Handbook of Plant Breeding

Johan Van Huylenbroeck *Editor*

Ornamental Crops

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Handbook of Plant Breeding

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The field of plant breeding covers a broad range of different species and categories of plants. While there are many techniques and issues that are similar across these species, there are many more that are unique to each category of species.

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Preface

Ornamental plants bring life to our indoor and outdoor spaces. They give us color, make us feel happier, and have positive effects on our health. They improve our air quality, lower concentrations of harmful substances in our environments, and increase biodiversity. The worldwide success of ornamentals would be impossible without plant breeders. They continuously create new cultivars, striving tirelessly to meet the changing needs and wants of growers and consumers. Breeding of ornamentals is everything except easy. Efforts are scattered due to a segmented market (cut flowers, indoor plants, bedding plants, perennials, shrubs, and trees), the wide range of different plant genera and species used, and the different propagation methods (seeds, cuttings, micropropagation, bulbs, and more). Large-scale breeding is limited to only a few genera; most ornamentals are either bred in small-scale professional programs or sometimes even by amateurs. Lack of knowledge hinders the efforts in many ornamental breeding companies. The gap between research and the industry's needs is so big that it could be called a chasm. The aim of this book is to bridge that chasm.

The main goal in ornamental breeding has remained unchanged in a changing world: to develop new cultivars with improved floral attributes (color, shape, perfume, and enhanced vase life), leaf characteristics, or plant habit. Breeding for sustainability in the form of enhanced disease and pest resistance and increased tolerance against abiotic stresses is a big challenge, but it has great potential for future markets.

Crossbreeding is still the most important method to obtain new cultivars in almost all ornamental species. In many crops, interspecific hybridization and chromosome doubling is used to enlarge the genetic diversity. Recent boosts in fundamental knowledge offer new opportunities for ornamentals. Molecular genetics and linked technologies are poised to break through in some of the economically important ornamental plants. This can revolutionize the understanding of the inheritance of targeted traits, with associated gains in breeding efficiency.

"Breeding Ornamental Crops" compiles the state-of-the art knowledge of several outstanding breeders and researchers. Other ornamental plant breeders and researchers in the field will find it highly relevant, together with teachers, students, and plant growers. Of the 29 chapters in this volume, 9 focus on specific traits or breeding techniques commonly used in ornamental plant breeding; the remaining 20 focus on one specific crop. The most current crop-relevant breeding knowledge is presented, together with information on the major breeding achievements, current breeding goals, breeding methods, and techniques. A wide range of cut flowers, pot plants, bulbous plants, garden plants, and woody ornamental plants have been chosen to cover the most economically important species as well as some minor species.

This book is a testament to the outstanding knowledge and experience of the breeders and researchers who have contributed to it. Many of them are colleagues and good friends. I owe them all a debt of gratitude for their time, willingness, and expertise.

I also thank the many people working behind the scenes who made this work possible, and I gratefully acknowledge my family for their support.

Melle, Belgium Johan Van Huylenbroeck

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About the Editor

Dr. Johan Van Huylenbroeck is a plant breeder at the Institute for Agricultural and Fisheries Research (ILVO) in Belgium. Besides practical breeding, he also coordinates numerous research projects on ornamental plants. Since 2006, he leads the Applied Breeding and Genetics group, a team of 20 researchers and 30 technical staff members. His research focuses mainly on (1) the development of efficient hybridization and selection strategies, (2) the creation of cultivars for sustainable agriculture and horticulture, (3) the use of DNA markers assisted breeding techniques for quantitative and qualitative traits, and (4) marker-based analysis of genetic diversity and identity. In close collaboration with the industry, his group runs breeding programs in azalea, outdoor roses, and woody ornamentals, among others. Specific breeding goals in ornamentals are disease resistance, enlargement of the existing diversity via interspecific hybridization, and compact growing plants.

Chapter 1
The Role of Biodiversity and Plant Conservation for Ornamental Breeding

Chunlin Long, Zhe Chen, Ying Zhou, and Bo Long

Abstract In this chapter, the world's plant biodiversity is briefly introduced. It is estimated that there are 340,000–390,900 species of vascular plants in 452 families on the earth based on biodiversity informatics analysis. The species number of ornamental plants and their wild relatives is estimated to be 85,000–99,000. Four strategies to conserve ornamental plants can be distinguished, namely, in situ conservation, ex situ conservation, sustainable uses, and legal system establishment. The Convention on Biological Diversity and other international legal systems, together with national or local laws and regulations, are mainstreaming the conservation of biodiversity and sustainable uses of biological resources. The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization will profoundly affect the collection, breeding, and commercialization of ornamental plants around the world. New technologies as genome sequencing accelerate our understanding of plant genetic diversity and will enhance breeding and development of ornamental plants.

Keywords World plant species · Ornamental plants · Conservation · Nagoya Protocol

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1.1 Biodiversity of the World's Plants

Biodiversity informatics, a discipline which studies the data and information generated from biological and other relevant researches through the approaches of information science and techniques, is rapidly developing. A lot of national and global biodiversity informatics projects have been implemented or already achieved (Ma 2014). Most of them have been disseminated and shared among the communities of biodiversity and other organizations in which Catalogue of Life – Species 2000 (COL-Species 2000) (Roskov et al. 2017), Global Biodiversity Information Facility (GBIF), International Plant Name Index (IPNI), Barcoding of Life (CBOL), National Center for Biotechnology Information (NCBI), Encyclopedia of Life (EOL), Tree of Life (TOL), USDA PLANTS, and Biodiversity Heritage Library (BHL) are their representatives. The emerging of big data era provides solutions to integrate data and information available via internet or databases. This enables people to analyze and mine biodiversity information on an easy and accessible way. It is well acknowledged that more plants have been documented than animals based on their species proportions and numbers estimated by scientists. In recent years, the outlines of the world's plants had been touched through big data analysis.

Although most countries do not finalize floras while new plant species are continually discovered, massive data and information related to the world's plant biodiversity are available from databases and literatures. For instance, the plant information of Uganda can be accessed through publications like Hamilton et al. (2016) and other literatures. Data obtained from internet particularly biodiversity informatics make it possible for scientists to estimate the plant biodiversity at global level. A recent statistical analysis revealed that there are more than 600 biodiversity informatics projects initiated in the world (Ma 2014; Wang et al. 2010). Some important plant biodiversity informatics projects are listed in Table 1.1. The Royal Botanic Gardens Kew has made great contributions to the documentation of global plant biodiversity such as the International Plant Names Index (IPNI), the Plant List (TPL), the World Checklist of Selected Plant Families (WCSP), and partly other projects. The Missouri Botanical Garden is another outstanding organization which contributed to the floras of many countries with rich plant diversity.

Here we will only cover the vascular plants, in terms of their potentials for aesthetic purposes. According to Species 2000 and Integrated Taxonomic Information System (ITIS) of Catalogue of Life (COL), 336,369 vascular plant species have been cataloged (Roskov et al. 2017). The estimated number of species known to taxonomists was about 340,000 (Table 1.2). However, other scientists believed this number has to be estimated at 390,900 in which 369,400 species are flowering plants or angiosperms, according to the State of the World's Plants 2016 (RBG Kew 2016). No matter COL's estimation or Kew's statement, it updated our knowledge of plant species number which is much higher than that in traditional textbooks (e.g., Judd et al. 2008) where only 260,000 species of vascular plants are reported.

The molecular evidences based on DNA sequencing technologies overcame the limitation of morphological features of plants so that they are widely used in

Table 1.1 List of some important plant biodiversity informatics projects in the world

System name (Abbreviation)	Core data	Web site
International Plant Names Index (IPNI)	Plant species names	www.ipni.org
Species 2000 and ITIS Catalogue of Life (COL)	Plants, animals, fungi, and other organisms	www.catalogueoflife.org/col
Global Biodiversity Information Facility (GBIF)	Herbarium specimens including plants	www.gbif.org/
The Plant List (TPL)	Vascular plants and bryophytes	www.theplantlist.org/
The World Checklist of Selected Plant Families (WCSP)	173 seed plant families from 22 countries	apps.kew.org/wcsp/
Barcoding of Life (CBOL)	DNA barcodes including those of plants	www.barcodinglife.org/
Tree of Life (TOL)	Phylogenetic data of organisms	tolweb.org/tree/
USDA PLANTS	Plant species information	plants.usda.gov/
Encyclopedia of Life (EOL)	Species information	www.eol.org/
Flora of China	Plants in China	flora.huh.harvard.edu/china/
Flora brasiliensis – The Project	Brazilian plants	florabrasiliensis.cria.org.br
Flora of North America	North American plants	floranorthamerica.org/
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	Checklist of CITES species	www.cites.org/
2000 IUCN Red List of Threatened Species	All threatened species	www.iucnredlist.org/
Botanic Gardens Conservation International (BGCI)	Plant conservation and public engagement	www.bgci.org/
The Flower Expert	Flowers and gardening	www.theflowerexpert.com/

Modified from Ma (2014)

identification of plant species. The Angiosperm Phylogeny Group (APG) started international collaboration between botanists from different countries to establish phylogeny of angiosperms and to explore the world's plant diversity since 1990s. In 2016 they recognized 416 families of flowering plants (the Angiosperm Phylogeny Group 2016). So far, scientists have identified 452 families of vascular plant families across the world, in which 12 families are gymnosperms and 24 are ferns, horsetails, and lycopods (RBG Kew 2017).

Scientists identified 17 countries as the most biodiversity-rich countries of the world, with a particular focus on endemic species. The identified megadiverse countries include Australia, Brazil, China, Colombia, Congo, Ecuador, India, Indonesia, Madagascar, Malaysia, Mexico, Papua New Guinea, Peru, the Philippines, South Africa, the United States, and Venezuela. These megadiverse countries account for at least 2/3 of all non-fish vertebrate species and 3/4 of all higher plant species (UNEP-WCMC 2014). Among these most biodiversity-rich countries, Brazil,

Table 1.2 Species numbers of vascular plants in the world

Class	Number of species	Estimated number of species known to taxonomists	Percentage covered by COL (%)	Example of ornamental(s) in the class
Cycadopsida	353	317	100	*Cycas revoluta*, *Zamia amazonum*
Equisetopsida	38	40	95	*Equisetum arvense*
Ginkgoopsida	1	1	100	*Gingko biloba*
Gnetopsida	112	112	100	*Gnetum montanum*, *Welwitschia mirabilis*
Liliopsida	74,230	72,926	100	*Roystonea regia*, *Tulipa gesneriana*
Lycopodiopsida	1393	1330	100	*Lycopodium japonicum*
Magnoliopsida	247,825	246,366	100	*Nelumbo nucifera*, *Rosa chinensis*
Marattiopsida	133	140	95	*Angiopteris fokiensis*
Pinopsida	615	615	100	*Araucaria cunninghamii*, *Podocarpus macrophyllus*
Polypodiopsida	11,530	11,530	100	*Cibotium arachnoideum*, *Adiantum flabellatum*
Psilotopsida	139	123	100	*Psilotum nudum*
Total	336,369	340,000	99	

Sources: Roskov et al. (2017), Catalogue of Life – Species (2000)

China, Indonesia, Mexico, and Columbia are 5 countries with most vascular plant species, which are 32,364, 29,650, 29,375, 25,036, and 24,500 species, respectively (Li and Miao 2016). The megadiverse countries are also major contributors of new described taxa of vascular plants. The biggest countries are Brazil, Australia, and China, with 2220, 1648, and 1537 species, respectively, based on a statistics of new plant species discovered in 2015. Many new plant species were also discovered in other megadiverse countries such as Columbia, Ecuador, Mexico, Peru, Malaysia, South Africa, and Indonesia (RBG Kew 2016).

There are 14 terrestrial biomes or habitat types on the earth (Olson and Dinerstein 1998; Olson et al. 2001). These are (1) mangroves (subtropical and tropical, salt water inundated); (2) tropical and subtropical moist broadleaf forests (tropical and subtropical, humid); (3) tropical and subtropical dry broadleaf forests (tropical and subtropical, semihumid); (4) tropical and subtropical coniferous forests (tropical and subtropical, semihumid); (5) temperate broadleaf and mixed forests (temperate, humid); (6) temperate coniferous forests (temperate, humid to semihumid); (7) boreal forests/taiga (subarctic, humid); (8) tropical and subtropical grasslands, savannas, and shrublands (tropical and subtropical, semiarid); (9) temperate grasslands, savannas, and shrublands (temperate, semiarid); (10) flooded grasslands and savannas (temperate to tropical, fresh- or brackish water inundated); (11) montane grasslands and shrublands (alpine or montane climate); (12) tundra (Arctic); (13) Mediterranean forests, woodlands, and shrub or sclerophyll forests (temperate warm, semihumid to semiarid with winter rainfall); and (14) deserts and xeric shrublands (temperate to tropical, arid), respectively. These diverse biomes and vegetation types provide plants with various habitats.

At genetic diversity level, a lot of new achievements have revealed great diversity of plants through molecular markers and DNA sequencing. The costs for DNA sequencing continue to plummet, and more plant species with assembled draft whole genome sequences are available online. Plants with whole genome sequences reached 225 species by January 2017. They are mostly crops (rice, maize, wheat, barley, potato, and others), followed by model species and relatives and crop wild relatives (RBG Kew 2016). A few species for ornamental purposes have been sequenced, such as *meihua* flower (*Prunus mume*) (Zhang et al. 2012). Very recently, the Beijing Genomics Institute (BGI), the world's largest genome sequencing center located in Shenzhen of South China, issued the 10 K Plant Genome Program during the 19th International Botanical Congress held in late July 2017. According to this program, BGI and its collaborators will finish sequencing 10,000 species of plants by the end of 2022. More ornamental plants will be selected for sequencing in this program.

1.2 Diversity of Ornamental Plants

It is still a question to answer how many species of ornamental plants growing in the world. Based on a record of Flower Auction Aalsmeer (the Netherlands), the total taxa (species and cultivars) number of commercial ornamental plants was about 1600 in 1990s. About 15,500 taxa of garden plants have been included in *Encyclopedia of Garden Plants* published by the Royal Horticultural Society, covering new and exotic varieties (Brickell 2008). Bailey and Bailey (1976) reported 23,979 taxa (families, genera, and species) of horticultural plants, which is the biggest number of plant taxa for ornamentals.

Taking all taxa as species level, the horticultural plants reported by Bailey and Bailey (1976) occupied only 7.13% (COL) or 6.13% (Kew) of world's vascular plants. These proportions may not be true according to our investigations (Long et al. 2015). In China, for example, the estimation of about 6000 species of vascular plants with gardening values was commonly accepted (Chen 2000), which is 20.24% of total vascular plant species occurring in China. Some authors believed over 15,000 species (Xue 2005) or 10,000 species (Zhu et al. 2007) are with garden and horticultural potentials. A recent estimation was about 7500 ornamental and garden plants native to China (Huang 2011). We adopt the number of 7500 based on their aesthetic traits as ornamentals, which occupies 25.29% of China's flora. Following this ratio, there should be 85,067 (COL)–98,858 (Kew) species of ornamental plants in the world. These numbers covered the wild relatives of cultivated ornamentals.

Many groups of vascular plants are well-known ornamentals. Almost all *Rhododendron* species, for instance, are potentially garden plants or cultivated as ornamentals. This genus consists of about 1000 species. Thousands of cultivars have been bred in Asia, Europe, and North America. Most species of Cactaceae, a tropical and subtropical family with over 1000 species, have been cultivated as indoors or greenhouses' ornamental plants. Members in *Viburnum* (Adoxaceae) are also nice garden plants, with 200–250 species in the genus (Dirr 2008; Long et al. 2015). Other members from many different groups such as Arecaceae, Begoniaceae, Bromeliaceae, Iridaceae, Magnoliaceae, Orchidaceae, Podocarpaceae, Theaceae, *Anthurium*, *Buddleja*, *Chrysanthemum*, *Clematis*, *Cycas*, *Hypericum*, *Impatiens*, *Lilium*, *Osmanthus*, *Paeonia*, *Philodendron*, *Prunus*, *Rosa*, *Syringa*, and *Tulipa* are commonly cultivated as ornamentals.

The habitats for ornamentals are various, from the tropics to temperate, from lowlands to alpines, from humid to arid areas, and from terrestrial to aquatic environments. The life forms of ornamental plants are also very diverse. Most conifers and many angiosperms are arborous, represented by *Araucaria* and palms in the tropics, *Cinnamomum* (Zhou and Yan 2015) and *Magnolia* in the subtropics, and *Ulmus* and *Populus* in the temperate. Succulents are now popular as indoor ornamentals, especially *Aloe*, *Beaucarnea*, *Cactus*, *Crassula*, *Euphorbia*, *Kalanchoe*, *Sansevieria*, and *Sedum*. Many epiphytes are welcome in the warm urban areas, such as *Ananas*, *Asplenium*, *Dendrobium*, *Phalaenopsis*, and *Vanda*. Lianas have widely been used for decoration of indoors and gardens, including *Campsis*, *Clematis*, *Hedera*, *Lonicera*, *Parthenocissus*, *Quisqualis*, *Rhaphidophora*, *Rosa*, *Vitis*, and *Wisteria* (Chen et al. 2013). Most ornamentals are herbaceous plants and shrubs. They are used for cutting flowers, bonsais, indoor decorations, ground cover plants, garden landscape uses, and roadside afforestations or beautification.

Massive cultivars or varieties had been bred for ornamental purposes. Examples include *Chrysanthemum* × *morifolium* (20,000–30,000 cultivars), *Prunus mume* (over 400 cultivars), and *Paeonia suffruticosa* (ca. 2000 cultivars) (Long et al. 2015). Lotus (*Nelumbo nucifera*) is an ornamental and sacred plant with great cultural values in Asian countries. Over 200 cultivars have been bred as aquatic ornamentals and food and for cultural purposes in China, India, and some other countries. The whole genome sequence of some ornamental plants such as *meihua* flower (*Prunus mume*) (Zhang et al. 2012), *Phalaenopsis equestris* (Cai et al. 2015), and rose (Foucher et al. 2015) had been issued. Massive genomic data of ornamental plants will be released very soon because the costs for DNA sequencing continue to reduce rapidly and a lot of genome projects have been implemented (e.g., the Orchidaceae Genome Project initiated by the Orchid Conservation and Research Center of Shenzhen and BGI in July 2017 and the Convolvulaceae Genome Project initiated by Shanghai Institutes for Biological Sciences of the Chinese Academy of Sciences and partners in August 2017).

1.3 Conservation of Ornamental Plants

The ecosystems to foster plant biodiversity around the world have been changed at a dramatic speed since the industrial revolution. The land-cover changes greatly happened in the last decade. In all the 14 biomes on the earth, vegetations suffered from land-cover changes. The largest change in 14 vegetation types is observed in mangrove, which reached 26% in 2012, while the smallest one is in desert and xeric shrubland which was 7% (RBG Kew 2016). Ornamental plants growing in all vegetation types have been threatened along with the land-cover changes. Many wild ornamental species have become endangered, such as *Aloe*, *Cycas*, *Pachypodium*, *Paphiopedilum*, and *Sarracenia*.

Human activities have resulted in organism moving around the world for centuries. Plants, animals, and microbes moved from their native range to other areas may become invasive species. As one of the most important drivers of biodiversity loss, invasive plants have been paid more attentions for their impacts on environment and economy. The costs of invasive species were estimated at nearly 5% of the world's economy (RBG Kew 2016). The movement and introduction of ornamental plants has been regarded as a main driving factor to cause invasions of alien species. Sometimes the ornamental plants themselves become harmful invasive species. The most famous examples are probably *Lupinus polyphyllus*, *Solidago canadensis*, *Tagetes patula*, *Eichhornia crassipes*, and *Myriophyllum spicatum*. They are beautiful plants but resulted in ecological disasters in many countries and threatened other ornamentals. The introduction of ornamental plants has also brought pests and diseases to their new territories, which will be harmful to biodiversity including ornamentals.

The general strategies to conserve biodiversity include (1) in situ conservation, (2) ex situ conservation, (3) sustainable uses, and (4) legal system establishment. The important plant areas (IPAs) criteria system offers a pragmatic yet scientifically rigorous means of delivering datasets, enabled informed national- or regional-scale conservation prioritization, and is contributing significantly toward global prioritization systems (Darbyshire et al. 2017). Scientists have identified 1771 IPAs around the world, and IPAs have formally been recognized as an in situ conservation tool under Target 5 of the Convention on Biological Diversity (CBD) Global Strategy for Plant Conservation. These IPAs should be protected with priorities, as they are the most important habitats for animals and plants including ornamentals. Unfortunately, very few currently have effective conservation activities. Even in Europe, some IPAs have no legal protection or active management plan; thus a significant number are imminently threatened (RBG Kew 2016). Nature reserve (or protected area or national park) is an important type for biodiversity conservation in situ; sometimes it may overlap with an IPA. Some nature reserves particularly those in developing countries cannot implement effective conservation because of lack of financial supports, professional technicians, capacities or facilities, and guarantee of legal systems. Probably the holy groves and sacred sites are the cheapest but effective systems for biodiversity conservation in situ. Many plants and animals have been protected by religions and traditional cultures or customary laws, with no or low costs. For example, many ornamental plant species, including *Ardisia* spp., *Dendrobium* spp., *Ficus* spp., *Paramichelia baillonii*, and *Podocarpus imbricatus*, have been protected by the Jinuo people in sacred forests of Xishuangbanna, China (Long and Zhou 2001). The way to maintain ornamental plants in traditional agro-ecosystems is another significant method of in situ conservation, or on-farm conservation. The indigenous Shuar and Mestizo settlers in seven villages of southeastern Ecuador grow ten native palm species in their traditional home gardens. Most of them are ornamentals, together with uses of food, construction, medicine, and handicraft (Byg and Balslev 2006; Long et al. 2017).

Ex situ conservation is essential for plants and animals because of land-cover changes and other factors. Ornamental plants can be preserved in human controlled or managed environment. The botanical gardens are the most conventional methods of ex situ conservation. There are about 3300 botanical gardens (arboretums) in the world according to the Botanic Gardens Conservation International (BGCI) (http://www.bgci.org/). It is estimated that one third of the world's vascular plant species have been preserved in botanical gardens, in which 10,000 species are rare and endangered plants (Sharrock 2012). The germplasm banks have widely been accepted for preserving plants ex situ since the 1990s. The Millennium Seed Bank at the Royal Botanic Gardens (MSB-RBG Kew) (UK) and the Germplasm Bank of Wild Species at the Kunming Institute of Botany (GBWS-KIB, Chinese Academy of Sciences, China) are the biggest banks to preserve wild plants. Up to now, 82,896 accessions (of 37,770 species) from 189 countries and territories at MSB-RBG Kew and 179,570 accessions (of 16,554 species) at GBWS-KIB of wild plants have been collected and preserved in the banks. The famous seed banks for crops and wild relatives are the National Genetic Resources Program (NGRP-USDA, USA), the Center for Crop Germplasm Resources at the Institute of Crop Sciences (Chinese Academy of Agricultural Sciences, China), the Seed Bank at the Russian Institute of Plant Genetic Resources (Russia), and the Svalbard Seed Bank at the Nordic Gene Bank (SSB-NGB, Norway), where preserved 508,994, 412,038, 322,238, and 860,000 accessions of crop seeds, respectively (Liu 2015). The Svalbard Seed Bank, with a capacity of 4,500,000 accessions/samples, is a backup of about 1700 seed banks around the world. Scientists proposed the "3E" principle to collect and preserve germplasm resources in seed banks. The three "E"s refer to endangered, endemic, and economic. This principle is useful to recognize priorities to collect and preserve plants in germplasm banks (Huang and Long 2011). MSB-RBG Kew and GBWS-KIB adopted this principle and preserved seeds, in vitro materials, and DNA materials.

The Ornamental Plant Germplasm Center (OPGC) located in Columbus, Ohio, USA, is an ex situ conservation facility for herbaceous ornamentals. Established in 2001, OPGC has dedicated to conserve and develop germplasm resources of plants with aesthetic values. The OPGC holds approximately 3200 accessions within about 200 genera of herbaceous ornamental plants that are distributed to investigators, breeders, and educators worldwide upon request (https://opgc.osu.edu/). China issued the list of national germplasm centers of ornamental plants in 2016. These 34 living collections and in vitro banks cover 22 groups of ornamental plants, namely, lotus, ornamental ferns, water lilies, Amaryllidaceae, Liliaceae, *Camellia* spp., *Chaenomeles* spp., *Chrysanthemum* × *morifolium*, *Cymbidium* spp., *Dendrobium* spp., *Gerbera jamesonii*, *Hosta* spp., *Iris* spp., *Lagerstroemia* spp., *Osmanthus* spp., *Paeonia* spp., *Phalaenopsis* spp., *Prunus mume*, *Rhododendron* spp., *Rosa chinensis*, *Tulipa* spp., and a few species of tuff grass. Over 27,000 accessions of ornamental plants have been conserved in China's national germplasm centers. These collections of ornamental plants are precious materials for breeding and horticultural industries.

According to the United Nations Food and Agriculture Organization, 40% of the world's economy is based directly and indirectly on the use of biological resources. Sustainable use is an ultimate way for biodiversity conservation. It can greatly attract public interests and awareness if a species or cultivar has been used sustainably. Examples from China may provide cases for sustainable uses of ornamental plants. *Parakmeria yunnanensis* Hu, a rare and endangered plant, has been listed in the Red Data Book of China because very limited individuals can be available from the wild habitats. It is a beautiful arbor species endemic to southwest China. Technicians have developed its seedling production and cultivation techniques for garden and street greening. It has become popular in urban areas and local townships, and the pressure on wild populations has been decreased. Another example is the use of *Musella lasiocarpa*, a narrow endemic species with very small wild populations. The local ethnic people have developed techniques related to the sustainable uses, such as propagation, breeding, cultivation, disease control, and sustainable harvest. Therefore, these endangered species have been conserved effectively, based on their sustainable uses (Long et al. 2015).

The Convention on Biological Diversity (CBD) was opened for signature on 5 June 1992 at the United Nations Conference on Environment and Development (the Rio "Earth Summit"). By February 2004, 188 parties (countries) had signed the convention. It represents a dramatic step forward in the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the use of genetic resources (https://www.cbd.int/convention/). CBD is the most important legal document for the conservation of biological diversity including plants.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has been playing a major role in world trade of plants dominated by agriculture, horticulture, and timber industries. According to a statistics at Heathrow Airport in 2015, 65% of illegal plant confiscations are ornamental plants (42% orchids, 12% *Hoodia*, 6% *Aloe*, and 5% cacti) (RBG Kew 2016).

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (Nagoya Protocol) came into force in October 2014 may exert a huge influence on ornamental industries, from prior informed consent to collection of genetic resources and associated traditional knowledge, from breeding to commercialization, and from trade to profit-sharing of final products. The Access and Benefit-Sharing (ABS) is an international agreement which aims at sharing the benefits arising from the utilization of genetic resources in a fair and equitable way. Up to now, 92 parties (countries) signed the Nagoya Protocol (https://www.cbd.int/abs/). It is very different from traditional ways to access and use genetic resources of ornamental plants for breeding, and it will improve the conservation of ornamental plants and associated traditional knowledge and equitable benefit-sharing.

The Global Strategy for Plant Conservation 2011–2020, as one of CBD programs, is in implementation together with the Strategic Plan for Biodiversity, the Global Partnership for Plant Conservation, and a range of other actors, to understand, conserve, and use sustainably the world's plant diversity. By 2020, the Strategy will achieve the following five objectives: (1) plant diversity is well understood, documented, and recognized; (2) plant diversity is urgently and effectively conserved; (3) plant diversity is used in a sustainable and equitable manner; (4) education and awareness about plant diversity, its role in sustainable livelihoods, and importance to all life on Earth is promoted; and (5) the capacities and public engagement necessary to implement the Strategy have been developed (https://www.cbd.int/gspc/). The Strategy is facilitating the conservation, breeding, and sustainable uses of world's ornamental plants.

In addition to international conventions, the legal systems on plant conservation have also been established at national, provincial, prefectural, county, and community levels or will be initiated. Activities related to ornamental plants should obey these regulations.

1.4 Conclusions

The recent development of biodiversity informatics and utilization of big data make it possible to approach the status of world's plant biodiversity. Based on COL, GBIF, IPNI, floras, and other biodiversity databases, the world's vascular plants were estimated to be 340,000–390,900 species in 452 families. The richest countries in plant diversity are Brazil, China, Indonesia, Mexico, and Columbia with 32,364, 29,650, 29,375, 25,036, and 24,500 species, respectively. Various vegetation types as well as 14 biomes on the earth provide vascular plants with diverse habitats and form complicated ecosystems. New technologies accelerate our understanding of plant genetic diversity. The whole genomes of 225 plant species have been sequenced. More and more ornamental plants will be sequenced in the near future.

At species level, the number of global ornamental plant species is still a question mark although Bailey and Bailey reported 23,979 taxa (families, genera, and species) of horticultural plants in 1976. We estimate there are 85,000–99,000 species of ornamental plants in the world. In some cases, almost all members in the whole family or whole genus have been used as ornamentals. Arecaceae, Cactaceae, *Philodendron*, *Rosa*, and others are their representatives. The cultivars and varieties of many ornamental plants are diversified and numerous. For example, 20,000–30,000 cultivars of *Chrysanthemum* × *morifolium* have been bred and cultivated.

It is essential to conserve genetic resources of ornamental plants for breeding and future development. Many wild relatives of ornamentals become endangered because of land-cover changes, invasive species, and other factors. Ornamental plants can be conserved through approaches of in situ conservation, ex situ conservation, sustainable uses, and legal system establishment. Nature reserves, seed banks, and germplasm centers play important roles in the conservation of ornamentals. Under the auspices of legal systems, sustainable use of ornamental plants will be one of the best solutions of conservation. CBD, CITES, and other legal systems at global, regional, national, and local levels will ensure the conservation and sustainable uses of ornamentals. The ABS agreement may be a milestone for ornamental industry, which is very different from traditional ways via collection to breeding and then to commercialization.

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Chapter 2
The Genetic Basis of Floral Organ Identity and Its Applications in Ornamental Plant Breeding

Mathilde Chopy, Patrice Morel, Enrico Costanzo, Suzanne Rodrigues Bento, Pierre Chambrier, and Michiel Vandenbussche

Abstract *Petunia hybrida* (or garden petunia) is worldwide one of the most popular bedding plants. At the same time, petunia has a decades-long history as a model species for scientific research to study a variety of processes, including floral organ development. Here we explain the genetic basis of floral organ identity in a comprehensible manner and illustrate the potential of floral organ identity mutants for ornamental plant breeding, using petunia as an example. Although the B- and C-floral organ identity functions are well conserved at the molecular level, indicating broad applicability, different species may exhibit significant differences in the degree of redundancy versus subfunctionalization/specialization among duplicated pairs of the homeotic genes. This is a direct consequence of the complex origin of different plant genomes, which were shaped by whole-genome, large and small-scale duplication events, often leading to (partial) genetic redundancy. Since classical genetic screens only can uncover nonredundant functions, this is probably the main reason why the use of floral organ identity mutants as breeding targets has remained unexplored in many ornamentals. We discuss how different breeding strategies may cope with this phenomenon.

Keywords Petunia · Floral development · Homeotic mutation · ABC model · Ornamental · Floral organ identity

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2.1 Introduction

When you look around in your garden or in the wild, did you ever wonder if you accidentally arrived in the middle of a flower beauty contest? What you see is indeed a competition, but a cruel one that has been going on for millions of years, and of which the result is a matter of life and death for its participants. From a biological point of view, plants acquired these beautiful flowers simply as a strategy to improve their reproduction efficiency through the attraction and interaction with pollinators. To achieve this goal, a huge number of variations in flower architecture appeared, demonstrating their ability to evolve and adapt, resulting in a highly successful conquest of all terrestrial ecosystems with an estimated 350,000 species. While most plant species need to offer a nutritional reward (such as nectar) to keep their pollinators motivated, a taxonomically very diverse group of plants, commonly called "ornamentals", probably reached the ultimate step in flower evolution: independently, they all succeeded to recruit a new pollinator species that does not even require this nutritional reward anymore. Indeed, motivated simply by the mere beauty of their flowers, this novel mammalian pollinator species, called *Homo sapiens*, further facilitated ornamentals to increase their reproductive survival and habitat range, and this on a massive and unprecedented scale.

The aim of this chapter is to explain the basic principles of floral organ identity control in a comprehensible manner and to demonstrate how this knowledge, mainly obtained from fundamental research, may be of direct interest for ornamental plant breeding. Research on the molecular mechanisms of floral organ identity control in petunia started more than two decades ago and has ever since provided significant contributions to the field of floral development. Because of its qualities (being both a research model and a popular ornamental), petunia is ideally positioned to illustrate the interest of floral organ identity mutants for ornamental plant breeding.

2.2 Petunia as an Ornamental Species and Research Model

The cultivated petunia (*P. hybrida*) is worldwide a popular bedding plant, and nearly two centuries of intensive breeding has resulted in an impressive diversity of flower colors and plant architecture in different cultivars. The genus *Petunia* is native to South America and groups into the Solanaceae, which harbors major (food) crops (potato, tomato, pepper, eggplant, tobacco), as well as ornamentals (e.g., petunia, *Calibrachoa*, *Datura*, *Schizanthus*, and many others) (Sarkinen et al. 2013). Cultivated *P. hybrida* and also many laboratory lines are derived from crosses between the moth-pollinated white *P. axillaris* and one or more members of the bee-pollinated *P. integrifolia* clade, grouping several closely related violet-flowered species including *P. inflata* (Fig. 2.1) (Stehmann et al. 2009; Segatto et al. 2014). These hybrids were produced by European botanists, as early as the beginning of the nineteenth century (Sink 1984).