before the subsequent industrialization of agriculture and urbanization, which together led to the *in situ* loss of significant genetic diversity. This valuable diversity had been timely preserved by Vavilov *ex situ*.

Following Vavilov's death, his ideas were carried forward by scientists both within Russia and internationally. In particular, Jack R. Harlan further elaborated the concept of gene pools—primary, secondary, and tertiary – which remains central to crop breeding [15]. To solve the problem of monitoring the genetic purity and integrity of plant genetic resources when they are stored in collections, as well as the problem of monitoring varietal purity in seed production, [16]. proposed using proteins as genetic markers. Anatoly F. Merezhko proposed and substantiated a system for searching, creating and using donors of valuable breeding traits and distinguished between the concepts of "donor" and "source" of a valuable trait [17]. Tatiana A. Gavrilenko and Irena G. Chukhina proposed a comprehensive strategy for registering the varietal gene pool in gene banks based on nomenclatural standards and genetic passports [18]. The continuation of large-scale exploration, characterization, and systematization of plant genetic resources at VIR firmly established linking Vavilov's theoretical legacy with modern molecular and genomic approaches [8, 9, 12, 13, 19].

Infrastructure, Collections, and Operational Scale

As of 2024, VIR hosts 438,951 seed storage units in St.Petersburg, including 308,481 under medium-term storage at –10 °C and 130,470 under long-term storage at –20 °C, distributed across more than 750,000 storage units together with those in VIR seed storage in Kuban region [12]. The main facility in St. Petersburg houses cold rooms, a cryobank, *in vitro* laboratories, a phytotron greenhouse, and an herbarium. The Institute employs ca. 1200 staff, including ca. 500 research staff organized into 26 research departments/ laboratories and 15 branches ensures conservation across Russia's diverse agro-ecological zones.

Composition and Scope of Collections

The breadth of VIR's holdings is exceptional. The wheat collection alone contains around 52,600 accessions, including cultivars, landraces, and wild relatives. Cereals such as barley, oats, and rye contribute another 36,400 accessions, while groat crops including maize, sorghum, and millet account for 48,500. Legume collections number approximately 46,500 accessions, and vegetables around 52,000. Forage crops add 32,000 accessions, while oil

Table 1. VIR Infrastructure Overview

Component	Details
Seed storage units	438,951 in St.Petersburg (including 308,481 (–10 °C), 130,470 (–20 °C)), total >750,000 storage units (with storage in Kuban region)
Storage Facilities	Seed bank, cryobank, phytotron greenhouse, in vitro labs
Regional Network	15 field branches in varied agro-ecological zones
Organizational Structure	~500 researchers; 26 departments/ labs

Table 2. Crop Collection Highlights at VIR

Crop Category	Approx. Accessions	Notable Details
Wheat	~52,600	Includes landraces and wild relatives
Cereals (barley, oats, rye)	~36,400	Multi-species collections
Groat crops	~48,500	Includes maize, sorghum, millet
Legumes	~46,500	Broad inter-generic representation
Vegetables	~52,000	High intra-species diversity
Forage crops	~32,000	Includes alfalfa, temperate grasses
Oil/Fiber crops	~28,500	Sunflower, flax, cotton
Potato	~8,300	Wild species, cultivars, disease resistance
Fruits & Ornamentals	~22,750	Fruits and berries maintained *in situ*

and fibre crops, including sunflower, flax, and cotton, amount to 28,500. The potato collection includes over 8,300 accessions representing both cultivated and wild species, offering critical resistance traits. Fruits and ornamentals number ca. 23,000 accessions [5, 8].

Contributions to Breeding and Crop Improvement

The germplasm conserved at the Vavilov Institute (VIR) has been instrumental in enhancing both Russian and global agriculture through its direct contributions to cultivar development and adaptive expansion of crops. Since its early years, VIR has fuelled the release of more than 2,500 cultivars, of which 450 are cultivated over approximately 63 million hectares. Remarkably, nearly 80 percent of all wheat cultivars currently grown in Russia incorporate genetic material originating from VIR collections [20]. Over the past six decades, the adoption of VIR-based cultivars has translated into significant yield increases: cereal yields surged by two- to fivefold, while potato yields rose by two- to fourfold, underscoring the germplasm's contribution to productivity. Moreover, VIR germplasm enabled the geographical expansion of several crops into challenging agro-climatic zones. Notably, maize cultivation was extended nearly 2,000 km northward and 10,000 km eastward owing to adaptive traits derived from VIR material. Barley accessions amassed in the 1920s provided durable resistance to greenbug pests – harboring rare resistance genes that have continued to benefit breeding programs for decades. Beyond adaptation to climatic and pest stress, germplasm from VIR catalyzed the introduction and domestication of novel species in Russia – such as spelt, amaranth, stevia, cherry plum, Actinidia, and sea buckthorn – enabling cultivation across acidic and desertified terrains. The Institute distributed to breeding centres an average of 5,000 accessions annually reinforcing its role as a hub of genetic resource dissemination [5, 8].

International collaboration during the last decade

In recent years, VIR has been actively involved in international research projects aimed at unlocking the potential of PGR and gaining new knowledge about the inheritance patterns of economically valuable traits [8]. VIR staff, led by Dr. Margarita Vishnyakova, participated in the INCREASE (Intelligent Collections of Food Legumes Genetic Resources for European Agrofood Systems) project of the Horizon 2020 Program. VIR also participated in the AGENT (Activated GEnebank Network) project of the Horizon 2020 Program (led on the Russian side by Dr. Alexander Rodionov and Prof. Igor Lockutov).

VIR recently participated in bilateral projects with a partner from the Republic of Belarus, the Institute of Genetics and Cytology of the National Academy of Sciences of Belarus: (1) “Study of the genetic mechanisms regulating the accumulation of anthocyanins and carotenoids in vegetable nightshade (Solanaceae) and cabbage (Brassicaceae) crops” (supervised by Dr. Anna Artemieva); (2) “Introgression into the cultivated potato genome of genetic material from wild Mexican species of the genus Solanum “ carriers of the B genome using various methods for producing interspecific hybrids and their progeny” (supervised by Dr. Tatiana Gavrilenko); and in bilateral projects with the Royal Society of London: (3) “Study of potato resistance genes to late blight and their role in the formation of pathogen effector diversity” (supervised by Dr. Elena Rogozina); (4) “The Process of Oat Domestication and Untapped Genetic Diversity of Its Wild and Weedy Field Relatives” (led by Prof. Igor Lockutov). Also, in recent years, VIR has implemented a bilateral project with its German partner, the Leibniz Institute for Vegetable and Ornamental Crops, “Functional Analysis of Glucosinolate Degradation Products in Relation to Pest Resistance in Brassica rapa” (led by Dr. Anna Artemieva) [8].

Technological Advances and Conservation Strategies

VIR has not confined itself to classical seed storage techniques but has embraced advanced preservation technologies to safeguard genetic diversity. The introduction of hermetic packaging, using laminated foil (Figure 1) and glass, represents a pivotal advancement in extending seed longevity and reducing regeneration frequency – consequently lowering operational costs [2].

Beyond conventional seed vaults (Figure 2), VIR has notably expanded its conservation repertoire. Its herbarium, surpassing 370,000 specimens, serves as a botanical archive complementing seed collections.

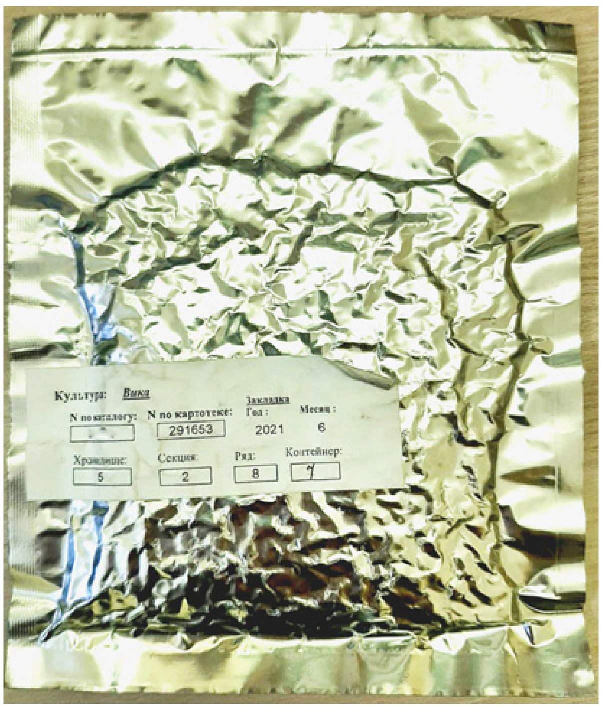

Figure 1. Example of storage unit in laminated foil (VIR, 2025)

Figure 2. Cold storage for long-term preservation of seed samples (VIR, 2025)

Meanwhile, biotechnology-based approaches (including *in vitro* conservation, cryopreservation) and digital technologies ensure multi-tiered security of valuable germplasm [8, 13, 18, 19, 21].

Cryopreservation technology, particularly via modified droplet-vitrification protocols, represents a state-of-the-art conservation strategy at VIR [22]. For potato germplasm, modified cryoprotocols enable the secure long-term preservation of cultivars with post-thaw regeneration rates of 40–95 percent, while even lower percentages (20–39 percent) remain acceptable for long-term storage [23, 24]. Furthermore, four modern potato cultivars – ‘Grand’, ‘Gusar’, ‘Signal’, and ‘Utro’– retained an average post-thaw regeneration capacity of 41.8 percent after seven months in cryo-storage, verifying the efficacy of these methods [25]. VIR has also adapted these approaches to other crops – red raspberry cultivars preserved *in vitro* exhibited accelerated cryopreservation protocols, reducing procedure duration from fourteen to eleven weeks with successful regeneration outcomes [26]. A total of 3,677 samples of vegetatively propagated crops are maintained as a dormant buds, cuttings, microplants apexes and pollen in VIR cryobank (Figure 3).

A comprehensive strategy for registering the varietal gene pool in gene banks based on nomenclatural standards and genetic passports, proposed in 2020 [18]. now covers hundreds of accessions of vegetatively propagated crops [19].

Concurrently, VIR has embraced digitization and molecular tools to enhance the accessibility and analytical potential of its collections. Digital record-keeping facilitates germplasm selection and sharing, aligning with

Figure 3. Cryobank (VIR, 2025)

global trends in plant genetic resource informatics [1]. In managing information about its collection samples, VIR is currently transitioning from an information-analytical system (data platform) to a state information system, which is used to create catalogs of the VIR collection and small PGR collections of other Russian institutes, as well as a national catalog of particularly valuable plant genetic resource samples. This work is a part of the Development Program of the National Center for Plant Genetic Resources for 2023-2030 [19].

Investigation of VIR collection currently implements a large number of molecular genetic, genomic and postgenomic (including all omics approaches, GWAS, Genome editing, etc.) approaches (summarized in [8, 13, 27].

CONCLUSION

The Vavilov Institute of Plant Genetic Resources represents the convergence of scientific vision and institutional resilience in the service of global seed conservation. Its collections, built systematically over more than a century, have not only shaped Russian agriculture but also influenced global policy and practice. Looking ahead, genomic dissection of adaptive traits, modelling crop adaptation under climate change, and institutional analysis under socio-political transitions present fertile grounds for future research. In its scope, impact, and continuing relevance, VIR remains a cornerstone of global conservation and a model for seed science worldwide.

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