Handbook of Plant Breeding

Johannes Novak
Wolf-Dieter Blüthner *Editors*

Medicinal, Aromatic and Stimulant Plants

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Preface

Medicinal and aromatic plants (MAPs) and stimulant plants include many thousand plant species with specific physiological effects of their plant secondary compounds on health, taste of food, and well-being. They can be found in all plant families worldwide, and their use is not only restricted to humans but also extended more and more to animal husbandry and plant protection.

The detection and use of these effects by humans date back to ancient times based on trial and error and are region-specific. However, during history, important plants and their application were exchanged between cultures and have been incorporated into world knowledge.

A major characteristic of MAPs is their richness in species. Whereas less than 5 food plants (sugarcane, rice, wheat, corn, potato) (Joy et al. 1998) save more than half of the world harvested yield, MAPs comprise between 52,000 species (out of 422,000 flowering plant species). In Germany, for example, 1,543 species are traded, but only 50–100 of these are exclusively sourced from cultivation. Extrapolating from the figure, only a few hundred species are under cultivation (Schippmann et al. 2002). With increasing pressure on natural populations, domestication is promoted, and the number of cultivated species will increase. Therefore, breeding different wild MAP species will increase in the short term.

In food plants, only a few chemical groups with a modest number of substances are used, namely, carbohydrates, fatty oils, and proteins, while in MAPs, several hundred thousand different products of the secondary metabolism are of value. However, with increasing popularity of polyphenols as antioxidants, breeding is trying to enrich food, vegetables, and fruits with beneficial compounds for healthier and tastier food. So, the borders between food and MAPs are blurred:

- Aromatic plants (herbs and spices) can still be distinguished from “flavor-improved” food by their property of not having nutritional value. They are in a strict sense not “food” but change the properties of food.
- Stimulant plants, like nicotine, coffee, cocoa, and tea, are also not food but estimated due to their stimulating effect, often bringing also complex flavors into our diet.
- Medicinal plants improve or maintain health but are sometimes used because of their flavor as food (e.g., herbal teas).

Medicinal plants are used (a) as traditional medicine; (b) as phytomedicines, registered according to pharmaceutical regulatory requirements; and (c) as food supplements (botanicals), products based on medicinal plants targeting primarily health maintenance, which are known from traditional medicine to be safe and effective (but regulated by food law). So, also here, the borders between medicinal and food use are blurred.

In legislation, however, we need to think in black and white resulting in pharmaceutical law and regulations that are dominantly a "negative law" (to say it bold and simple, "Everything is forbidden that is not allowed.") and food law and regulations, a "positive law" ("Everything is allowed that is not forbidden."), which can become quite challenging for breeding, if quality criteria – differently defined for medicine and food – need to be considered.

Only a few species, where seed sales are able to refinance breeding investments, are in intensive and continuous breeding programs of professional breeding companies. As a result, only a few cultivars are registered and protected, most selections are used in closed production systems, and maintenance breeding is restricted to the product life cycle. For most of the MAP species, breeding is project-based, so time-restricted and as part of a complex optimization of agricultural production. Here, product sales are refinancing optimization investments. For this group, academia, farmer associations and sometimes even raw material processors, traders, and product producers are practically breeding in a pragmatic way. This form of breeding is often performed with only simple breeding techniques like mass selection. This approach, however, can lead in many cases to a fast, significant improvement in just a few generations based on the wide natural variability in the starting materials collected from the wild.

In this book, a few important genera or species are covered in 17 specific chapters. Three general chapters reflect the particularities of MAP research and breeding. Two chapters summarize information on over 2,000 MAP species on available genetic resources, DNA particularities, and pollination biology. Two chapters can help entering more efficiently in more detailed research and breeding work. Another chapter focuses on peculiarities of chemical analysis of plant secondary compounds and some approaches to adapt analytics to breeding requirements.

Under the plethora of available literature on MAPs, breeding is severely neglected. We hope that this compilation contributes to a wider view on MAPs.

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Chapter 1
Genetic Resources of Medicinal and Aromatic Plants

Ulrike Lohwasser and Stephan Weise

1.1 Medicinal and Aromatic Plants of the World

In the State of the World's Plants Report (Kew 2016; Willis 2017), 391,000 vascular plant species from 452 plant families are described worldwide. At least 28,187 plant species are currently recorded as being of medicinal use (Willis 2017). Information on medicinal and aromatic plants can be found in many different databases and scientific information systems (Bartol and Baricevic 2015). Around 5000 species are cited in regulatory medicinal publications but much more are in use based on traditional knowledge. A total of 12 plant families have a high proportion of medicinal plants (e.g., 22.5% of the Moraceae species are used for medicinal purpose (Willis 2017)). Other estimations by the World Health Organization (WHO) report 21,000 plant taxa for medicinal purpose (Groombridge 1992). Farnsworth and Soejarto (1991) speak about 70,000 species used for folk medicine. Another question is how strict the term medicinal and aromatic plants (MAPs) is defined. If we cover not only medicinally used plants sensu *strictu* but also the whole range including cosmetics, condiments, and food, we end up with more than 72,000 plant species (Table 1.1) (Schippmann et al. 2006). Plants with known medicinal uses have been a source of vital pharmaceutical drugs for the treatment of many diseases. For example, artemisinin (discovered in *Artemisia annua* L.) and quinine (from *Cinchona officinalis* L.) remain among the most important weapons against malaria. Since 1980, 15 drugs have been registered for the treatment of cancer. For example, paclitaxel has been isolated from the yew tree (*Taxus* spp.), camptothecin from the

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Table 1.1 MAPs used medicinally worldwide with some country examples

Country	Plant species	Medicinal plant species
Bulgaria	3567	750
China	32,200	4941
France	4630	900
Hungary	2,24	270
India	18,664	3000
Jordan	2100	363
Korea, Rep. of	2898	1000
Malaysia	15,500	1200
Nepal	6973	900
Pakistan	4950	1500
Philippines	8931	850
Sri Lanka	3314	550
Thailand	11,625	1800
USA	21,641	2564
Vietnam	10,500	1800
World	**422,000**	**72,000**

Schippmann et al. 2006, modified

happy tree (*Camptotheca acuminata* Decne.), and podophyllotoxin from the may-apple (*Podophyllum hexandrum* Royle and *P. peltatum* L.). Another study documents 656 flowering plant species used traditionally for diabetes, representing 437 genera and 111 families. For example, *Galega officinalis* L. (goat's rue) provided a useful compound for the design of the antidiabetic drug metformin, while another plant used traditionally for diabetes, *Stevia rebaudiana* (Bertoni) Bertoni (sweet-leaf), is a source of sweetener compounds used in the food industry (Willis 2017).

For thousands of years, medicinal plants have been used in various cultures. They play an important role in human history, culture, and tradition. Cave paintings dating back to 13,000–25,000 BC depict the use of medicinal plants (Cooper and Deakin 2016). The oldest written evidence of medicinal plants' usage for preparation of drugs has been found on a Sumerian clay slab from Nagpur, approximately 5000 years old (Petrovska 2012). Different regions of the world have different preferences in the use and consumption of medicinal plants also based on historical and traditional knowledge. Probably the oldest, richest, and most diverse cultural traditions in the use of medicinal plants are in India (Lange 2004). About 7500–8000 plant species are used in ethnomedicines (Chandra 2016; Shankar and Majumdar 1997) which is half of the country's 17,000 Indian native plant species. The well-known ancient Indian medicine system, which is called Ayurveda, is a set of guidelines to maintain balance and harmony and to ensure a long and happy life. Famous Ayurvedic medicinal plants include *Azadirachta indica* A. Juss (neem, nimtree), *Centella asiatica* (L.) Urb. (Asiatic pennywort, gotu kola), *Cinnamomum verum* J. Presl (cinnamon), *Elettaria cardamomum* (L.) Maton (cardamom), *Rauvolfia serpentina* (L.) Benth. ex Kurz (Indian snakeroot), *Santalum album* L. (sandalwood), *Terminalia chebula* Retz. (black myrobalan) and other *Terminalia* species, and *Withania somnifera* (L.) Dunal (Indian ginseng) (van Wyk and Wink 2017). Also, the traditional Chinese medicine is believed to be more than 5000 years old (van Wyk and Wink 2017). The total number of plant species here is up to 6000 according to Xiao (1991) and more than 10,000 according to He and Sheng (1997). Examples of famous Chinese medicinal plants are *Angelica sinensis* (Oliv.) Diels (dang gui, Chinese angelica), *Artemisia annua* L. (qing hao, sweet wormwood), *Ephedra sinica* Stapf (ma huang, Chinese ephedra), *Paeonia lactiflora* Pall. (bai shao yao, Chinese peony), *Panax ginseng* C. A. Mey. (ren shen, Chinese ginseng), and *Rheum palmatum* L. (da huang, Chinese rhubarb) (van Wyk and Wink 2017). However, not only India and China have important MAPs, but also the other Asian countries have a long history in well-documented traditional knowledge and a long-standing practice of traditional medicine (ICS-UNIDO 2003; Handa et al. 2006; Yaniv and Dudai 2014). Especially from the Middle East, many important plants are known such as *Allium cepa* L. (onion), *Astracantha gummifera* (Labill.) Podlech (tragacanth), *Carthamus tinctorius* L. (safflower), *Ferula assa-foetida* L. (asafetida), *Juniperus phoenicea* L. (Phoenicean juniper), *Lawsonia inermis* L. (henna), *Myrtus communis* L. (myrtle), *Papaver somniferum* L. (opium poppy), *Peganum harmala* L. (Syrian rue), *Pinus halepensis* Mill. (Aleppo pine), *Pistacia lentiscus* L. (mastic), *Prunus dulcis* (Mill.) D. A. Webb (almond), *Punica granatum* L. (pomegranate), *Rosa* x *damascena* Herrm. (Damask rose), *Ricinus communis* L. (castor), *Salvadora persica* L. (toothbrush tree), *Senna alexandrina* Mill. (senna), *Sesamum indicum* L. (sesame), *Trachyspermum ammi* (L.) Sprague (ajowan), *Trigonella foenum-graecum* L. (fenugreek), and *Vitis vinifera* L. (grape) (van Wyk and Wink 2017; Yaniv and Dudai 2014).

African traditional medicine is perhaps one of the most diverse medicine systems in the world but unfortunately poorly recorded. The biological and cultural diversity of Africa that constitutes the cradle of mankind shows many regional differences in healing practices (Gurib-Fakim 2006; van Wyk and Wink 2017). About 80% of the population relies on traditional medicine for healthcare needs. Within the rich African flora with a high rate of endemic species, around 3000 MAPs are recorded from Southern Africa and 7000 from Northern Africa. In Eastern Africa, many biological resources are used for obtaining pharmaceuticals. Western Africa is the home of large rainforests constituting many MAPs (Vasisht and Kumar 2004). Other references speak about more than 5000 African plant species that are in use for medicinal purpose (Iwu 1993; Lange 2004; Neffati et al. 2017). The most important and well-known African MAPs are listed in van Wyk (2017). Some very famous plants should be mentioned here such as *Agathosma betulina* (P. J. Bergius) Pillans (buchu), *Aloe ferox* Mill. (bitter aloe, Cape aloe), *Aloe vera* (L.) Burm. f. (true aloe, of North African origin), *Artemisia afra* Jacq. ex Willd. (African wormwood), *Aspalathus linearis* (Burm. F.) R. Dahlgren (rooibos tea), *Boswellia sacra* Flueck. (frankincense), *Catha edulis* (Vahl) Endl. (khat), *Commiphora myrrha* (Nees) Engl. (myrrh), *Harpagophytum procumbens* (Burch.) DC. ex Meisn. (devil's claw), *Hibiscus sabdariffa* L. (roselle), *Hypoxis hemerocallidea* Fisch., C. A. Mey. &

Avé-Lall. (African potato), *Prunus africana* (Hook. f.) Kalkman (African cherry), and *Senegalia senegal* (L.) Britton) (gum arabic) (van Wyk and Wink 2017).

The European healing system originated with Hippocrates (460–377 BC) and Aristotle (384–322 BC). Their ideas go back to ancient beliefs from India and Egypt (van Wyk and Wink 2017). In the ancient Western world, the Greeks contributed significantly to the rational development of the use of herbal drugs. Europe has a long tradition in the use of botanicals. A large number of traditional herbal remedies have become widely known as a result of commercialization, and a number of active compounds have been isolated from medicinal plants and are used today as single chemical entities (Gurib-Fakim 2006). About 2000 MAPs are used on a commercial basis of which 1200–1300 are native in Europe (Barata et al. 2016; Lange 2004). Examples can be listed as follows: *Arnica montana* L. (arnica), *Atropa belladonna* L. (deadly nightshare), *Drimia maritima* (L.) Stearn (squill), *Foeniculum vulgare* Mill. (fennel), *Matricaria chamomilla* L. (chamomile), *Silybum marianum* (L.) Gaertn. (milk thistle), *Urtica dioica* L. (nettle), and *Valeriana officinalis* L. (valerian) (van Wyk and Wink 2017).

For North and South America, 2564 medicinal plants are listed in the literature (Mamedov 2012; Moerman 2009). The region is very rich in the diversity of plant resources; the number of plants used for medicines in different ways by different people is probably endless. The American flora represents one of the world's wealthiest sources of material with pharmacological activity. Detailed information about the status of MAPs in the different countries can be found in Gupta et al. (2014). Especially in South but also in North America, the rich but diverse healing cultures based on indigenous healer or shaman approaches are poorly recorded but will be a source of many new herbal remedies. Rural people in many American countries still use traditional Indian herbal medicine (Gurib-Fakim 2006; van Wyk and Wink 2017). Some important MAPs for North America are *Digitalis purpurea* L. (foxglove), *Echinacea purpurea* (L.) Moench (purple coneflower), *Hydrastis canadensis* L. (goldenseal), *Lobelia inflata* L. (Indian tobacco), and *Taxus canadensis* Marshall (Pacific yew). For South America, famous examples are *Cinchona pubescens* Vahl (Peruvian bark), *Erythroxylum coca* Lam. (coca), *Handroanthus impetiginosus* (Mart. ex. DC.) Mattos (lapacho), *Ilex paraguariensis* A. St.-Hil. (maté), *Myroxylon balsamum* (L.) Harms (Tolu balsam), *Paullinia cupana* Kunth (guaraná), *Peumus boldus* Molina (boldo), *Psidium guajava* L. (guava), *Spilanthes acmella* (L.) L. (Brazilian cress), and *Uncaria tomentosa* (Willd. ex Schult.) DC. (cat's claw) (Gupta et al. 2014; van Wyk and Wink 2017).

As a result of geographic isolation, Australia is home to a large variety of unique and distinct flora not found elsewhere in the world. Herbal medicines have played an important role in the health, culture, and traditions of Australian Aboriginal people. Old literature speaks about 9000 flowering plant species used as medicinal plants (von Mueller 1889). Unfortunately, most Aboriginal knowledge of plant usage is not systematically reported (Gurib-Fakim 2006). Nevertheless, some information about the used plant species is available. Later on with the arrival of the European settlers, the plant usage is much better documented (Cock 2011; Lassak and McCarthy 2011; Williams 2010). Among others, some very important MAPs from Australia are *Backhousia citriodora* F. Muell. (Australian lemon myrtle), *Duboisia hopwoodii* (F. Muell.) F. Muell. (pituri), *Eucalyptus globulus* Labill. (bluegum), and *Melaleuca alternifolia* (Maiden & Betche) Cheel (tea tree) (Cock 2011; van Wyk and Wink 2017).

Determining an exact number of MAPs worldwide is very difficult. However, the number of used species as medicinal and spice plants is quite impressive.

1.2 Conservation Strategies

Globally, an estimated 70,000 species are used for their medicinal, nutritional, and aromatic properties. Every year more than 500,000 tons of materials of such species are traded (Farnsworth and Soejarto 1991; WHO 2015). The increased global interest in the use of MAPs and the increasing demand on raw materials by various processing industries (pharmaceutical, food, cosmetic, perfume, etc.) have resulted in the increasing demand for MAPs. This places pressure on natural resources, since most species used are still collected in the wild (Barata et al. 2016). Overharvesting, habitat alteration, and climate change are among major drivers of declines in commercially important wild plant resources used for medicinal purposes (Canter et al. 2005; WHO 2015). There is no reliable estimate for the number of MAPs that are globally threatened (Hamilton 2004). An extrapolation based on the total number of threatened species leads to estimate that at least 15,000 MAP species are threatened at least to some degree (Chen et al. 2016; Schippmann et al. 2006). In the European Red List of Medicinal Plants, 400 taxa are described as endangered (Allen et al. 2014). Looking into the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN 2018), 1500 species (filtered for medicine, poison, manufacturing chemicals, and other chemicals) are mentioned as threatened or endangered, but the list includes only 25,452 plant species. The principal tool for monitoring or restricting trade of species threatened by overexploitation is the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES). In total, 30,345 plant species are protected by CITES (CITES 2018) from which, based on literature, only 17 species are MAPs (Schippmann et al. 2002; Hamilton 2004). Several declarations and sets of recommendations calling for the conservation and sustainable use of biodiversity including also medicinal plants exist. Among these, the Convention on Biological Diversity (CBD) has implemented three major goals since its adoption in 1992: (1) conservation of biological diversity, (2) sustainable use of its components, and (3) fair and equitable sharing of the benefits from the use of genetic resources. All of them are fully applicable to MAP resources (Máthé 2015; Schippmann et al. 2002). In April 2002, the CBD adopted the Global Strategy for Plant Conservation, which was updated in a strategy 2011–2020 (CBD 2018). Following the CBD goals and strategy, it is necessary to have a concept of sustainability. This means for MAPs that conservation strategies are essential in order to avoid loss of natural resources. For example, the revised Guidelines on the Conservation of Medicinal Plants (WHO/IUCN/WWF/TRAFFIC forthcoming) and the WHO Guidelines on Good Agricultural and Collection Practices (GACP) for Medicinal Plants provide general recommendations (Kathe 2006; Leaman 2006; MPSG 2007). Beside a sustainable system for harvesting MAPs in the wild, various conservation strategies including both in situ and ex situ conservation are necessary. In situ conservation involves protection and establishment of plants in the location of their natural occurrence. In addition, identification of ecosystems is very essential (Okigbo et al. 2008). Ex situ conservation aims to cultivate MAP species to ensure their continued survival (Chen et al. 2016). MAP genetic resources conservation can be considered from both points of view: On the one hand, in situ conservation involves the establishment and/or maintenance of natural reserves where species are allowed to remain in optimal ecosystems. On the other hand, ex situ conservation involves the use of botanical gardens, field plantations, seed stores, and gene banks. In gene banks, seeds can be safely stored at low moisture contents (5–8% RH) and at low temperatures (−18 °C) (Ford-Lloyd et al. 2014). Plant in vitro technology and cryopreservation in liquid nitrogen (−196 °C) offer potential solutions for the long-term conservation of difficult to store germplasm categories (Carlen and Simonnet 2015). MAPs represent a consistent part of the natural biodiversity; effective conservation strategies should take place (Okigbo et al. 2008).

1.3 Genetic Resources of Medicinal and Aromatic Plants

Many countries have recognized the need for a complete national inventory of cultivated plant genetic resources, wild relatives, ecosystems, and the traditional knowledge associated with them. In situ conservation efforts worldwide have mostly focused on establishing protected areas and taken an ecosystem-oriented rather than a species-oriented approach. Many priority sites for conserving crop wild relatives in situ have been identified around the world. In some cases, new protected areas have been proposed for conserving a particular genus or even species (FAO 2010). Some examples of successful programs for in situ conservation of MAPs are described in Heywood and Dulloo (2005) and Labokas and Karpavičienė (2018). However, the focus of this paragraph will be on ex situ conservation because it is rather difficult to give exact figures about in situ conservation of MAPs.

Ex situ approaches to conserve and maintain MAPs involve the preservation of samples mainly in botanical gardens and gene banks (Shahidulla and Haque 2015). Some 1800 medicinal plant taxa are represented in botanical garden collections globally (FAO 2010). Detailed information about the holdings of MAPs in botanical gardens worldwide can be found in a plant conservation network, which is called

Botanic Gardens Conservation International (BGCI). BGCI provides a database of living plant, seed, and tissue collections. In the database, 1,384,852 collection records representing 548,973 taxa at 1100 contributing institutions are searchable including Red List and CITES status; 1786 medicinal plant species are listed here together with the number of botanical gardens in which the species are conserved (BGCI 2018).

From the 1920s, several countries initiated collection missions in order to accumulate and store genetic resources in ex situ gene banks (Börner 2006). Today, worldwide, more than 7.4 million accessions are conserved in ex situ collections. The largest groups are cereals (3.2 million) and food legumes (1.1 million). Looking into literature, only 160,050 accessions of medicinal, aromatic, spice, and stimulant crops are available in global germplasm holdings (FAO 2010).

Based on a list of 12,235 important vascular plant species, 3578 are defined as MAPs sensu *lato* (Wiersema and León 2013). The information about the potential usage of this plant species are obtained from the Germplasm Resources Information Network (GRIN 2018) and comprise the use as medicine, food additives, materials, or for social purposes, respectively. Out of the 3578 identified MAP species, 2507 could be found in ex situ collections with at least one accession. The accession passport data used are obtained from various information systems and give an overview on gene bank holdings from all over the world. Data on accessions maintained in European gene banks are retrieved from the European Search Catalogue for Plant Genetic Resources (EURISCO). This information system is being maintained by the European Cooperative Programme for Plant Genetic Resources (ECPGR) and provides information about almost two million accessions maintained at more than 370 institutions (Weise et al. 2017). A second important source is the information system Genesys, which is being funded by the Global Crop Diversity Trust. Genesys provides information about the US National Plant Germplasm System and about the CGIAR gene banks. Moreover, Genesys also provides data about different Embrapa collections from Brazil and some Australian gene banks. Further information was downloaded from different databases or provided by curators (Table 1.2). However, not from all countries English websites or contacts are available so that some countries with large gene bank collections are missing.

In total, 770,701 MAP accessions could be found in worldwide gene bank collections based on a total number of 4,302,721 available passport data over all continents. The largest holdings of MAPs are in Europe (373,555 accessions) and in North America (170,169) followed by Latin America (87,077) and Asia (86,548). The smallest collections are in Oceania (28,669) and in Africa (24,683) (Table 1.3). The species with the most accessions (133,037) all over the world is *Zea mays* L. which is not only known as cereal. Used parts for medicinal purpose are styles and stigmas, containing some essential oil (carvacrol and other terpenes) and having a diuretic and anti-inflammatory effect; the other used part of corn is pollen as extract for a urological purpose and raw pollen as appetite stimulant based on the presence of sterols (van Wyk and Wink 2017). Number

Table 1.2 Data sources of gene bank holdings

Region	Country	Institute	No of accs.	Data source
Africa	Ivory Coast	West African Rice Development Association	19,868	Genesys[a]
	Ivory Coast	Station de Recherche Marc Delorme, Centre National de Recherches Agronomiques	147	Genesys[a]
	Ethiopia	International Livestock Research Institute	18,640	Genesys[a]
	Kenya	Genetic Resources Unit, ICRAF	5391	Genesys[a]
	Kenya	Genetic Resources Research Institute	50,885	Genesys[a]
	Nigeria	International Institute of Tropical Agriculture	33,713	Genesys[a]
	Tunisia	Banque national de gènes de Tunisie	3166	Genesys[a]
	Zambia	SADC Plant Genetic Resources Centre	11,326	Genesys[a]
Asia	India	International Crop Research Institute for the Semi-Arid Tropics	126,830	Genesys[a]
	India	ICAR - National Bureau of Plant Genetic Resources	5593	Provided by NBPGR[b]
	Philippines	International Rice Research Institute	130,175	Genesys[a]
	Syria	International Centre for Agricultural Research in Dry Areas	155,414	Genesys[a]
	Taiwan	World Vegetable Center	59,954	Genesys[a]
	Republic of Korea	National Agrobiodiversity Center	172,352	Download from web information system[c]
	Japan	Genetic Resources Center, National Agriculture and Food Research Organization	101,160	Download from web information system[d]
Europe	various	372 institutes throughout Europe	1,983,324	EURISCO[e]
Latin America	Brazil	Embrapa	192,356	Genesys[a]
	Colombia	Centro Internacional de Agricultura Tropical	67,770	Genesys[a]
	Costa Rica	Centro Agronómico Tropical de Investigación y Enseñanza	1990	Genesys[a]
	Mexico	Centro Internacional de Mejoramiento de Maíz y Trigo	165,240	Genesys[a]
	Peru	Centro Internacional de la Papa	17,898	Genesys[a]
North America	Canada	Plant Gene Resources of Canada	23,948	Provided by PGRC[f]
	USA	US National Plant Germplasm System	639,764	Genesys[a]
Oceania	Australia	South Johnstone Research Station Queensland Department Primary Industries	282	Genesys[a]
	Australia	Australian Grains Genebank, Department of Economic Development Jobs Transport and Resources	138,016	Genesys[a]

(continued)

Table 1.2 (continued)

Region	Country	Institute	No of accs.	Data source
	Australia	Australian Pastures Genebank	83,838	Genesys[a]
	Australia	Australian PlantBank	10,609	Australian Seedbank Partnership[g]
	Australia	South Australian Seed Conservation Centre	1322	Australian Seedbank Partnership[g]
	Australia	Australian National Botanic Gardens Seedbank	11,788	Australian Seedbank Partnership[g]
	Australia	Brisbane Botanic Gardens Conservation Seedbank	918	Australian Seedbank Partnership[g]
	Australia	Tasmanian Seed Conservation Centre	1755	Australian Seedbank Partnership[g]
	Australia	Victorian Conservation Seedbank	1289	Australian Seedbank Partnership[g]
	Australia	Western Australia Seed Technology Centre	11,687	Australian Seedbank Partnership[g]
	Australia	Threatened Flora Seed Centre	4544	Australian Seedbank Partnership[g]
	Fiji Islands	Centre for Pacific Crops and Trees	2163	Genesys[a]
	New Zealand	Margot Forde Germplasm Centre	46,606	Download from web information system[h]

[a]Genesys, https://www.genesys-pgr.org, provided from Genesys at 2018-10-10
[b]ICAR – National Bureau of Plant Genetic Resources of India (NBPGR, http://www.nbpgr.ernet.in/) provided information about 5593 Indian MAP accessions at 2018-10-30
[c]Information about 172,352 accessions was downloaded from the National Agrobiodiversity Center, Republic of Korea (http://genebank.rda.go.kr/, 2018-09-24)
[d]Information about 101,160 accessions maintained in Japan was downloaded from the Genetic Resources Center, National Agriculture and Food Research Organization (http://www.gene.affrc.go.jp/databases-plant_search_en.php, 2018-09-25)
[e]EURISCO, European Search Portal for Plant Genetic Resources, http://eurisco.ecpgr.org, provided from EURISCO at 2018-11-07
[f]Plant Gene Resources of Canada (PGRC, http://pgrc3.agr.gc.ca, 2018-10-01) provided information about 23,948 Canadian MAP accessions
[g]Information about 43,912 additional Australian gene bank accessions was available from the Australian Seedbank Partnership (Atlas of Living Australia occurrence download at https://biocache.ala.org.au/occurrences/search?&q=*%3A*&qc=data_hub_uid%3Adh4 accessed on Fri Aug 03 21:23:40 AEST 2018)
[h]Information about 46,606 accessions maintained in New Zealand was downloaded from the Margot Forde Germplasm Centre (https://www.agresearch.co.nz/margot-forde-forage-germplasm-centre/, 2018-08-07)

Table 1.3 Overview of accession passport data available for comparison

Region	No of acc.	No of MAPs
Africa	143,136	24,683
Asia	751,478	86,548
Europe	1,983,324	373,555
Latin America	445,254	87,077
North America	663,712	170,169
Oceania	315,817	28,669
Total	**4,302,721**	**770,701**

two in the species list is *Avena sativa* L. (61,070) which is also well known as cereal. However, the grains of oat are used for dietary aid; the straw (added to a bath) has antipruritic effects for the relief of inflammatory and seborrheic skin disease because of containing high levels of soluble silica and minerals (iron, manganese, zinc) (van Wyk and Wink 2017). The species with the third highest numbers of accessions is *Vitis vinifera* L. (29,741). Grape vine is not only the base of a famous alcoholic drink, but also even red wine is considered to be healthy if taken in moderation. In addition, extracts from grape seeds have an antioxidative effect; the active ingredients in grape seed oil are non-hydrolyzable or condensed tannins (van Wyk and Wink 2017). Number four is *Malus domestica* Borkh. (28,165). Apples are not only popular fruits, but also they are used traditionally against diarrhea and dyspepsia and have antioxidant effects. Active ingredients are polyphenols, fruit acids (malic acid), pectin, sucrose, amines, vitamins, and mineral salts (van Wyk and Wink 2017). Position five in the top five ranking has *Linum usitatissimum* L. with 27,556 accessions. Flax has cultivars grown for stem fibers, others for seeds or seed oil. The active ingredients are mucilage in the outer cell layer of the seed coat. The main compounds in the seed are oil including linoleic acid and α-linolenic acid, proteins, and fibers having a bulk laxative effect. The mucilage is also beneficial in cases of gastritis and enteritis (van Wyk and Wink 2017). Meanwhile, 1071 MAP species are not listed in any gene bank collection; 433 out of 2507 species have just one accession available in ex situ collections, and 1408 species have a number lower than 10. Detailed information about the holdings can be found in Table 1.4. About 48 species of the 2507 have an entry in the different appendices of CITES, one in appendix I, 45 in appendix II, and two in appendix III. Appendices I (all parts or derivatives are always regulated and cannot be exempted), II, and III (exemptions of certain commodities and products are possible) to the convention are lists of species afforded different levels or types of protection from overexploitation (CITES 2018; Schippmann 2018). In the IUCN Red List, 475 MAP species of the 2507 have an entry, from "data deficient" to "extinct in the wild." Three species, all belonging to the genus *Brugmansia*, are listed as "extinct in the wild," four species (*Castanea dentata* (Marshall) Borkh., *Commiphora wightii* (Arn.)

Bhandari, *Fraxinus americana* L., *Fraxinus nigra* (Marshall)) have a status as "critically endangered," and 17 a status of "endangered" (IUCN 2018). Further details about CITES and/or Red List status can be found in Table 1.4.

1.4 Use of MAP Genetic Resources for Breeding Purpose

MAPs comprise a huge number of plant species. Compared with other groups of cultivated food plants, they utilize only a very small cultivation area. Plant breeding offers the opportunity to adapt these most diverse species to the specific demands of their users. Breeding for increased yield of valuable compounds, for elimination of unwanted compounds, for tolerance against abiotic and biotic stresses, and for better homogeneity of the cultivars is an important issue. Gene banks, botanical gardens, and other institutions collect and maintain a wide diversity of different accessions of the great variety of MAP species (Carlen 2012; Pank 2007). Especially gene banks play an important role for the long-term conservation of MAPs. Thereby, the focus is not only on the aspect of pure conservation. Screening of gene bank material can lead to new chemical compounds as shown in sage (*Salvia officinalis* L.) where a new viridiflorol chemotype could be described (Lamien-Meda et al. 2010). Often, the beginning of a breeding program starts with screening and selection of accessions coming from different gene banks. The large genetic diversity stored in gene banks is also used to provide new impulses to traditional breeding (e.g., by adding new alleles to existing breeding stocks) (Hoisington et al. 1999). An older literature survey over the last three decades of the last century shows more than 300 scientific publications about resistance research and breeding in MAPs (Gabler 2002). However, in many cases, it is not known which sources were used for breeding purposes. Examples for successful breeding including gene bank accessions are available from peppermint (*Mentha x piperita* L.) for yield, constituents and sensory quality, bitter fennel (*Foeniculum vulgare* Mill. subsp. *vulgare* var. *vulgare*) for essential oil content, St. John's wort (*Hypericum perforatum* L.) for high constituent content, and summer savory (*Satureja hortensis* L.) for essential oil content (Pank 2010). Nevertheless, gene bank accessions can have a high potential for breeding efforts.

With more than 770,000 MAP samples in ex situ collections worldwide, it seems that a good base for long-term conservation and breeding of medicinal and aromatic plant genetic resources is available. However, from more than 1000 species, no sample exists in any collection; and many species have a very low number of samples. More than one-third (36%) of all MAP accessions come from the top five which are, with partly exception of flax, not primarily medicinal plants. Some of the species are extinct in the wild or critically endangered. In conclusion, further strategies are urgently necessary to conserve and maintain the rich biodiversity of medicinal and aromatic plants.

Table 1.4 List of MAP species with gene bank holdings

Taxon	Usage code	Usage type	Europe	Africa	Asia	North America	Latin America	Oceania	Total	CITES appendix	IUCN Red List status
Abelmoschus esculentus (L.) Moench	Medicine	Folklore	72	29	1197	2484	198	5	3985		
Abelmoschus moschatus Medik.	Additive, material, medicine	Flavoring, essential oils, folklore	3		15	68		1	87		
Abies alba Mill.	Material	Essential oils	6			1			7		Least concern
Abies amabilis Douglas ex J. Forbes	Social	Religious/secular	10						10		Least concern
Abies balsamea (L.) Mill.	Material, medicine, social	Essential oils, folklore, religious/secular	8			2			10		Least concern
Abies concolor (Gordon & Glend.) Lindl. ex Hildebr.	Social	Religious/secular	10			2			12		Least concern
Abies fraseri (Pursh) Poir.	Medicine, social	Folklore, religious/secular	14			2			16		Endangered
Abies grandis (Douglas ex D. Don) Lindl.	Social	Religious/secular	7						7		Least concern
Abies nordmanniana (Steven) Spach	Social	Religious/secular	5			9			14		Least concern
Abies procera Rehder	Social	Religious/secular	3						3		Least concern
Abies religiosa (Kunth) Schltdl. and Cham.	Medicine	Folklore	1						1		Least concern

Abies sachalinensis (F. Schmidt) Mast.	Material	Essential oils	4			1			5		Least concern
Abies veitchii Lindl.	Social	Religious/secular	4						4		Least concern
Abroma augustum (L.) L. f.	Medicine	Folklore			13				13		
Abrus precatorius L.	Medicine	Folklore	20	6	129	4	21	9	189		
Abutilon indicum (L.) Sweet	Medicine	Folklore	5		59	1		7	72		
Acacia confusa Merr.	Material	Tannin/dyestuff				1			1		
Acacia cyclops A. Cunn. ex G. Don	Material	Tannin/dyestuff		4		2		36	42		
Acacia dealbata Link	Material	Essential oils, tannin/dyestuff	6	1		3		31	41		
Acacia decurrens Willd.	Material	Tannin/dyestuff	1	4		2		15	22		
Acacia elata A. Cunn. ex Benth.	Material	Tannin/dyestuff	1					3	4		
Acacia mearnsii De Wild.	Material	Tannin/dyestuff	1	7		1		7	16		
Acacia saligna (Labill.) H. L. Wendl.	Material	Tannin/dyestuff	2	4		4	1	40	51		
Acaciella angustissima (Mill.) Britton and Rose	Medicine	Folklore	15			17		9	41		
Acalypha fruticosa Forssk.	Medicine	Folklore		1					1		
Acalypha hispida Burm. f.	Medicine	Folklore				1			1		

(continued)

Table 1.4 (continued)

Taxon	Usage code	Usage type	Europe	Africa	Asia	North America	Latin America	Oceania	Total	CITES appendix	IUCN Red List status
Acalypha indica L.	Medicine	Folklore	1						1		
Acanthosicyos horridus Welw. ex Benth. and Hook. f.	Medicine	Folklore	2						2		
Acanthospermum australe (Loefl.) Kuntze	Medicine	Folklore	2						2		
Acanthospermum hispidum DC.	Medicine	Folklore	2	3					5		
Acanthus mollis L.	Medicine	Folklore	1						1		
Acer rubrum L.	Medicine	Folklore	6			5			11		Least concern
Acer spicatum Lam.	Medicine	Folklore	1			8			9		
Achillea alpina L.	Medicine	Folklore	2			4			6		
Achillea erba-rotta All.	Additive	Flavoring	9						9		
Achillea fragrantissima (Forssk.) Sch. Bip.	Medicine	Folklore	16						16		
Achillea millefolium L.	Additive, medicine	Flavoring, folklore	394		7	73		15	489		Least concern
Achillea ptarmica L.	Medicine	Folklore	46			1			47		Least concern
Achyranthes aspera L.	Medicine	Folklore	17	6	35	2		5	65		
Achyranthes bidentata Blume	Medicine	Folklore	2			1			3		

Achyranthes fauriei H. Lev. and Vaniot	Medicine	Folklore	1		4				5		
Achyranthes japonica (Miq.) Nakai	Medicine	Folklore			4				4		
Achyrocline satureioides (Lam.) DC.	Medicine	Folklore					12		12		
Acmella oleracea (L.) R. K. Jansen	Medicine	Folklore	3						3		
Acokanthera schimperi (A. DC.) Benth. and Hook. f. ex Schweinf.	Medicine	Source of ouabain		3					3		
Aconitum carmichaelii Debeaux	Medicine	Folklore	1						1		
Aconitum columbianum Nutt.	Medicine	Folklore	1			6			7		
Aconitum coreanum (H. Lev.) Rapaics	Medicine	Folklore				2			2		Least concern
Aconitum falconeri Stapf	Medicine	Folklore			2				2		
Aconitum ferox Wall. ex Ser.	Medicine	Folklore			2				2		
Aconitum heterophyllum Wall. ex Royle	Medicine	Folklore	1		8				9		Endangered
Aconitum kusnezoffii Rchb.	Medicine	Folklore				1			1		

(continued)

Table 1.4 (continued)

Taxon	Usage code	Usage type	Europe	Africa	Asia	North America	Latin America	Oceania	Total	CITES appendix	IUCN Red List status
Aconitum nagarum Stapf	Medicine	Folklore	1						1		
Aconitum napellus L.	Medicine	Folklore	27			1			28		Least concern
Aconogonon alpinum (All.) Schur	Material	Tannin/dyestuff	1			1			2		
Acorus calamus L.	Material, medicine	Essential oils, folklore	32			1			33		Least concern
Acorus gramineus Sol. ex Aiton	Medicine	Folklore	2			5			7		Least concern
Actaea asiatica H. Hara	Medicine	Folklore	1			3			4		
Actaea cimicifuga L.	Medicine	Folklore			1				1		
Actaea heracleifolia (Kom.) J. Compton	Medicine	Folklore				3			3		
Actaea pachypoda Elliott	Medicine	Folklore	1						1		
Actaea racemosa L.	Medicine	Folklore	1			53			54		
Actaea rubra (Aiton) Willd.	Medicine	Folklore	10			10			20		
Actaea spicata L.	Medicine	Folklore	20						20		
Actinidia arguta (Siebold & Zucc.) Planch. ex Miq.	Material	Potential as chemicals	25		2	221			248		

Actinidia deliciosa (A. Chev.) C. F. Liang and A. R. Ferguson	Medicine	Folklore	62		4	54			120		
Actinidia polygama (Siebold & Zucc.) Maxim.	Medicine	Folklore	2			18			20		
Adansonia digitata L.	Material, medicine	Tannin/dyestuff, folklore	8	182		2			192		
Adansonia za Baill.	Medicine	Folklore	4			1			5		Lower risk/near threatened
Adenanthera pavonina L.	Medicine	Folklore	2	1	12	4	1		20		
Adenia venenata Forssk.	Medicine	Folklore		1		1			2		
Adenium obesum (Forssk.) Roem. and Schult.	Medicine	Folklore		1					1		
Adenophora liliifolia (L.) Besser	Medicine	Folklore	3						3		
Adenophora stricta Miq.	Medicine	Folklore	1						1		
Adenophora triphylla (Thunb.) A. DC.	Medicine	Folklore	4						4		
Adenostemma viscosum J. R. Forst. and G. Forst.	Medicine	Folklore	1						1		
Adiantum capillus-veneris L.	Medicine	Folklore				1			1		Least concern

(continued)

Table 1.4 (continued)

Taxon	Usage code	Usage type	Europe	Africa	Asia	North America	Latin America	Oceania	Total	CITES appendix	IUCN Red List status
Adiantum pedatum L.	Medicine	Folklore				1			1		
Adonis amurensis Regel & Radde	Medicine	Folklore				8			8		
Adonis vernalis L.	Medicine	Source of adoniside	69			1			70	II	
Aegle marmelos (L.) Correa	Material, medicine	Essential oils, folklore	1		13	5			19		
Aegopodium podagraria L.	Medicine	Folklore	44						44		
Aerva javanica (Burm. f.) Juss. ex Schult.	Medicine	Folklore	12	6	1			3	22		
Aerva lanata (L.) Juss. ex Schult.	Medicine	Folklore		5	3				8		
Aesculus glabra Willd.	Medicine	Folklore	1			4			5		Least concern
Aesculus hippocastanum L.	Medicine	Source of aescin	18						18		Vulnerable
Aethusa cynapium L.	Medicine	Folklore	12			1			13		
Afzelia xylocarpa (Kurz) Craib	Medicine	Folklore	1						1		Endangered
Agastache foeniculum (Pursh) Kuntze	Additive, medicine	Flavoring, folklore	22			15			37		
Agastache rugosa (Fisch. & C. A. Mey.) Kuntze	Material, medicine	Essential oils, folklore	19		10	16			45		