



Exploration and practice of botanical gardens in the collection, conservation, and development of plant resources: A case study of Nanjing Botanical Garden Mem. Sun Yat-sen

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1 | INTRODUCTION

In addition to providing basic human needs, such as food, medicine, and fuel, plants play a crucial role in maintaining ecological balance, regulating the climate, and supporting the biodiversity. Strengthening the conservation and sustainable utilization of global plant resources is therefore essential for ecologically development, especially in the face of exacerbating climate change.

In this context, botanical gardens play an irreplaceable role in plant conservation and resource utilization. Their work spans plant ex-situ conservation, the preservation of endangered and rare plants, the establishment of germplasm banks, resource development, and ecological restoration.¹ Many botanical gardens worldwide have achieved remarkable success in these areas. For example, the Royal Botanic Gardens of Kew in the United Kingdom, one of the world's most renowned botanical gardens, has conserved over 50,000 species and successfully protected plant species in threatened habitats.² Moreover, through the introduction and acclimatization of rubber trees, Kew enabled the rubber industry to migrate from Brazil to Southeast Asia, thereby advancing the global rubber industry. Botanical gardens in China have also made significant contributions to the rapid growth of the rubber industry. In the 1950s, the South China Botanical Garden, Chinese Academy of Sciences and the Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, initiated the "Moving Rubber Northward" project, enabling the large-scale cultivation of rubber trees in the regions between 18° and 24° north latitude.³ This marked a significant advancement in rubber tree cultivation, helping to alleviate the rubber shortage in China. Another successful example of plant resource introduction and utilization was the migration of the kiwifruit industry. Specifically, New Zealand introduced kiwifruit, originally known as Chinese

gooseberry, from Hubei Province, China in 1904, and succeeded in cultivating seedlings, which led to the global spread of the fruit.⁴ Interestingly, from the 1980s, the introduction of new kiwifruit varieties bred by the Wuhan Botanical Garden, Chinese Academy of Sciences, further altered the distribution pattern of kiwifruit varieties on the international market. The migration of both the rubber and kiwifruit industries began with seeds, after which the resources were developed and utilized to promote industrial development. Today, the Svalbard Global Seed Vault in Norway⁵ and the Southwest China Germplasm Bank of Wild Species⁶ collectively preserve millions of seed samples all over the world. The resources preserved by these germplasm banks will facilitate the next agricultural industry.

Considering the importance of botanical gardens in the propagation and sustainable utilization of plant resources and the environmental threats caused by climate change, China plans to establish a national botanical garden system within the next decade.⁷ It is expected that this system will incorporate an increasing number of regional and local botanical gardens to jointly promote the breeding and sustainable utilization of plant resources. To provide experience and a reference for these institutions, this study takes Nanjing Botanical Garden as an example to explore specific practices in plant resource conservation and utilization.

2 | PROGRESS IN PLANT RESOURCE COLLECTION AND CONSERVATION AT NANJING BOTANICAL GARDEN MEM. SUN YAT-SEN

Plant germplasm resources are the foundational materials for breeding new varieties, essential assets for improving agricultural productivity, and a reflection of plant genetic diversity. Countries

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around the world attach importance to the collection, conservation, evaluation, and utilization of plant germplasm resources. Wild plant germplasm resources represent a vast resource pool for existing cultivated plants and serve as the material basis for breeding new varieties. Effectively collecting, conserving, and protecting germplasm resources will provide crucial physical materials and relevant data for the further development and utilization of plant resources.

As one of the most historically significant botanical gardens in China, Nanjing Botanical Garden has made significant achievements in the collection, conservation, and protection of plant resources (Figure 1). Up to the present, the botanical garden has collected over 12,000 plant species, spanning various categories of plants, such as trees, shrubs, herbaceous plants, and vines, with particularly noteworthy achievements in the collection of medicinal plants, economic fruit trees, and ornamental plants. Amongst, there are 106 species of gymnosperms and 7718 species of angiosperms. At the family level, *Cactaceae* and *Orchidaceae* are the largest, with 294 and 246 species, respectively. Furthermore, in terms of rare and endangered plants, a total of 267 species are listed in the List of National Key Protected Wild Plants, whereas 319 species are included in the Red List of China's Biodiversity, highlighting the garden's commitment to preserving threatened plant species. Our future efforts will focus on launching our website and updating the species lists to ensure the availability of the most reliable and current data. In collaboration

with the global seed bank, we will facilitate the exchange of valuable plant resources and data, fostering a global network that is dedicated to the shared goals of plant conservation and environmental sustainability.

2.1 | Progress in the collection and development of medicinal plant resources at Nanjing Botanical Garden Mem. Sun Yat-sen

Nanjing Botanical Garden has collected numerous medicinal plant species with important medicinal value, such as *Dioscorea*, *Lycoris*, mint, *Taxus*, *Stevia rebaudiana*, and *Euphorbia lathyris*, providing abundant resources for relevant research and applications. For instance, the genus *Dioscorea* contains diosgenin, an important raw material for synthesizing contraceptives and steroid hormone drugs. Since the 1950s, a nationwide effort has been undertaken to collect *Dioscorea* plant resources. A resource bank has been established that contains nearly 10,000 specimens of *Dioscorea* plants, over 2000 molecular DNA samples, and more than 200 populations of 50 species of living plants. Nanjing Botanical Garden pioneered the use of the gravimetric method to determine diosgenin content, confirming that the species *Dioscorea zingiberensis* has the highest diosgenin content in the genus. This work reduced the dependence on imported

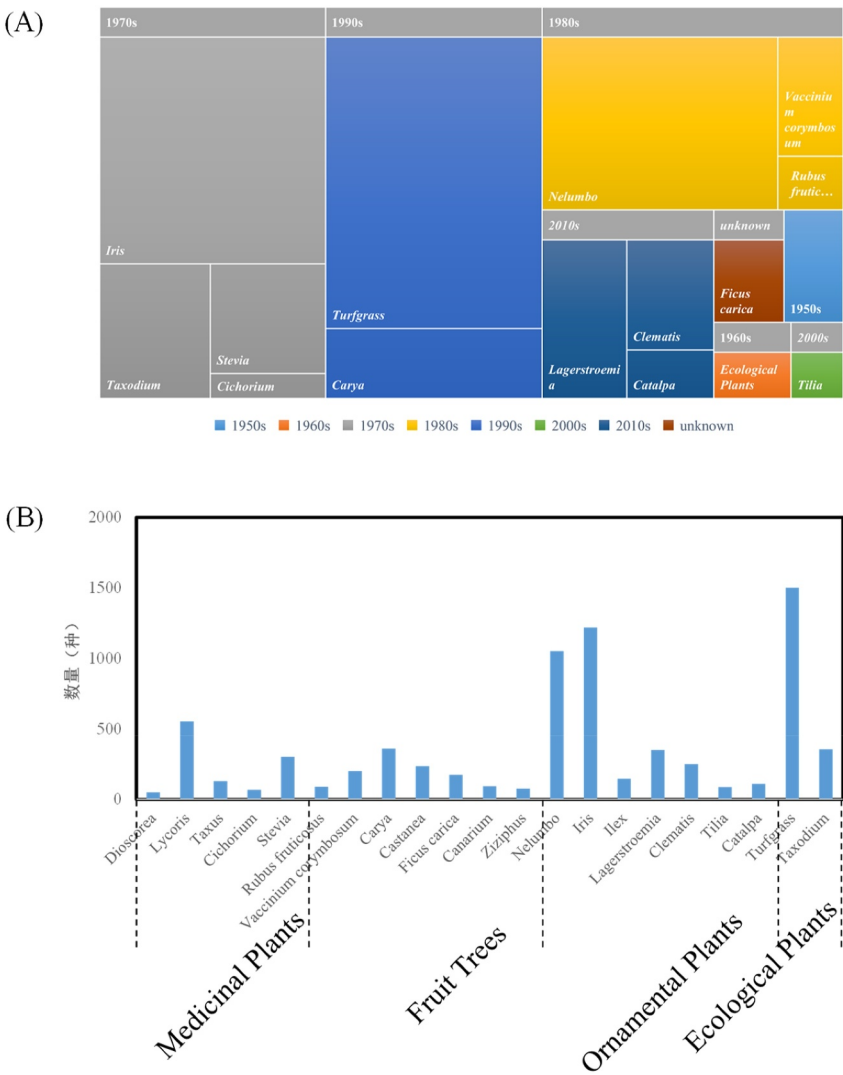


FIGURE 1 Progress in plant resource collection at Nanjing Botanical Garden Mem. Sun Yat-sen. (A) Tree diagram showing the types of plant resources collected by Nanjing Botanical Garden Mem. Sun Yat-sen in different years. (B) Bar chart depicting the classification and quantity of plant resources collected by Nanjing Botanical Garden Mem. Sun Yat-sen.

raw materials and thus promoted the research and development of steroid hormone drugs in China.

The genus *Lycoris* is another important group of medicinal plants collected by Nanjing Botanical Garden. The bulbs of *Lycoris* plants are rich in a variety of bioactive alkaloids, including galantamine and lycorine, which play essential roles in treating Alzheimer's disease and improving the human immune system. To date, 552 germplasm resources from the *Lycoris* genus have been successfully preserved by the Nanjing Botanical Garden, covering all known species in the genus. Notably, a modular self-assembled plant *P450* functional expression system has been established to achieve the high-efficiency *de novo* synthesis of *p*-hydroxycinnamic acid, a key intermediate of Amaryllidaceae alkaloids. This advancement significantly reduced the production cost and cycle time for producing Amaryllidaceae alkaloids, supporting the industrial application of economically valuable plants and improving the efficiency and sustainability of plant resource utilization.

Nanjing Botanical Garden is also the center for *S. rebaudiana* research in China. Stevia is an important special sugar crop, which was first introduced by Nanjing Botanical Garden from Japan and attracted a great deal of attention from both domestic and international industries. Then, more than 200 wild and semiwild germplasm accessions were introduced in multiple batches from Paraguay and Mexico. Currently, over 300 valuable germplasm materials are preserved, including high-yield, high-total glycoside, salt-tolerant, and cold-resistant varieties. Notably, the best stevia varieties have been released and widely utilized in China's five major stevia production bases, including Dongtai in Jiangsu, Mingguang in Anhui, Hailin in Heilongjiang, Jiuquan in Gansu, and Xing'an League in Inner Mongolia. The coverage rate of the best varieties has reached over 95%, which has generated significant economic and social benefits. These research outcomes have reached the international leading level.

Chicory is an edible medicinal plant known for its health benefits, including promoting digestion, supporting liver function, aiding bile secretion, inducing diuresis, and reducing edema. Nanjing Botanical Garden introduced chicory from the Netherlands in 1975 and established large-scale cultivation in Dongtai, Jiangsu Province. The garden's germplasm resource bank now includes 68 of the most abundant chicory accessions in China. Additionally, two softened-type chicory lines, "Suqi 1" and "Ningte 1," were bred, and modern cultivation techniques, such as drip irrigation, water-fertilizer integration, and darkroom three-dimensional hydroponics for buds, were developed.

2.2 | Progress in the collection and utilization of economic forest and fruit plant resources at Nanjing Botanical Garden Mem. Sun Yat-sen

Fruit tree resources are also an important collection area at Nanjing Botanical Garden, particularly blackberries and blueberries, which are rich in vitamins, organic acids, and anthocyanins, offering benefits such as antioxidation, immunity enhancement, and vision improvement. The garden has been collecting these species since 1986, preserving 90 blackberry accessions and 200 blueberry accessions. This collection supports breeding and functional component discovery. To date, nine new blueberry varieties with independent property

rights, including "Xinxin 1," have been developed. Using high-efficiency cultivation technologies, these new varieties have been utilized in an area of more than 200,000 mu, forming a new blueberry production zone in southern China. This new production zone has generated a total economic value of 1 billion yuan, becoming a pillar industry for the alleviation of poverty in regions such as Majiang in Guizhou and northern Sichuan. Nanjing Botanical Garden has also bred 16 elite blackberry varieties, covering more than 200,000 mu, with a cumulative output value of nearly 10 billion yuan. Notably, the development of 11 products, including blackberry puree, concentrated juice, dried fruits, and jam, along with 16 high-value-added ultra-processed functional products, such as fermented fruit wine, chewable tablets, and oral liquids, has extended the industrial chain and increased its economic benefits.

Thin-shelled pecan (*Carya illinoensis*) is a valuable woody oil tree species that also offers high-quality nuts, valuable timber, and landscape value. Nanjing Botanical Garden serves as the center of China's pecan research. Beginning its pecan introduction in 1900, the garden established China's first pecan germplasm resource bank. Today, it has collected 61 elite pecan varieties and more than 300 valuable seedling lines. The garden pioneered a comprehensive technical system for evaluating and discovering pecan germplasm resources, overcoming key challenges such as the long juvenile phase and the asynchronous male and female flowering times of pecan. These advancements have accelerated the development of China's pecan industry, brought about significant ecological, social, and economic benefits, and contributed to rural revitalization, wealth generation, and poverty alleviation.

Chinese chestnut (*Castanea mollissima* Bl.) is a traditional dry fruit tree species known as "woody food" in China. Its production and export volumes rank first among all other cultivated chestnut species in the world. Chestnut research at Nanjing Botanical Garden began in the 1950s, focusing on basic and applied sciences regarding the germplasm resources, genetic breeding, and biology of chestnut. Over the years, nearly 300 local chestnut varieties from across China have been collected and more than 50 germplasm accessions have been introduced. Varieties, such as "Jiujiazhong," "Chushuhong," and "Jiandingyouli," have been extensively utilized in impoverished hilly areas of subtropical regions including Jiangsu, Hunan, Hubei, and Anhui. By 1999, these research results have been utilized in an area of over 1.169 million mu. In recent years, efforts have focused on transformation low-yield chestnut orchards and conducting economic studies on forest-understory economics, improving the economic benefits of chestnut forests and aiding rural industrial adjustments.

Oil olive (*Olea europaea*), one of the world's four major woody oil tree species, has been widely utilized in food, health care, medicine, chemicals, and landscape planting and offers very high economic, ecological, and social benefits. In 1958, Nanjing Botanical Garden introduced olive trees from the Nikitsky Botanical Garden in the former Soviet Union, followed by further introductions from many other regions. The garden now preserves 92 elite olive varieties from the Mediterranean and Crimea. By 1980, over 23 million olive trees had been planted across 16 provinces in China, including Sichuan, Shaanxi, Yunnan, and Jiangsu. Nanjing Botanical Garden was one of the earliest in China to introduce and study olive trees, conducting systematic research on the introduction, cultivation, and breeding of oil olive. The garden also published two influential books, *Oil Olive*

Introduction and Cultivation and *Oil Olive Breeding and Domestication*, which facilitated the development of China's woody oil plant industry.

Additionally, Nanjing Botanical Garden has implemented the introduction, acclimation, development, and utilization of other economic fruit tree resources, such as figs, loquats, apricots, jujubes, and kiwifruit.

2.3 | Progress in the collection and utilization of ornamental plant resources at Nanjing Botanical Garden Mem. Sun Yat-sen

Nanjing Botanical Garden has extensively collected and preserved ornamental plants germplasm resources, including *Taxodium*, *Cynodon*, *Nelumbo* (lotus), *Iris*, *Lagerstroemia* (crape myrtle), *Ilex* (holly), *Tilia*, and *Clematis*. Over 1000 germplasm accessions are preserved for each genus. These rich ornamental plant resources not only provide diverse materials for horticulture and landscape design but also offer valuable data for the study of ecological horticulture and landscape ecology, thereby promoting the development of related fields. Among its ornamental plant resources, Nanjing Botanical Garden has collected 1050 lotus germplasm accessions from many countries, including the United States, Thailand, Vietnam, India, Australia, and Myanmar. Twenty-eight new varieties have been bred and utilized in an area of over 855,000 mu, which has enhanced the integrated development of the lotus industry across primary, secondary, and tertiary sectors, yielded significant industrial benefits, and increased farmers' incomes. Nanjing Botanical Garden was one of the earliest institutions to introduce the *Iris* genus into China. Currently, the botanical garden has preserved 1218 accessions of *Iris* germplasm resources, spanning five major cultivated series. The botanical garden has developed 54 new *Iris* varieties, which have been utilized in an area of more than 70,000 mu in the middle and lower reaches of the Yangtze River. These varieties have demonstrated multiple functions in improving the environment, enhancing the local quality of life, and promoting rural revitalization.

Nanjing Botanical Garden was also one of the earliest institutions in China to conduct research on the *Ilex* genus. Today, the botanical garden has collected and preserved 146 accessions of germplasm resources (varieties). Nanjing Botanical Garden has developed 16 new and improved *Ilex* varieties. The breeding of the *Lagerstroemia* genus began relatively late, with the first breeding research conducted in the 21st century. To date, 350 *Lagerstroemia* germplasm accessions have been collected, and 32 new varieties, including both colored-leaf and normal-leaf types, have been bred, of which 23 varieties have received national plant variety rights. The development and utilization of these ornamental plant resources will gradually manifest during the implementation of the "Building Beautiful China and Promoting Rural Revitalization" policy.

2.4 | Progress in the conservation of endangered and rare plants at Nanjing Botanical Garden Mem. Sun Yat-sen

Nanjing Botanical Garden has made remarkable progress in the conservation of plant resources through a combination of scientific

research, artificial propagation, and in situ reintroduction. For instance, Nanjing Botanical Garden has been deeply involved in the comprehensive conservation of *Parrotia subaequalis*, beginning with its taxonomic identification and initial field surveys. In 2022, the Garden implemented an in situ reintroduction program, successfully reintroduced 200 individuals into their native habitat, highlighting the effectiveness of this strategy. Similarly, Nanjing Botanical Garden introduced 11 individuals of *Taxus chinensis* trees from Jiangxi Province in the 1950s, and this small artificial population has expanded to nearly 800 individuals after more than 70 years of natural regeneration and conservation management, forming a stable population with ecological significance. Another significant example is the protection of *Sinojackia xylocarpa* Hu. Notably, Nanjing Botanical Garden has extensively collected germplasm resources, successfully developed efficient propagation techniques, such as cutting and tissue culture, and implemented reintroduction planting programs to effectively expand its wild population. Furthermore, phylogenetic studies using low-copy genes and chloroplast gene tree analyses have elucidated interspecific relationships and species differentiation, providing a robust foundation for conserving genetic diversity.

Conservation efforts led by Nanjing Botanical Garden have also been successfully implemented for rare plants such as *Yulania zenii*, *Isoetes changxingensis*, and *Tacca subflabellata*. These achievements emphasize the critical role of botanical gardens in plant resource conservation and showcase the seamless integration of scientific research with technological innovation, providing valuable insights and experience for advancing the protection of plant biodiversity.

2.5 | Progress in ecological protection at Nanjing Botanical Garden Mem. Sun Yat-sen

Nanjing Botanical Garden has closely aligned its work with the national strategy of ecological protection of the Yangtze River. The garden's efforts to protect and enhance the natural environment are not only crucial for the ecological health of the region but also hold significant cultural and historical value. The garden has actively promoted the study and application of new tree species from the *Taxodium* genus. Beginning in 1973, hybridization between *Taxodium* species and the selection of varieties resistant to water logging and alkaline stress have been systemically conducted. Their research team has developed more than 10 tree varieties, including "Zhongshan Shan 301" and "Zhongshan Shan 401," and established tree propagation and breeding bases in Jiangsu, Hubei, and Hunan. These trees have been successfully utilized in the ecological restoration of the water-level fluctuation zone in the Three Gorges Reservoir area, where they contribute significantly to soil conservation, water source preservation, and environmental improvement. Notably, by reducing soil erosion and enhancing water retention, they play a critical role in stabilizing the fragile Yangtze River ecosystem and providing an important buffer against climate change impacts such as increasing floods and droughts. The trees also offer benefits for the establishment of an ecological barrier for the river and the construction of a beautiful China.

Nanjing Botanical Garden is a global leader in the development and utilization of warm season turfgrass germplasm resources. In

response to important national strategic needs related to national defense and security, the Belt and Road Initiative, and infrastructure development, the botanical garden pioneered a simplified system for establishing and maintaining turfgrass ecological lawns on tropical coral reef islands. The research team overcame the universal challenges of multiple stresses, such as extremely high salinity and alkalinity, drought, and a lack of soil nutrients to grow lawns on reef sands with a high calcium carbonate content. This innovative approach not only preserves ecological integrity in these fragile ecosystems but also offers a model for integrating ecological protection with cultural tourism and sustainable development.

3 | CONCLUSIONS AND FUTURE INSIGHTS

Plant resources are among the most precious natural resources on Earth, closely tied to human survival and development. Their reasonable development and utilization are critical for improving agricultural productivity, meeting basic human needs, and supporting ecosystem sustainability. Moreover, these resources are also essential for promoting future technological innovations and economic growth. Notably, global climate change has become one of the most severe environmental challenges, with rising global temperatures, sea-level increases, and the frequent occurrence of extreme weather events threatening ecosystems. Plants, in particular, are highly vulnerable, with their growth, geographical distribution, and diversity significantly impacted than many other organisms. Therefore, it is urgent to establish a national botanical garden system to protect endangered plant resources, collect and develop plant resources for sustainable utilization, preserve an extensive variety of plant resources, and improve supporting technical systems.

Botanical gardens around the world have made remarkable achievements in multiple fields, including plant resource collection, germplasm innovation, the development of cultivation technology, and the deep utilization of resources. These achievements provide strong support for developing the economic and ecological value of certain special plants, and the researchers have obtained valuable experience relevant to the conservation and utilization of global plant resources. When compared to other well-known botanical gardens worldwide, including China's National Botanical Garden, Nanjing Botanical Garden holds distinct advantages. These include its rich historical and cultural heritage, regionally focused plant collections, and extensive experience in ex situ conservation across various plant species. Nevertheless, the garden also faces significant challenges. One such issue is the insufficient integration between the garden's operational functions and scientific research, with a pressing need to strengthen the link between research findings and their practical applications. Moreover, although some progress has been made in recent years, the influence of its public science education remains limited, hindering the broader dissemination of plant conservation concepts.

Looking forward, Nanjing Botanical Garden plans to further enhance its role in plant resource conservation and development. For example, the botanical garden will continue expanding its plant resource bank, with a particular focus on the rare, endangered, or economically important plants in special regions, and will establish a

more comprehensive plant germplasm resource bank. Additionally, the study of plant adaptability to extreme climatic conditions will be prioritized, and new cultivation techniques and breeding methods will be developed to improve the resilience of plants under climate change. The botanical garden will strengthen cooperation with botanical gardens and research institutions in western China, aiming to jointly promote the efficient and sustainable utilization of plant resources in the western region. This effort is essential for addressing biodiversity loss on a global scale. Through these efforts, Nanjing Botanical Garden will further consolidate its position as a national leader in plant resource conservation and utilization, making a greater contribution to global plant resource utilization and ecologically sustainable development.

AUTHOR CONTRIBUTIONS

Dongrui Yao: Conceptualization; investigation; data curation; methodology. **Yanwei Zhou:** Writing—review and editing; conceptualization; writing—original draft. **Yuming Sun:** Visualization; formal analysis. **Maolin Geng:** Data curation; resources. **Naiwei Li:** Conceptualization; writing—original draft; investigation.

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