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CHRONICLE

M.M. Gryshko National Botanical Garden of the NAS of Ukraine: a leading scientific and educational center for the introduction, conservation and rational use of phyto-genetic resources for the sustainable development and post-war recovery of Ukraine

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Abstract

The paper highlights the role of the M. M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine (NBG) as a leading scientific and educational center for plant introduction, conservation, and rational use of phyto-genetic resources, a role of primary importance for Ukraine's sustainable development and post-war recovery. The historical formation of the institution and its contribution to the advancement of botanical science are outlined, particularly in the fields of plant introduction and acclimatization, dendrology, breeding, genetics, biotechnology, phytoenergetics, allelopathy, bioindication, and biodiversity conservation.

The main directions of the NBG's scientific research are presented. Particular attention is paid to the activities of scientific schools established within the NBG that have made significant contributions to the development of introduction, breeding, allelopathy, and biodiversity conservation. Scientific objects of the NBG holding the status of National Heritage of Ukraine are characterized, including: collections of tropical and subtropical plants, collections of floral and ornamental plants, monocultural gardens, and the collection fund of energy and aromatic plants. Their significance as genetic resources for breeding, scientific research, and environmental education is emphasized.

The results of fundamental and applied research, international projects, and programs of the National Academy of Sciences of Ukraine are provided. It is demonstrated that the NBG is one of the largest centers for the conservation of rare species of Ukrainian flora, where the scientific foundations for *ex situ* biodiversity conservation, modeling of introduction populations, and optimization of protection measures have been developed. Criteria for increasing plant adaptability to climate change and stress factors have been established, and new models for resistance research and approaches to increasing plant productivity have been developed.

The strategic importance of the NBG as a center of science, education, and innovation is emphasized, ensuring the integration of fundamental research, applied development, and public outreach, thereby creating the conditions for ecological security, agricultural development, bioenergetics, and the strengthening of environmental consciousness within society.

Keywords: M.M. Gryshko National Botanical Garden of the NAS of Ukraine, fundamental research, applied research, botanical collections, scientific schools, innovation center, national heritage

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Historically, the Academic Botanical Garden was formed as Ukraine's leading scientific institution, conducting comprehensive research into the introduction and acclimatization of plants, dendrology, and park science. It focuses on the conservation of the gene pool of rare and endangered plant species, as well as the breeding and genetics of floral-ornamental, fruit, energy-resource, vegetable, aromatic, and industrial crops. The institution's scope further encompasses medical botany, phytoenergetics, the biotechnology of tropical, subtropical, and energy-resource plants, allelopathy, bioindication, and the environmental monitoring of pollution.

Since the beginning of the 21st century, the M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine (NBG) has been implementing a long-term strategy to integrate its research into the global scientific community, aiming to secure leading positions in biological sciences within its specialized fields.

In accordance with the Main Scientific Directions and the Key Problems of Fundamental Research in the Fields of Natural, Technical, and Humanities Sciences of the National Academy of Sciences of Ukraine for 2024–2028, and with the aim of ensuring a high level of scientific research and its orientation toward solving contemporary problems of science and technology, the NBG conducts research in the following main directions:

- biodiversity research aimed at its protection, conservation, restoration, and rational use;
- epigenetic, molecular, cellular, and physiological mechanisms of biological system functioning processes and their regulation;
- biotechnologies and nanobiotechnologies;
- conservation and reproduction of the gene pool of cultivated plants and their wild relatives.

Within the framework of the Research Program of the Department of General

Biology of the National Academy of Sciences of Ukraine, in accordance with the above-mentioned main scientific directions and key problems of fundamental research in the fields of natural, technical, and humanities sciences of the NAS of Ukraine, the NBG carries out scientific research in the following areas:

- plant introduction, acclimatization, and breeding;
- phytomonitoring and biodiversity conservation;
- structural and functional foundations of the formation of natural and artificial biogeocenoses;
- ecological and biological principles of landscape design and landscape gardening construction.

The NBG addresses scientific issues in the fields of plant physiology and biochemistry; allelopathy (chemical interaction of plants); plant biotechnologies; medical botany and biosafety; integrated use of medicinal, aromatic, food, and bioenergy plants; bioindication and chemosystematics; renewable phytoenergy; and environmental education and outreach activities.

For the NBG, scientific and scientific-technical activities are the core areas of operation. It serves as a national center for the organization of environmental education and public awareness, aimed at shaping environmental consciousness and engaging citizens in the conservation of natural heritage. For this purpose, the NBG utilizes living plant collections, creates specialized exhibitions, establishes ecological trails, publishes popular science literature, maintains an official website, organizes lectures and seminars, and conducts public outreach through print media, radio, and television.

The NBG functions as a base for education and practical training of students from higher education institutions, technical colleges, lyceums, vocational schools, and general schools, as well as participants in advanced training courses and their staff. The mission of the NBG in the field of education

is to make a substantial contribution to the development of Ukrainian society through the creation, formation, and dissemination of modern knowledge based on the integration of education and science, guided by the principles of creativity, academic integrity, and academic freedom. The NBG ensures comprehensive access to knowledge about plants, their diversity, and their interactions with the environment, and focuses on the training of highly qualified specialists in botany who are capable of being at the forefront of the development of modern biological science. The strategy of the NBG is aimed at strengthening the leading role of the institution in the field of biological sciences within the educational space of Ukraine and worldwide, as well as at enhancing the social responsibility of scientists in the face of contemporary global challenges.

A number of well-established scientific schools have been formed and are successfully operating at the NBG. They play a significant role in the development of biological sciences, the training of highly qualified personnel, the implementation of innovative technologies, and the popularization of scientific knowledge. Their activities encompass fundamental and applied research of substantial importance for biological science, the agricultural sector, environmental protection, biotechnology, and sustainable development.

The scientific school “Introduction and Breeding of Food, Forage, and Flower-Ornamental Plants”, founded by Academician Mykola Gryshko in 1950, is one of the oldest and most productive. Over the period of its existence, 16 Doctors of Sciences and 57 Candidates of Sciences (equal to PhD) have been trained. The main research areas include plant introduction, acclimatization, and breeding. Between 1958 and 2024, more than 450 cultivars were developed, 184 of which were created during the last five years alone. A total of 35 modern phytotechnologies were developed, as well as technological regulations for the production of high-vitamin food products, protein feeds, medicinal products, and alternative fuels. The theoretical foundations of plant introduction were expanded by the concept of biomorphological potential, as well as by the principles of creation and conservation of ornamental plant collections. Cultivars bred at the NBG are on

par with the world’s leading analogs in terms of productivity and resilience.

The scientific school “Chemical Interaction of Plants (Allelopathy)”, founded by Academician Andrii Grodzinsky in 1965, established a strong scientific tradition in the field of plant chemical ecology. Within this school, seven Doctors of Sciences and 53 Candidates of Sciences (equal to PhD) were trained. Allelopathy as a scientific field emerged at the intersection of geobotany and plant physiology and was comprehensively developed through the theoretical legacy of Andrii Grodzinsky. His research covered the definition of the essence of allelopathy, the description of 15 ecological mechanisms of plant interactions in biogeocenoses and agrophytocenoses, and the study of the role of allelopathically active substances in the mobilization of plant defense functions and the maintenance of soil fertility. Followers of the school continued these studies, elucidating the role of silicic acids, brassinosteroids, chemical elements, and sugars in the structural and functional organization of biogeocenoses.

The scientific school “Biodiversity Conservation”, founded by Corresponding Member of the National Academy of Sciences of Ukraine Tetiana Cherevchenko in 1985, focuses on the study, conservation, and enrichment of plant diversity. Within this school, five Doctors of Sciences and 37 Candidates of Sciences (equal to PhD) have been trained. The NBG has assembled over 17.2 thousand species, forms, and cultivars of plants from around the world, including approximately 4 thousand tropical and subtropical taxa. These collections (including flower-ornamental plants, monoculture gardens, energy and aromatic species) are recognized as National Heritage of Ukraine. Representatives of the school laid the foundations for integrated *ex situ* conservation of tropical plants, ranging from the study of their ecological and coenotic characteristics to the development of methods of mass propagation and the creation of exhibitions informing the public about global flora and the need for its conservation. On the basis of these plants, phytoremediation modules have been developed for the optimization of spaces with various functional purposes.

The NBG includes three objects that are designated as the National Heritage of Ukraine: “Collections of Tropical and Subtropical

Plants”, “Collections of Flower-Ornamental Plants and Monoculture Gardens”, and the “Collection Fund of Energy and Aromatic Plants” (Rakhmetov, 2019).

The Collections of Tropical and Subtropical Plants (approximately 4,000 taxa) are housed in greenhouses with a total area exceeding 5,000 square meters. One of the largest is the collection of tropical orchids, which comprises about 450 species and forms belonging to 160 genera. Particularly unique are the collections of tropical aroids, cultivars of Indian azalea (*Rhododendron indicum* (L.) Sweet) and Japanese camellia (*Camellia japonica* L.), as well as bulbous and short-rhizomatous geophytes, specimens of which were collected in their natural habitats. Based on these core collections, theoretical foundations for the integrated *ex situ* conservation of tropical plant biodiversity are being developed, along with the practical implementation of measures aimed at preserving the gene pool of tropical-origin flora under greenhouse cultivation conditions.

The Collections of Flower-Ornamental Plants and Monoculture Gardens include the “Rose Garden,” “Lilac Garden,” and “Peony Collection” (Rakhmetov, 2019).

The “Rose Garden” is a unique urban ecosystem, combining an architectural ensemble created by the prominent architects Olexandr Vlasov and Mykola Kholostenko with the largest rose collection in Ukraine, representing global trends in plant gene pool conservation. It is a large park composition in which rose plantings are integrated with numerous landscape and architectural elements, including fountains, stairways, arches, trellises, and plantings of coniferous and deciduous species. The rose collection of the NBG “Rosarium” was created and continues to be developed using the method of generic complexes. Of particular value are species of the natural flora of Europe, Asia, and North America belonging to two of the four subgenera of the genus *Rosa* L. The following cultivar groups are the largest in Ukraine or are represented exclusively at the NBG: old garden roses (50 cultivars), cultivars of *Rosa rugosa* Thunb. (35 cultivars), Canadian roses (20 cultivars), musk roses (15 cultivars), cultivars of *Rosa spinosissima* L. (ten cultivars), and hybrids between rose cultivars and *Hulthemia persica* (Michx. ex Juss.) Bornm.

(10 cultivars) (Rubtsova & Chyzhankova, 2019; Rakhmetov, 2019; Rubtsova et al., 2025).

The “Lilac Garden”, or “Syringarium,” is well known both in Ukraine and internationally, successfully combining high artistic and scientific value. In terms of taxonomic richness, the collection is not inferior to the best analogues of foreign botanical gardens; however, in terms of the picturesque landscape surrounding it and the exceptionally abundant flowering of shrubs, it has no equal worldwide. The establishment of the lilac collection began in 1946 on an area of 1.5 ha, starting with the first 30 cultivars of German breeding obtained from Germany. Today, the collection includes approximately 200 cultivars, species, and promising ornamental forms, represented by 1,500 plants, and the area has expanded to 2.35 ha. The collection of lilac species at the NBG is the most comprehensive in Europe, comprising 22 species out of 27 known in natural flora. Breeding work is conducted at the NBG, resulting in cultivars such as ‘Bohdan Khmelnytskyi’, ‘Vohni Donbasu’, ‘Taras Bulba’, and ‘Lesia Ukrainka’. In 2025, four highly ornamental cultivars were submitted for cultivar testing. In addition to common lilac cultivars, recent years have seen increased attention to Chinese lilac. Two dwarf forms, characterized by winter hardiness and drought resistance, have been obtained through breeding methods. Current research focuses on identifying effective propagation methods, as these forms may eventually become promising rootstocks for creating low-growing plants from genetically tall cultivars, primarily common lilac.

The “Peony Collection” is represented by three life forms: herbaceous peonies, semi-shrub peonies, and shrub (tree) peonies. This collection is the largest in Ukraine and one of the richest among neighboring countries and Eastern Europe. At present, its gene pool includes nine species, 650 cultivars, and 30 promising breeding accessions. Herbaceous peony cultivars are the most widely represented, including more than 50 cultivars bred by NBG breeders. The peony collection serves as a reference standard for cultivar identification (Rakhmetov, 2019; Gorobets, 2023).

The Collection Fund of Energy and Aromatic Plants of the NBG (Order of the Cabinet of Ministers of Ukraine dated 28 January

2015, No. 59-r) comprises 1,826 accessions. It includes collections of energy raw plants (714 accessions) for use in solid biofuels and biogas, oil crops for biodiesel production, sugar-bearing plants for bioethanol production, spice-aromatic plants (248), essential oil plants (215), medicinal plants (419), the exhibition plot “Garden of Aromas” (120 accessions), and an exhibition-breeding plot of new crops and cultivars of the NBG at the experimental farm of the NAS of Ukraine “Hlevakha” (110 accessions).

The collection fund was formed by NBG researchers over a long period (the collection of aromatic plants for more than 80 years and energy plants for more than 30 years) and represents the largest base collection of these plant groups in Ukraine. The collection fund includes plants from various botanical and geographical regions of the world. Most accessions have undergone long-term introduction trials, are adapted to the conditions of Ukraine, ensure high productive potential, and are capable of reproduction, while some representatives are capable of naturalization (Rakhmetov, 2024a).

The collection fund includes plants of exceptional scientific, economic, social, educational, and cognitive-ethnobotanical significance. This collection is particularly valuable from the perspective of *ex situ* conservation of plant diversity and represents an important genetic resource for breeding and the development of new plant forms and cultivars (Rakhmetov, 2019).

It is also significant that the collection fund comprises approximately 140 cultivars of in-house breeding, for which authors’ certificates and patents have been obtained and which are recommended for cultivation in various soil and climatic zones of Ukraine.

During recent years (2019–2024), the NBG carried out 16 departmental research and development (R&D) projects in the field of fundamental studies under the priority direction of science and technology development “Fundamental scientific research on the most important problems of scientific and technological, socio-economic, socio-political, and human potential development to ensure the global competitiveness of Ukraine and the sustainable development of society and the state”; four departmental applied R&D projects under the priority thematic area

“Rational nature management. Technologies for sustainable use, conservation, and enhancement of bioresources and improvement of their quality and safety, and biodiversity conservation”; 19 program-targeted and competitive R&D projects of the National Academy of Sciences of Ukraine, and 27 contract-based projects. Researchers of the NBG also participated in the implementation of 11 international scientific projects.

Within the framework of fundamental research R&D, the NBG has developed and implemented a scientifically substantiated approach to the *ex situ* conservation of floristic diversity through modelling of introduction populations of rare and endangered species in forest and steppe cultural phytocoenoses. The botanical-geographical plots and the collection “Rare Plants of the Flora of Ukraine” include 128 species listed in the Red Data Book of Ukraine, 35 regionally rare plant species of the flora of Kyiv, 11 species listed under the Bern Convention, 24 species listed under the CITES Convention, 18 species from the European Red List, and 14 species from the IUCN Red List, making the NBG one of the largest centers for the conservation of rare plant species in Ukraine.

Of particular value are the botanical-geographical plots representing the vegetation of the Caucasus, Central Asia, the Altai, and the Far East, where, over a period of more than 80 years, cultural phytocoenoses close to natural ones have been formed. These have become unique centers of floristic diversity, in which rare species have found favorable ecological niches and are actively reproducing. Based on comparative ecological-coenotic and population analyses, as well as monitoring of spontaneous flora, proposals were developed for the optimization of conservation measures. The results formed the basis for the establishment of new objects of the Nature Reserve Fund of Ukraine, including the Kholodny Yar National Nature Park and 22 additional territories, ensuring the protection of 34 rare plant species listed in the Red Data Book of Ukraine (Gaponenko & Gnatiuk, 2021; Gritsenko & Shynder, 2022; Rak et al., 2023).

The scientific foundations for the conservation, enrichment, and efficient use of resources of valuable introducers and rare plants under the impact of climate change in Ukraine have been developed.

The fundamental principles of introduction, acclimatization, breeding, and biotechnology aimed at the mobilization and creation of new plant genetic resources have been elaborated to ensure the conservation, enrichment, and efficient use of the global potential of tropical, subtropical, flower-ornamental, fruit, food, and energy introducers, as well as rare species of various plant life forms from the flora of different countries and Ukraine under conditions of environmental change (Zaimenko & Rakhmetov, 2022).

Recommendations have been developed for the rational use of the ecological potential of disturbed and degraded territories, and a range of plant species promising for the revitalization of eroded landscapes of Ukraine has been identified. Optimal conditions have been created for rare plants and valuable introducers, ensuring high ornamental value and longevity of plantings, and their economic efficiency and feasibility of use have been substantiated.

Biological-ecological, morphological-anatomical, physiological-biochemical, allelopathic, breeding-genetic, and phytocoenotic criteria have been established for increasing adaptive capacity and resistance of plants, improving reproductive function, productivity, and quantitative-qualitative characteristics of valuable introducers and rare plant species, with the aim of forecasting and preventing the negative impacts of changing climatic conditions. Predictive models have been developed to study the mechanisms of plant resistance to biotic and abiotic stresses. Based on nanomaterials of silicon-containing minerals and allelopathically active substances, the scientific foundations for enhancing plant productivity and resistance to abiotic stressors have been developed. The allelopathic features of plants and their role in species adaptive strategies under climate change conditions have been identified (Rakhmetov & Zaimenko, 2022).

In the arboretum of the NBG, the composition of the gene pool has been analyzed and the condition of collection plantings optimized. A total of 122 taxa (species, varieties, cultivars, and hybrids) have been integrated, 61 of which are new to the collection. Despite the challenges of war and extreme climatic fluctuations, not only has the collection been preserved, but it has also been actively enriched, confirming the effectiveness

of adaptive introduction strategies. Phenological monitoring revealed significant differences in the timing of phenophase onset compared with archival data from 10–50 years ago, allowing an assessment of the impact of climate change. A comprehensive register of gymnosperm taxa cultivated in 67 botanical institutions of Ukraine has been compiled, and a research base of somatic mutations (84 samples from six genera) has been created, opening prospects for the study of genetic variability and adaptive potential. Ukrainian options of the international BBCH scale have been proposed for describing the phases of seasonal development of woody plants and harmonizing them with traditional scales, contributing to the unification of phenological research. The levels of winter hardiness and drought resistance of representatives of the genus *Hamamelis* L. have been determined, which is of practical importance for plant introduction and landscape greening under climate change conditions (Nesterova et al., 2019; Zaimenko & Rakhmetov, 2022).

The fundamental principles for the mobilization, conservation, enrichment, and efficient use of resources of introduced and autochthonous plants have been developed to ensure the food, energy, and environmental security of Ukraine. Physiological-biochemical, genetic, and biotechnological mechanisms for increasing the efficiency of acclimatization, adaptation, and plant introduction processes, as well as for the reproduction of plant genetic diversity, have been elaborated, resulting in the creation of one of the richest collections of economically important plants. A valuable gene pool (2,560 taxa) has been assembled, and the introduction and genetic potential of new energy, raw-material, technical, spice-flavoring, essential-oil, forage, and vegetable plants (approximately 50 species, forms, and cultivars) has been assessed (Rakhmetov, 2020; Rakhmetov et al., 2024a).

Original methods for the regulation of growth and production processes in plants have been proposed, and the potential of crops new to Ukraine has been revealed. The most promising sources of proteins, lipids, sugars, and biologically active compounds have been identified based on the evaluation and selection of the most valuable genotypes with enhanced quantitative and qualitative characteristics of plant raw material (Rakhmetov et al., 2020).

Methods for increasing the adaptive potential of valuable introducers and endemic useful plants of the flora of Ukraine have been elaborated. The principles of phytoconversion based on plants with a C₄-type of photosynthesis, characterized by high resistance and productivity, have been formed.

For the first time, a new botanical taxon, the hybridogenic species *Rumex kioviensis* Rakhmetov, A.S.Mosyakin & Mosyakin (Kyiv dock), has been described and registered. On its basis, five cultivars have been created and included in the State Register of Plant Varieties of Ukraine, confirming the leading role of the NBG as a scientific center for the creation of new botanical taxa (Rakhmetov et al., 2024b).

Comprehensive studies on the conservation and enrichment of the gene pool of flower-ornamental plants have been carried out using modern introduction and breeding-genetic methods, analysis of global resources, and mobilization of source material of species promising for landscaping and breeding. Morphological-biological, biological-ecological, reproductive, and adaptive characteristics of new cultivars have been determined. The collections have been enriched with 47 species and 202 cultivars; at present, the flower-ornamental plant collection of the NBG comprises 5,196 accessions, represented by 4,167 cultivars and 1,029 species. The most comprehensive collections of flower-ornamental plants in Ukraine have been formed, among which annuals, peonies, and astilbes occupy leading positions in Eastern Europe.

An introduction assessment of more than 60 species and cultivars of the genera *Pulsatilla* Mill., *Iris* Tourn. ex L. (subgenus *Limniris* (Tausch) Spach), and *Paeonia* L. (Itoh Group) was conducted, including analyses of distribution ranges, ecological resistance, winter and drought resistance, morphogenesis, reproductive capacity, and phenology. The dependence of the duration of phenophases of Itoh Group peonies on the sum of effective temperatures was established, which made it possible to form a cultivar assortment for continuous flowering over two months and to select 25 cultivars for ornamental horticulture and landscape design. Thirty-nine winter-hardy iris cultivars (Siberian, Louisiana, Spuria)

were selected, and six species of *Pulsatilla* were recommended for cultivation and seed production under the conditions of the Right-Bank Forest-Steppe of Ukraine, contributing to the conservation of natural populations. The foundations of a scientifically substantiated technology for cultivation, propagation, and use of promising introducers in ornamental horticulture, taking into account their adaptive potential under climate change conditions, have been established.

The processes of introduction and adaptation of underutilized fruit plants have been theoretically substantiated through analysis of their evolutionary development, genetic and geographical origin, and comparison of climatic conditions of natural ranges with introduction regions. Forecasting and evaluation of factors of successful introduction were carried out, ensuring the formation of gene pools and the creation of promising cultivars. A unique gene pool comprising 855 taxa from 39 genera and 18 families of autochthonous and introduced species has been preserved and enriched; their fruits are characterized by a high content of biologically active compounds with adaptogenic, geroprotective, and therapeutic-dietary properties.

A collection-breeding fund has been established as a source of new genotypes of the genera *Actinidia* Lindl., *Asimina* Adans., *Elaeagnus* Tourn. ex L., *Cornus* L., *Cydonia* Daubenton & P.Daubenton, *Schisandra chinensis* (Turcz.) Baill., *Malus* Mill., *Prunus* L., and *Lonicera caerulea* L., which are characterized by a wide ecological range and suitability for cultivation under various soil and climatic conditions. New adapted cultivars of *Asimina triloba* (L.) Dunal, *Cydonia oblonga* Mill., *Cornus mas* L., *Mespilus germanica* L., and *Pseudocydonia sinensis* (Dum.Cours.) C.K.Schneid. with a complex of economically valuable traits have been bred and recommended for state variety testing.

A scientific concept of a homeostatic ideotype of a cultivar with defined morphological and functional parameters has been substantiated. The model is based on the analysis of the best genotypes and takes into account modern breeding requirements aimed at solving new agroecological and economic tasks. A concept of adaptive introduction has been developed, combining seed propagation,

natural and artificial selection, and synthetic breeding methods, ensuring an increase in the adaptive potential of introducers, the development of form-creating processes, and the expansion of the breeding base.

The phytochemical composition and adaptive properties of new and underutilized southern fruit plants of the genera *Actinidia*, *Lycium* L., *Chaenomeles* Lindl., *Cornus* L., *Schisandra* Michx., *Lonicera* L., *Asimina*, *Pseudocystodonia* (C.K.Schneid.) C.K.Schneid., *Prunus*, and others have been investigated. The content of polyphenols, flavones, polysaccharides, hemicelluloses, as well as phenological, morphological, anatomical, and biochemical characteristics and propagation methods under conditions of global climate change, have been analyzed. A wide spectrum of biological activity of these plants has been established, including adaptogenic, tonic, immunostimulatory, anti-inflammatory, regenerative, and antitumor effects. The drought resistance of apple cultivars has been evaluated, and the content of free proline has been identified as a reliable marker of resistance to drought and anthropogenic pressure. The biological and biochemical characteristics of *Schisandra chinensis* have been revealed, in particular its high content of organic acids, lignans, saponins, vitamins, flavonoids, and trace elements, confirming its significant potential for use in the pharmaceutical, cosmetic, and food industries (Klymenko et al., 2020; Zaimenko & Rakhmetov, 2022).

The results of studies on plants of tropical biomes have been summarized. The modular organization, phenological, morphological, and anatomical characteristics, as well as reproductive systems of representatives of tropical orchids (*Coelogyne* Lindl., *Guarianthe* Dressler & W.E.Higgins, *Dendrobium* Sw., *Paphiopedilum* Pfitzer) under *in vivo* and *in vitro* conditions have been established. Biological markers of stress presence have been identified to assess the impact of climate change on plants of this taxonomic group, which is considered one of the most threatened plant groups under global climate change.

The taxonomic composition of epiphytic algae associated with tropicogenic orchids has been investigated, and the specificity of associations between lower photobionts and

higher plants has been established. It has been shown that the colonization of orchid velamen by lower autotrophs is ordered in nature, and that the degree of photobiont specificity depends on the orchid species. Cases of cospecificity among diatoms and cyanoprokaryotes have been identified. Using the cyanobacterial strain *Nostoc punctiforme* (Kütz.) Har. and three species of epiphytic orchids as model systems, the features of their interactions under artificial greenhouse climate conditions and *in vitro* culture were investigated. The creation of such associations *in vitro* opens prospects for improving technologies for cultivation and deposition of rare and endangered orchid species, as well as for deepening the understanding of interactions between higher plants and lower photobionts.

The antioxidant activity of leaf extracts of six cultivars of *Camellia japonica* was determined using protein oxidation biomarkers. It was established that the content of aldehyde and ketone derivatives does not change significantly after *in vitro* incubation, and that screening of the spectrum of biological activity (antioxidant and anti-inflammatory) is promising for the search for preventive agents in the pathogenesis of metabolic diseases. Among tropicogenic orchids of the genus *Dendrobium* in the NBG collection, the most valuable producers of biologically active substances (BAS) were identified, with phenolic acids and flavonoids as the main components of their extracts. Sterile cultures of selected species were obtained, protocols for their *in vitro* cultivation were developed, and it was demonstrated that materials based on silica and orchid extracts ensure prolonged deposition of BAS. The created prototypes of prolonged-action preparations guarantee uniform and rapid release of extract components, slowing of desorption, and long-term activity of the antioxidant pool of compounds.

For the first time in Ukraine, “phytoremediation modules” have been developed for the optimization of the indoor human living environment, particularly in facilities with closed localization, such as medical and preventive institutions and rehabilitation centers. This development is based on fundamental scientific research in the fields of medicine, microbiology, plant

physiology, and applied botany. The presented author's concept of "phytoremediation clusters" has been elaborated taking into account the real needs of Ukrainian society under wartime conditions and post-war reconstruction (Yakimets et al., 2024).

The impact of global climate change on carbon and nitrogen pools and fluxes in natural and artificial ecosystems has been investigated. Based on a comparative analysis of forest and meadow-steppe biogeocenoses, the concept of balanced and unbalanced ecosystems was proposed, and their key characteristics were identified. Methods for the assessment and forecasting of ecosystem development using indicator parameters (including CO₂ emissions, plant species composition, microbiological and enzymatic activity of soils, distribution of biogenic elements, and phenolic compound content) have been developed. Biochemical and microbiological markers of CO₂ sequestration intensity have been identified. It has been demonstrated that natural biogeocenoses (beech primeval forests of the Carpathian Biosphere Reserve and the steppes of Askania-Nova) are balanced and capable of self-restoration, whereas artificial biogeocenoses of the botanical-geographical plots of the NBG, due to significant indicator fluctuations, remain unbalanced, unmanaged, and require substantial agrotechnical efforts to stabilize soil processes (Zaimenko et al., 2022; Zaimenko & Rakhmetov, 2022).

The role of secondary metabolites in the formation of allelopathic potential within the "soil-plant-soil" system has been investigated. A hypothesis was proposed suggesting that regulating ammonium nitrogen content in the rhizosphere soil can influence the intensity of strontium accumulation in the leaves of studied ornamental and fruit plants. Mechanisms of structural-functional organization of the "soil-plant-soil" system were determined to clarify the role of allelopathically active compounds in the formation of biogeocenoses, which involves analyzing the relationship between the bioavailability of mineral nutrients and the synthesis and release of secondary metabolites by plants into the environment. This approach revealed a barrier-free effect in rose plants regarding aluminum accumulation in leaves, indicating the feasibility of cultivating these plants on contaminated soils.

A positive correlation was established between air temperature and the absence of precipitation with triterpenoid accumulation in soil. An inverse correlation was observed between the pool of triterpenoids in soil, which are directly involved in forming stable humus structures, and the reduction in mobility of phenolic compounds alongside increased ammonium nitrogen content.

A technology for controlled growth of *Penicillium roseopurpureum* Dierckx R.P. and *P. rubrum* Stoll O. strains (producers of curvularin) was proposed, involving cultivation on various nutrient media in the presence of siliceous minerals (analcime, diatomite). The role of microelements in the synthesis of curvularin and rubratoxin was elucidated. Recommendations were developed for cultivating *P. roseopurpureum* and *P. rubrum* to obtain antibiotics on an industrial scale.

An ecosystem-based approach for optimizing urban landscapes was proposed. Microevolutionary processes in introduction populations were theoretically substantiated, and their role in forming long-lived and resilient green plantings in urban ecosystems was clarified. Ecotypic differentiation and genotypic diversity of major NBG collections were studied. Diagnostic sex traits were identified based on morphological characteristics of vegetative organs in juvenile and generative individuals of *Populus tremula* L., *Eucommia ulmoides* Oliv., and *Ginkgo biloba* L.

The dynamics of introduced plant resistance to aggressive phytophages and pathogens under botanical garden conditions were examined. It was found that the introduction of non-native plant species leads to the arrival of adventive pests into Ukraine's natural ecosystems, to which local species exhibit low resistance. Existing measures for protecting botanical garden plantings against pests and diseases were improved, and appropriate technological protection schemes were developed for different collections.

Within applied research, an informational analysis and bio-phytochemical evaluation of medicinal plants of the Ukrainian flora were conducted to develop innovative therapeutic and preventive phytoproducts. Comprehensive approaches were developed to identify promising species among native and introduced plants characterized by high

levels of biologically active compounds with pronounced antimicrobial and antioxidant activities. Based on these studies, adaptogenic phytocomplexes were developed and recommended for inclusion in specialized functional foods, particularly for military personnel, to enhance resistance to stress and adverse environmental factors. As a result of comprehensive biological, phytochemical, and insecticidal research, declaration patents for utility models were prepared and submitted, including: “Plant-based agent with antimicrobial activity,” “Blended plant oil based on sea buckthorn fruit oil,” and “Method for preparing the insecto-acaricidal preparation ‘ARTEDOK’”.

An ecologically justified technology for overcoming soil fatigue has been implemented in the green spaces of Kyiv, based on the integrated use of siliceous minerals and a synthetic analogue of salicylic acid. This technology relies on a synecological approach, which ensures optimization of soil properties (pH level, nutrient balance, reduction of toxicity), stabilization of coenotic and trophic relationships, and increased resilience of cultivated plants to abiotic and biotic factors, including phytopathogens. Modern methods for overcoming soil fatigue using phyto-sources of non-humified organic matter have been developed, and technological conditions for forming plant assortments and introducing new ornamental perennials into landscape compositions have been proposed to integrate them into urban landscapes while maintaining the ecological balance of phytocenoses.

A collection of approximately 100 sugar sorghum genotypes was established, and highly productive forms (14 samples) were selected for bioethanol and biobutanol production. The biological and technological properties of the biomass as a second-generation raw material were determined. New cultivars with increased sugar content for biobutanol production were developed (Rakhmetov, 2024b).

The pools and fluxes of CO₂ in model and natural terrestrial ecosystems of Ukraine were assessed. The effect of the No-till technology, widely applied for carbon sequestration, on allelopathic, biochemical, and microbiological soil regimes was analyzed. It was found that under No-till conditions in barley,

maize, and soybean crops, soil phytotoxicity increased due to the accumulation of phenolic compounds, manganese, and ammonium nitrogen compared to conventional plowing. A method for rapid assessment of potential soil fertility for various soil-climatic conditions was developed based on indicators of organic carbon, laccase activity, and the abundance of melanin-containing micromycetes. Rapid prediction methods for plant productivity based on quantitative indicators of chloroplasts in cells and chlorophyll *b* content in leaves were proposed.

The impact of airborne and light pollution on the structural-functional organization of urban phytocenoses was investigated. A hypothesis was proposed and substantiated regarding the stress effects of artificial night lighting on the anatomical-morphological structure and physiological-biochemical processes in the leaves of urban trees in Kyiv. New patterns of artificial light with different spectral compositions on the content of photosynthetic pigments and protective antioxidant secondary metabolites in leaves were identified. Differences in adaptive changes in the ultrastructural organization of mesophyll cells and secondary metabolism between the studied tree species under different spectral compositions of artificial light were established. The positive effect of red light on the synthesis of protective compounds such as flavonoids, tannins, and brassinosteroids was demonstrated.

The role of biogenic elements in inducing brassinosteroid synthesis to enhance plant stress resistance was shown. For the first time, a synergistic enhancement effect was observed when exogenous brassinosteroids and ammonium nitrate were applied simultaneously, improving the allelopathic and biochemical status of rhizosphere soil. New significant patterns of physiological interactions between endogenous brassinosteroids and sugars in the leaf tissues of *Crambe cordifolia* Steven and *Stevia rebaudiana* (Bertoni) Bertoni, as well as between brassinosteroids and silicon in the bulbs of *Allium ursinum* L. and *Leucojum vernum* L., were established. The autonomy of assimilate distribution in multicolored leaves of chimeric plants was demonstrated for the first time (Rakhmetov & Zaimenko, 2022; Zaimenko & Rakhmetov, 2022).

For the first time in Ukraine, scientific and methodological principles have been developed, and new oilseed crops have been introduced into cultivation. Methods to enhance plant resistance and improve physiological processes have been elaborated. The qualitative and quantitative composition of lipids, as well as macro- and microelements in plant biomass, has been assessed. Methods for improving the biotrophic properties of soil through the use of siliceous fertilizers have been developed. Approaches for zero-waste utilization of by-products have also been explored (Rakhmetov & Zaimenko, 2025).

Based on theoretical generalizations and experimental studies, the cultivation conditions, growth and development features, and biomass formation of medicinal plants were determined for: chamomile (*Matricaria chamomilla* L.), striped urn orchid (*Bletilla striata* (Thunb.) Rchb.f.), common yarrow (*Achillea millefolium* L.), and common St. John's wort (*Hypericum perforatum* L.). The productive potential of the plants was analyzed, and extraction and quantification of secondary metabolites were performed. The effectiveness of acute seed irradiation for stimulating growth and development processes was evaluated for chamomile, yarrow, and St. John's wort (Rakhmetov, 2025).

Studies were conducted to assess atmospheric pollution in parts of Ukraine, within the Volyn and Novhorod-Siverskyi Polissia regions, by toxic heavy metals, for inclusion in the "Atlas of Atmospheric Heavy Metal Deposition in Europe" within the framework of the International Cooperative Programme on Vegetation (ICP Vegetation) of the United Nations Economic Commission for Europe (UNECE). This program involves 28 European countries and monitors long-term, large-scale biogeochemical deposition of 11 toxic heavy metals (As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, Sb, V, and Zn) in the atmosphere using moss biomonitoring, in accordance with the UN Convention on Long-Range Transboundary Air Pollution (CLRTAP). The data are utilized by national environmental agencies to inform international policymakers about the effectiveness of air pollution control measures under the UN LRTAP Convention and to develop strategies for improving air quality in Europe.

The implementation of an open geoinformation system for the preservation of the natural and cultural heritage of the NBG has begun. Based on the ZERUM GIS information-analytical platform, the NBG Geoportal has been established as an open geoinformation system accessible via a web browser. Using innovative information technologies, materials have been prepared on the botanical garden's natural and cultural heritage sites, its most notable collections, and sections representing landscape art – national treasures, as well as aged and memorial trees, the historical Red Courtyard, Zvirynets fortifications of the Kyiv Fortress, and others. An ecological-historical excursion route, "Secrets of the Zvirynets Fortification," has been developed, presenting the monument and the collection-exposition sections of the NBG with organized visitor access while ensuring compliance with the protection regime and preservation of the natural environment of protected areas in Ukraine (Gaponenko et al., 2024).

The NBG is a research institution and a protected area of the national nature reserve fund, performing recreational functions and serving as a unique urban compensation zone in the central part of Kyiv. The institution manages a territory of approximately 130 ha, encompassing sites that require special conditions for maintenance, care, and conservation. This area represents a unique space where scientific research, breeding work, biodiversity conservation, and educational activities are integrated. All activities are carried out with the active participation of scientific staff, who ensure proper plant care, monitor their condition, and implement new agrotechnical solutions.

At the NBG, unique collections of ornamental, medicinal, fruit, vegetable, spice-aromatic, energy, and industrial plants from all botanical-geographical regions of the world have been established, totaling over 17,200 species, forms, and cultivars. These collections hold exceptional scientific and economic value and are particularly important given global trends of decreasing plant diversity and the extinction of many flora species (Rakhmetov, 2020; Gorobets, 2023).

The NBG has achieved significant success in creating intellectual property objects. Between 2020 and 2024 alone, more than ninety patents were obtained for plant varieties, utility

models, and inventions. This scale of research activity opens wide opportunities for practical application, commercialization, and cross-sector collaboration.

Utility models and inventions, particularly those related to cultivation methods, plant productivity assessment, biofuel or fertilizer production, are integrated into the production processes of agricultural enterprises, ornamental horticulture, and bioenergy. Special attention is given to the potential use of patents in educational and therapeutic programs. Additionally, inventions concerning soil fertility assessment and alleviation of soil fatigue can serve as the basis for ecological initiatives aimed at the restoration of degraded lands (Zaimenko & Rakhmetov, 2022).

In recent years, the NBG has established ethnobotanical exhibits demonstrating elements of the unique natural and cultural heritage of various regions and peoples of the world. The need for comprehensive research into the historical and cultural heritage of botanical gardens and arboreta has been recognized by the Botanic Gardens Conservation International (BGCI) as one of the most important tasks for modern botanical institutions.

A concept for the development of botanical exhibits has been formulated. Creating ethnobotanical displays is particularly relevant for enhancing the aesthetic perception of the territory and promoting global ecological culture and achievements in landscape art from different peoples. The Eastern sector is the most fully represented, including the Korean Traditional Garden, the Tibetan Nature and Culture section, and the Indonesian Garden. The Japanese and Chinese Gardens are under development, and a site dedicated to the culture and landscape art of Turkey is in the design phase.

Conclusions

The M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine (NBG) has developed into a leading scientific center that integrates fundamental research, applied studies, and educational and outreach activities aimed at the conservation and sustainable use of phylogenetic plant resources. Decades of

experience in introduction, acclimatization, breeding, biotechnology, allelopathy, and biodiversity conservation have led to the formation of unique scientific schools and the establishment of collections recognized as part of Ukraine's National Heritage.

The research results of the NBG demonstrate its exceptional role in preserving rare and endangered plant species, forming introduction populations, and developing new approaches to enhancing plant adaptability under conditions of climate change and anthropogenic impacts. The institution has made a significant contribution to the creation of new plant varieties and phytotechnologies, which are of strategic importance for the agricultural sector, bioenergy, and the country's environmental security.

The educational and outreach activities of the NBG foster ecological awareness in society, ensure the training of highly qualified specialists, and promote the integration of Ukrainian science into the global scientific community. The comprehensiveness of its scientific programs, participation in international projects, and systematic work in biodiversity conservation make the NBG one of the key institutional resources for sustainable development and post-war recovery in Ukraine.

The NBG will continue to expand its participation in the most important and ambitious scientific initiatives, ensuring a high level of their implementation. In the near future, the priorities of NBG's scientific activities will focus on fundamental and applied research in biology and natural sciences, particularly in the areas of floristics, ecology, plant introduction and acclimatization, plant resilience and adaptation, genetics and physiology, phytochemistry, bioindication and environmental monitoring, plant biotechnology, bioenergy, phytoremediation, as well as the scientific foundations for biodiversity conservation and landscape design.

Special attention will be given to scientific and technical developments aimed at the conservation and restoration of biodiversity under conditions of profound environmental transformation caused by climate change, anthropogenic pressures, and the consequences of military actions. The implementation of these tasks will contribute

to the generation of new scientific knowledge and its effective application to ensure ecological stability and the restoration of Ukraine's natural resources.

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Національний ботанічний сад імені М.М. Гришка НАН України: провідний науково-освітній центр інтродукції, збереження та раціонального використання фітогенетичних ресурсів для сталого розвитку та післявоєнного відновлення України

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У статті висвітлено роль Національного ботанічного саду імені М.М. Гришка Національної академії наук України (НБС) як провідного науково-освітнього центру з інтродукції рослин, збереження та раціонального використання фітогенетичних ресурсів, що має першочергове значення для сталого розвитку та післявоєнного відновлення України. Окреслено історичне становлення установи та її внесок у розвиток ботанічної науки, зокрема в галузях інтродукції та акліматизації рослин, дендрології, селекції, генетики, біотехнології, фітоенергетики, алелопатії, біоіндикації та збереження біорізноманіття.

Представлено основні напрямки наукових досліджень НБС. Особливу увагу приділено діяльності наукових шкіл, створених у НБС, які зробили значний внесок у розвиток інтродукції, селекції, алелопатії та збереження біорізноманіття. Охарактеризовано наукові об'єкти НБС, що мають статус Національного надбання України, зокрема: колекції тропічних та субтропічних рослин, колекції квіткових та декоративних рослин, монокультурні сади та колекційний фонд енергетичних та ароматичних рослин. Підкреслено їх значення як генетичних ресурсів для селекції, наукових досліджень та екологічної освіти.

Наведено результати фундаментальних та прикладних досліджень, міжнародних проєктів та програм Національної академії наук України. Показано, що НБС є одним з провідних центрів зі збереження рідкісних видів флори України, де розроблено наукові основи збереження біорізноманіття *ex situ*, моделювання інтродукційних популяцій та оптимізації захисних заходів. Встановлено критерії підвищення адаптивності рослин до зміни клімату та стресових факторів, розроблено нові моделі дослідження стійкості та підходи до підвищення продуктивності рослин.

Підкреслено стратегічне значення НБС як центру науки, освіти та інновацій, що забезпечує інтеграцію фундаментальних досліджень, прикладних розробок та інформаційно-просвітницької роботи, створюючи тим самим умови для екологічної безпеки, розвитку сільського господарства, біоенергетики та зміцнення екологічної свідомості в суспільстві.

Ключові слова: Національний ботанічний сад імені М.М. Гришка НАН України, фундаментальні дослідження, прикладні дослідження, ботанічні колекції, наукові школи, інноваційний центр, національне надбання