# Chapter 2
# Botanical Aspects of Medicinal and Aromatic Plants

**Ákos Máthé**

**Abstract** Botany, the science of plants, is linked with medicinal and aromatic plants in many different ways. The ca. 40,000 plant species used for ethnomedicinal purposes, since the beginning of recorded history, have traditionally been collected and gathered from the wild. Botanical sciences (like plant systematics, morphology and physiology) have been assisting the study and utilization of MAPs in a multiple of ways.

The study and utilization of MAPs should begin with the correct identification of plants. Formerly this was done mainly on the basis of morphological characters. With the progress of scientific – technical development, the chemical traits were also involved. Recent research trends have opened up new opportunities for revealing the DNA and biosynthetic causes of chemo-differentiation, and ultimately the information supplied by the plant metabolome. As thus, botany assisted by other scientific achievements, seems to open up promising perspectives for the breeding of new, highly powerful chemo-cultivars of medicinal and aromatic taxa.

In the case of medicinal and aromatic plants the inheritance patterns, as well as the interrelatedness of economically important traits is complex. Their variability as complemented by the ecological plasticity of plants make it difficult to arrive at reliable research conclusions, to sort out the inheritable characteristics making MAP-breeding still quite a challenge.

The efficiency of cultivation of these species is fundamentally dependent on the productivity of the plant biomass within which the active principles are synthesized and frequently accumulated. Their quantities and composition are important preconditions for utilization, therefore also intensively investigated botanical domains.

Floristics or Vegetation Science deals with plants in geographic dimensions. The knowledge and economic mapping of MAP resources is an important contribution to the sustainable management and utilization of these species.

Á. Máthé (✉)
Faculty of Agriculture and Food Science, University of West Hungary, Budapest, Hungary
e-mail: akos.mathe@upcmail.hu

 
Á. Máthé (ed.), *Medicinal and Aromatic Plants of the World*, Medicinal and Aromatic Plants of the World 1, DOI 10.1007/978-94-017-9810-5_2

In the wake of the Chiang Mai Declaration (1988), appropriate policies and legal frameworks, standards, etc. (GAP, GCP, GMP, Fair Trade, etc.) have been elaborated to safeguard the already frequently endangered natural resources of MAPs and to assist their the protection. These and also other guidelines (standards) are meant to contribute to the survival and sustainable utilization of medicinal and aromatic plant resources.

**Keywords** Medicinal and Aromatic plants • Botanical aspects • Systematics • Ecology • Active ingredients • Variability • Production ecology • Collection • Production • Utilization

## 1 Introduction: MAPs in the History of Botanical Sciences

The vast diversity of the plant kingdom, the approximately 40,000 plant species used for ethnomedicinal purposes, since the beginning of recorded history, have traditionally been collected and gathered from the wild (Trease and Evans 2002; Máthé 2011b). Similarly, the science of plants (scientia "amabile"), **Botany** takes its origin in prehistory, as herbalism with the efforts of early humans to identify – and later to cultivate – edible, medicinal and poisonous plants, has made Botany one of the oldest domains of science (Sumner 2000).

The link between humans and the different uses of plants constitutes the applied branches of botany (e.g. economic botany). Owing to their versatility, MAPs cannot be ranked into one category, but various classes of the economic-botanical system. In a most simple way, one can differentiate between **wild growing** (wild-crafted) and **cultivated** medicinal and aromatic plants. The latter category comprises species that have been domesticated or introduced into cultivation, from different climatic, geographic regions of the world.

**Pharmacobotany** or **Medical Botany** covers all pharmaceutical aspects of botany, including cytology, histology, morphology and taxonomy of plants species used in the pharmacological practice i.e. it deals with the botanical aspects of plants affecting man's health (Medicinal and Aromatic Plants).

## 2 Botanical Aspects of MAPs

The knowledge of MAPs begins with the description (Anatomy/Morphology) and classification (Systematics/Taxonomy) of plants, especially in view of their healing or simply other useful properties.

**Botany**, also called **plant science(s)** or **plant biology**, is the science of plant-life, a branch of biology. Even until the eighteenth century, botany was involved mainly with the description of plants and their classification. As a *quasi* contrast, the modern Science of Botany is dealing with plants in a broad, multidisciplinary way and is based on inputs from numerous other areas of science.

## *2.1 Plant Morphology*

With regards to their botanical characteristics, medicinal plants are both rather specialized, and also diverse. In a broad sense this is a science that is concerned with the structure of plants. It involves external **morphology**, i.e. external form, arrangement and relationships of the various organs and **anatomy**, i.e. the internal structure, including the finer details of tissues (histology), cells (cytology). Before Charles Darwin's theories on the principles of inheritance, morphological traits of plants formed an important basis for plant systems. Sometimes even therapeutic significance was attributed to the plant form (which manifested itself in the Doctrine of Signatures) Plant organs with a similar shape to certain human organs, were claimed to have an effect and could be used for curing these organs (e.g. the liver shaped *Hepatica* sp. for liver problems, lungwort (*Pulmonaria sp.)* for pulmonary infections, etc.) The role of plant form was overestimated before the emergence of Darwin's theories. Darwin's influence facilitated the development of the first phylogenetic systems that based on the principles of inheritance, in addition to morphological features, took into consideration the results of also other sciences (e.g. geology, genetics, physiology, chemistry, etc.) in plant classification.

The morphological implications of morphological structures in MAPs have, however, maintained their importance, since the active principles are synthesized and frequently also accumulated in specific plant cells, tissues and organs. E.g.: essential oils, in the species of the Family Lamiaceae, accumulate in glandular hairs of the epidermis, whereas the tropane alkaloids of *Atropa, Datura, Hyosciamus* (Solanaceae) are synthesized in the root system of the plants from where they are transported to the aerial part of the plants via the xylem (Mothes et al. 1985). (For the sake of completeness, it should be mentioned that alkaloids can be synthesized and occur also in other plant organs, e.g.: leaves and stems and berries – *Solanum* sp., capsules – *Papaver somniferum*, etc.).

The discipline of **Pharmacognosy**, relies greatly on the morpho-anatomic characteristics, i.e. on the diverse presence or absence of morphological traits, since it needs well identifiable morphological/structural proofs both to determine the identity of crude drugs, and to eliminate adulterations. Histological structures e.g. crystolithic cells, starch grains, polygonal crystalloids and secretory structures (glandular hairs, schizolysigenous cavities and passage, lactiferous vessels, etc) aided by histochemical methods and electron microscopy facilitate drug identification, even in the dried crude drugs.

It has been long established that the basic physiological site for the synthesis of secondary metabolites can be found in the plant cells. It has been also long ago recognized that the occurrence/synthesis/accumulation of various secondary metabolites is organ specific, i.e. they are localized in the specific cells/tissues of specific plant organs. In practice, the utilization of plant organs and tissues is based on this feature. Mostly those plant organs and tissues are utilized (harvested) that contain the desired secondary metabolites in the highest optimal quality and quantity.

Regarding the active principle contents and morpho-anatomical features of MAPs, there is also a great deal of variability (inhomogeneity). Variability might exist in the course of the plant growth cycle. From the juvenile to the adult stage, the metabolic processes are changing which frequently can be related to plant organs. This, in turn, might influence the synthesis (quantity and quality) and accumulation of active principles (**time and organ specific variability**). The morphological features of plants (e.g. density of glandular cells) might also vary according to stage of growth and development. Similar morphological differences can be observed under the influence of ecological factors.

Knowledge of the optimal accumulation of active principles is important from the view-point of MAPs utilization. Herbal medicines are therefore also studied in detail by Pharmacognosy (the study of medicines derived from natural sources).

## *2.2 Plant Physiology*

**Plant physiology** is a subdiscipline of botany concerned with the functioning or physiology of plants. It is an experimental science that observes the effects of variations in environment and in heredity on the life-processes and uses this information to explain and to control plant behaviour. The various intensity of the production of active principles is also an important link between MAPs and botany (Robbins et al. 1957).

### 2.2.1 Primary and Secondary Metabolism

In every plant cell there is a multitude of chemical reactions taking place at any single moment. The sum of chemical reactions and processes is called **metabolism. Primary metabolism** produces mainly carbohydrates, lipids, proteins and nucleic acids, as primary compounds out of which living organisms are made. **Secondary metabolism** produces a wide range of compounds that are not found in all species. They are used e.g.: for defense, specialized structures or reproduction (Graham et al. 2006). These processes generally use intermediaries from the primary metabolic pathway.

In MAPs it is mainly the secondary metabolites that are utilized. The synthesis and biological role of these chemical principles, as related to the products of the primary metabolism, are special. Frequently they are metabolic end products, with no relevant role in the metabolism (e.g.: essential oils excreted by glandular hairs). Some others are actively transported, even translocated throughout the plant (e.g. alkaloids) (Nowacki and Waller 1973).

Secondary metabolites are also frequently called **special principles** relating to their special role in the plant metabolism, as contrast to the universally occurring substances (Vágujfalvi 1992). Their occurrence within the plant is not ubiquitous: frequently these compounds are synthesized (accumulated) by special cells/tissues/organs and serve important ecological functions (defense, attractant, reproduction, etc.).

The utilization of MAPs is based on the fact that plants are capable of producing a multitude of biologically active principles with useful properties for man. When we ingest MAPs or herbal medicines, we are adapting the very same compounds which the plants use themselves (Daniel 2006). As an example, the plant antioxidants can be used by man for the same function of protecting from free radicals or oxidative damages related to aging.

Differences in the physiological activity of MAPs make them distinguishable from any other members of the plant kingdom (Tétényi 1987). In this respect, we distinguish the primary metabolism from the production of secondary metabolites. Whereas **primary metabolites** are chemical principles generally occurring in most plants, the **secondary metabolites** are the products of the special metabolism of valuable ingredients and should not be regarded as products of secondary importance, or final products of the metabolism.

The physiological basis of either synthesis or accumulation of active principles represents a speciality of the taxon. As the same constituents can be synthesized in different ways, the pathways of their synthesis are characteristic of any plant. A good example for this was published by Hegenauer (1986): different plant families can synthesize structurally similar naphtoquinones e.g.: plumbagin (Plantaginaceae, Droseraceae, Ebenaceae, Apocynaceae) and lawsone (Lythraceae, Balsaminaceae, or chimaphillin (Pyrolaceae).

It is a remarkable feature of medicinal plant physiology that under environmental pressure qualitative changes can take place in plants, i.e. plants have the ability to change their synthesis. This ontogenetically related phenomenon was first recorded by Nilov (1934) and Berry at al. (1937). Similar **ontogentic changes** in the metabolism of glycoside and terpenoid containing species were recorded also by Tétényi (1970).

Differences in morphological traits are frequently used by plant breeders, however, in MAP breeding their role is frequently insignificant or misleading. Examples for the failure in breeding include the case of large, ovate capsule opium poppy and high glycoside yielding *Digitalis lanata* (Tétényi 1978). In spice crops (like *Coriandrum sativum* used for direct consumption), however, morphological traits could be successfully used in breeding large fruited varieties.

## *2.3 Plant Systematics and Taxonomy*

Medicinal and Aromatic Plants belong to numerous plant families which, frequently, produce characteristic similar active ingredients (as a result of similarities in the biosynthetic pathways). Thus, e.g. the plant-family Labiateae (Lamiaceae) comprises a large number of essential oil containing species (lavender, thyme, rosemary, sage, etc.) whereas other plant families, like the Solanaceae are characterized by the occurrence of several alkaloid containing species (belladonna, thorn apple, tobacco, etc.).

In view of the diversity of MAPs, Bennett and Balick (2008) emphasize the importance of correct and reproducible experiments in medicinal plant research. In this regards they state that MAP research should begin with a vouchered plant sample that has been accurately identified. Vouchers should be deposited in recognized herbaria. Also according to them a "voucher is more important than a correct identification", since an erroneous scientific name can be rectified or amended to reflect new taxonomic circumscriptions.

### 2.3.1 Taxonomic Value of Secondary Metabolites

The basic taxonomic unit of MAPs remains the *species* (sp.), with the related species constituting a *genus*. The categories *subspecies* (subsp.), *variety* (var.) and *form* (f.) are used to differentiate among dissimilar populations of wild-growing species. In an econo-botanical sense, both natural and cultivated species are divided into well distinguished *infraspecific varieties* (Terpó 1992). Cultivars are differentiated according to their features valued by human societies.

A special feature of MAPs is that sometimes a number of characteristic chemical, cytological, morphological, and occasionally even ecological properties may be used for their correct description. In these cases the species represents either a homogenous taxon of plants with little variation from one specimen to another, or it may include various varieties or races with distinctive features. Often, such varieties represent single gene mutations and are morphologically recognizable. In other instances the mutation gives rise to a variant having a different secondary metabolite profile, which is not necessarily noticeable in the morphological form. These are termed **chemical races** or **chemodemes** (Tétényi 1970, 1987).

In certain instances, there are also other genetic variations that affect the chemical constituents of the species, e.g. the appearance of polyploids, the addition of one or a few chromosomes above the normal complement (extra chromosomal types, gross structural changes to the chromosome, biotechnologically produced genetically modified plants).

Chemical races have been detected in numerous species including various chemical substances. E.g.: cyanogenetic glycosides in *Prunus communis*, alkaloids in *Duboisia* species, cardiac glycosides in *Digitalis purpurea*, essential oils in *Ocimum* spp, *Melissa* spp., *Thymus* spp., etc. (Trease and Evans 2002).

**Phylogenetic systems** classify medicinal and aromatic plants according to their purported evolutionary relationships or heredity. Remarkably, even to date, these systems are to a large extent based on the former **artificial system** of Linneaus (Linneaeus 1758). More refined taxonomic systems take into consideration the morphological traits of plants and evaluate them according to the principles of evolution and inheritance (Ehrendorfer and Heywood 1968; Cronquist 1981; Takhtajan 1997; Tétényi 1992).

In the second half of the last century, more and more attention was paid to the use of plant-derived chemical information: this was the advent of **Chemo-taxonomy** or **Phytochemical plant systematics** (Hegnauer 1962–1986; Swain 1976). The characters used in chemical taxonomy need to be ubiquitous, i.e. of intermediate distribution in the plant kingdom. Remarkably, many of these compounds (e.g. essential amino acids or common sugars) are of little taxonomic interest. Some secondary metabolites (e.g.: alkaloids, isoprenoids, flavonoids, characteristic glycosides, etc.), however have been studied frequently (Trease and Evans 2002).

Reason for this is that many secondary metabolites have been suggested to have important ecological functions in plants (Bennett and Wallsgrove 1994) e.g.:

- protect plants against being eaten by herbivores and/or being infected by microbial pathogens.
- serve as attractants (smell, color, taste) for pollinators and seed-dispersing animals,
- function as agents of plant-plant competition and plant-microbe symbioses.

Secondary metabolites have maintained their importance in chemical defense against predators, pathogens, allelopatic agents and help also in pollination, dispersal, etc. To date, however, their importance in plant systematics, however, seems to have somewhat eased (Gershenzon and Mary 1983; Singh 2004).

This can be attributed to the recent advances in the scientific and technical development of plant analytics, making it possible to study the molecular biological aspects of plants. This trend has led to the quantitative study of molecular structure and events underlying biological processes. The evolving new scientific domain, **Molecular Biology** deals with diverse issues like the study of the gene structure, function, and the mechanism by which genes are replicated and transcribed to control the metabolism (e.g.: synthesis of enzymes and proteins, and ultimately also secondary metabolites).

Recent trends, to use cytological and molecular biological traits in botanical classification (in **Molecular Systematics**), have established themselves as efficient tools and are expected to bring about also some changes in the already established phylogenetic systems (Minelli 1993; Stace 1991).

Modern botany has become a broad, multidisciplinary subject with inputs from other areas of science and technology. Its research domains include the study of plant structure, growth and differentiation, reproduction, biochemistry and primary/secondary metabolism, chemical products, development, diseases, evolutionary relationships, systematics, and plant taxonomy.

## 3 Vegetation Science Versus the Sourcing of Botanicals

Wild growing medicinal plants belong to natural ecosystems. **Floristics** (vegetation science) and **Biogeography** are subdomains of botany that study the distribution and relationships of plant species, including MAPs, over geographic areas.

The primary raw material resource for MAP production is gathering (wild-crafting). Over ninety percent of the traditionally used MAPs in economically poor countries are traditionally gathered. The natural resources of MAPs are, however, limited. If the biological equilibrium of natural ecosystems is impaired by irrational exploitation, this action could have disastrous repercussions also on the other components of the ecosystem (Bojor 1991).

It is not possible to establish a small- or medium scale industry based on the natural wild flora without assessing the quality and quantity of raw materials available for exploitation and without taking into account the protection of the environment (Bojor 1991). Mapping the spontaneous medicinal plant flora may generate important information that facilitates decision making on how to locate the required small industrial units used for the extraction of active substances, the drying equipment, the postharvest conditioning and primary processing of plants (Schippmann et al. 2002; Lange 2004; Maltry et al. 1975; Schippmann and Lange 2007).

To date it is a known fact that unthoughtful utilization has already lead to the overexploitation of natural resources endangering the survival of an increasing number of species and valuable incomes, especially for rural households in developing countries.

## 4 Sustainable Management of MAP Resources "Save Plants That Save Lives"

The belated growth in international awareness about the declining supply capacity of the world's medicinal plants, the over-harvesting of natural resources, the destructive harvesting practices accompanied by habitat loss, forest degradation of habitats, etc. have brought about alarming problems to biodiversity.

The need for the sustainable use of natural resources was recognized by the Chiang Mai Declaration (1988) that had expressed alarm over the consequences in the loss of plant diversity (WHO 1991). The Declaration highlighted "the urgent need for international cooperation and coordination to establish programs for the conservation of medicinal plants to ensure that adequate quantities are available for future generations". It has also called for a need to coordinate conservation actions based on both *in situ* and *ex situ* strategies.

The subsequent decades have been marked by several declarations and sets of recommendations calling for the **Conservation** and **Sustainable use** of biodiversity including also medicinal plants. Among these, The Convention on Biological Diversity (CBD), an international, legally binding treaty reached at the Earth Summit, in Rio de Janeiro (1992), established the following main goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources (Diversity 1992; Cunningham 1993).

The CBD that came into force in 1993, secured rights to control access to genetic resources for the countries in which those resources are located. In view of the objective to enable lesser-developed countries better benefit from their resources and traditional knowledge, the CBD rules that bio-prospectors are required to obtain informed consent to access such resources, and must share any benefits with the biodiversity-rich country (Shankar amd Majumdar 1995).

## *4.1 Methods and Standards for Sustainability*

Several field-based methods have been developed for the sustainable harvest, assessment and monitoring of MAPs. Limiting the harvest to a sustainable level requires an effective management system including annual harvest quotas, seasonal or geographical restrictions and restriction of harvest to particular plant parts or size classes. In many cases harvesting techniques need to be improved, since collecting methods are often crude and wasteful, resulting in loss of quality and reduction in price (Iqbal 1993, 2002; Vantomme 2002). In addition, clarification of the access and user rights to the resources providing MAPs is part of the essential baseline information (FAO 1995; Leaman et al. 1997; Prescott-Allen and Prescott-Allen 1996; Schippmann 1997; WHO 2002; WHO/IUCN/WWF, 1993 revision in Kathe 2006).

In the followings we discuss only some of the major examples of international standards to be observed and followed:

### 4.1.1 International Standard on Sustainable Wild Collection of MAPs (ISSC-MAP)

ISSC-MAP's mission is to ensure the long term survival of medicinal and aromatic plant populations in their natural habitats, while respecting the traditions, cultures and livelihoods of all stakeholders if the process. Through its holistic approach, the ISSC-MAP is aimed at bridging the gap between the existing broad conservation guidelines and management plans for local conditions. It is meant to provide guidance for **sustainable wild collection** of MAPs and also a basis for audit and **certification** in wild collection (*incl. the* organic sector). Ultimately, the standard is expected to have several benefits: e.g. substantially contribute to the livelihood improvement of those involved in wildcrafting of MAPs, serve as **a** "communication tool" for the industry, serve as a guideline for MAP protection, harvest, and monitoring. For collectors, it can offer both insurance against resource and market failures, and for consumers, reliability of claims about ecological as well as social sustainability. Most importantly, at the level of species and habitats, it can contribute to maintaining biodiversity.

#### 4.1.2 Guidelines for Good Agricultural (and Collection) Practice of MAPs (GA(C)P

Good Agricultural and/or Collection Practices (e.g.: Máthé and Franz 1999; EUROPAM 2006) for medicinal plants are the first step in quality assurance, on which the **safety and efficacy** of herbal medicinal products directly depend (Máthé and Máthé 2008). Harvesters of wild plants must apply collection practices that address not only their need to gain economic benefits from the sale of wild-harvested plants, but also make sure that each of the collected species survives. In addition to preserving plant populations, harvest practices must also minimize damage to local habitats (Akerele 1992).

These practices are also expected to play an important role in the **protection of natural resources of medicinal plants** for sustainable use.

#### 4.1.3 FairWild/FairTrade

Initiated by the Swiss Import Promotion Organization (SIPPO), FairWild is a verification system that offers a comprehensive guidance framework and certification option for all sustainably collected wild plant, fungi and lichen species worldwide. FairWild Standard covers both ecological sustainability (based on the ISSC-MAP1) and aspects of fair trade as well as social sustainability.

The FairWild Standard is implemented either by the FairWild Foundation (2010) and/or its partners. Although specifically designed for wild collection situations, FairWild also includes the collection of plants, lichens or fungi or parts or products thereof on cultivated land, if the target species for collection are only a by-product and not the target of cultivation.

SIPPO supports small and medium-sized enterprises (SMEs) from emerging markets and markets in transition to access the Swiss and European markets.

Similarly Fair Trade (an organized social movement) aims at helping producers in mostly developing countries achieve better trading conditions and promote sustainability. With a special focus on commodities like medicinal and aromatic plants, or products which are typically exported from developing countries to developed countries. Fair Trade is an alternative approach to conventional trade based on a partnership between producers and traders, businesses and consumers. The international Fairtrade system – made up of Fairtrade International and its member organizations – represents the world's largest and most recognized fair trade system. Details on its structure, vision of activities, as well as the FairTrade Standards can be found at http://www.fairtrade.net/

## 5 Botanical Aspects of MAPs in Wild-Crafting

The production of high quality crude drugs with favorable contents (high amounts and favorable composition) of active substances has its scientific basis in the botanical sciences. Despite the huge diversity of both plant species and substances concerned, some general the aspects in the production process of botanicals are more or less similar. Among these, the main steps involved are the following: (expert) collection practices (see: Sects. 4 and 5) proper processing, drying, packaging and correct storage.

In the followings, our focus will be on wild crafting (wild harvesting), however, it is important to mention that several botanical aspects mentioned hereafter are valid for the harvesting of cultivated MAPs, too.

### *5.1 Knowledge of the Plant Habitats*

This form of expertise can facilitate the identification of species which are difficult to distinguish, e.g. *Tussilago farfara* and *Petasites hybridus*. It can also provide useful information on the environmental load of plants, i.e. on areas that should be avoided due to heavy metal contamination, pesticide/herbicide residues, etc. Gatherers of MAPs should also avoid to operate in areas under environment protection, where collection would be subject to special permissions.

### *5.2 Determination of Plant Parts to Be Collected*

Besides the knowledge of the plants *in se* – it is also essential to know which part of the plant and in which developmental state the drug can be collected. Typically, in the case of *Herba* drugs, where the flowering above-ground plant parts are collected, with the stems containing low amounts of active substances, the stem length and/or diameter is limited. Similarly the quality of flower drugs can be deteriorated by the higher rate of flower stalks, therefore these are also limited (e.g.: *Chamomillae flos*, *Sambuci flos*).

Likewise, in root drugs, the rate of stem parts should be taken into consideration (e.g.: *Valerianae radix*, *Primulae radix*). In the case of fruit drugs, the fruit color is often an indicator of ripeness and is therefore an important trait to be considered. E. g.: in two rose species *Rosa dumalis* and *R. rubiginosa*, color changes were characterized during ripening of rose fruits: a large increase in redness was observed for the first three harvest dates, whereas yellowness decreased during the whole study (rose hips became darker and less yellow). Changes in calculated hue (visible colour) were related to changes in total sugar content and other traits, therefore it was postulated that it is possible to use colour as an indicator of optimum harvesting time (Uggla et al. 2005). This type of knowledge and expertise is contained in the relative drug standards or pharmacopoeia, and gatherers of MAPs are to be educated and trained accordingly.

### 5.3 Determination of Harvesting Time

Medicinal plants are generally collected in the so called **technical stage of maturity**/ripeness. It has been found that in most cases this coincides with the maximum level of valuable active substances in the plant organs to be collected. Due to the large number of influencing factors the exact **determination of the harvesting time is a complex issue** that needs farther studies. This statement is especially valid for wild-growing MAPs.

In general, dry, sunny weather conditions are favorable for the wild crafting of MAPs. Due to seasonal changes in the metabolic processes of plants, and thus in the level of active substances, it has become common practice that underground organs (roots, rhizomes) are collected in the dormancy period, whereas barks (cortex) are gathered after the start of sap flow in spring. For similar reasons buds (gemmae) are collected after bud break, while for leaves this is done in a fully opened stage. The optimal time for the collection of flowers and inflorescences is usually in full anthesis (with the majority of flowers open) or in the case of *Herba* at the beginning of anthesis.

### 5.4 Determination of the Appropriate Method of Gathering

There seems to be a consensus that the wild-crafting of medicinal plants will remain the main source of raw materials for the industry (Leaman and Salvador 2005), Stakeholders of medicinal plant production and utilization should therefore find ways and means to limit incurring damages and losses. In this regard, the selection of appropriate collection methods/techniques has gained on importance. The **susceptibility** of species to over-collection can vary **according to their life forms and/or plant parts** used. Annual/biannual and even perennial species (e.g.: *Primula* sp., *Ginseng* sp., etc.) are highly susceptible to the wild-crafting of root-drugs, and their populations can be easily destroyed by the persistent indiscriminate practices. Ultimately, sustainable wild collection contributes both to the production of good quality drugs, and serves to maintain the ecological balance of plant communities.

As a rule of thumb it should be emphasized that valuable plant parts should always be dissected/collected at the biologically appropriate time, and in a circumspect way, so that any irrecoverable damage to plants can be avoided. In this respect sharp scissors or dissection knifes can be used. In the same way, overharvesting of plant species should by any means be avoided.

## 6 From Wild Plants to Cultivated Species Domestication and Introduction into Cultivation of MAPs

Medicinal plants have co-evolved with the ecosystems that form their natural habitats, therefore their transfer from natural habitats to a cultivated field is not merely a matter of transplanting. Changes in the growth environment of plants, such as those associated with a move from the natural ecosystem to the cultivated field, can produce substantial modifications in plant growth, development and active principle content, influencing the physical acceptance for cultivation and the chemical value of plant derived products (Bernáth and Hornok 1992; Bernáth and Németh 2008). Several researchers have attempted to develop definitive schemes for successful plant introduction.

Domestication and cultivation of a wild species requires manipulation of the eco-physiological factors to match the environmental requirements necessary for the plants to grow and reproduce; or the modification of the plant to meet the ecological conditions present in the field. The ecological goal of medicinal plant introduction is to minimize the differences between the wild and cultivated plant habitats that would detrimentally affect feasible production of economically important natural products.

### *6.1 Essential Tasks of Plant Domestication*

According to Thompson (1990) the methods of new crop development (domestication) depend on the following factors: if it is developed by domesticating a wild species (1), adapting an existing crop from another area (2), making genetic changes in an established crop so that a new commodity is produced (3).

The system of new crop R + D is principally composed of five steps, i.e.: collection, evaluation, enhancement, development, utilization of germplasm in cultivar development, which is intimately involved with agronomic/horticultural evaluation, and the development of appropriate cultural and management systems, activities associated with full scale commercialization.

Planting systems, pest control procedures and soil preparation techniques must be tested to develop field environments suitable for vigorous plant growth with high chemical yield. Plant selection and breeding may be used to alter the plant, to increase homogeneity and improve characteristics that will enable the plant to withstand stresses caused by cultivation conditions (Máthé 2010). A variety of stresses has recently been shown to influence the resistance of plants to herbivores, while draught could make some plants susceptible to insect attack.

Remarkably, although one would assume that introduction of a plant into a new habitat would detrimentally affect its growth and chemical yield, this is not necessarily always valid. E.g.: *Chamomilla recutita* (Eliašová et al. 2004), *Catharanthus roseus* (Jaleel et al. 2008) and *Dioscorea bulbifera* (Narula et al. 2005) have been reported to accumulate higher levels of secondary metabolites under stressed conditions.

### *6.2 Input of Modern Botanical Sciences*

In the process of domestication several botany related activities (tasks), like **bioprospecting, genetic resource/biodiversity assessment, conservation**, **management** have a basic, important role to play.

It seems that bringing medicinal plants into cultivation means both challenges and opportunities for plant biotechnology (Canter et al. 2005). The application of modern *in situ* and/or *ex-situ* technologies in the **germplasm preservation and improvemen**t of MAPs is already wide spread. Sophisticated *in vitro* propagation and breeding (selection) technologies (see: relevant chapter of this volume) aided by advanced phytochemical and molecular biology based analytical techniques can farther assist this progress.

These methods have a raison d'etre especially due to the high costs of the relevant chemical analyses making the breeding of MAPs rather costly. These and also further considerations have led to the elaboration of **new analytical methods** that are not only more cost effective but also have the advantage, that they can be used in the chains of quality assurance. The study of the metabolome can be regarded as such an important contribution, since one single **metabolome**, the sum of primary and secondary metabolites in a plant, contains about 4,000 compounds and it is also estimated that the total number of compounds present in the plant kingdom amounts to ca. 2,000,000 (Daniel 2006).

## 7 Scope of Heredity and Variability in MAPs

At different levels of evolution, the chemistry of living organisms, including medicinal and aromatic plants, is different. The rise of chemical taxa can be considered as the result of biochemical and metabolic processes mostly under genetic control. It is accepted that differentiation in cells is mostly manifested in **chemo-differentiation** at a molecular level and the fundamental differences in the course of ontogeny manifest themselves mainly in the differences of proteins present in the organism, i.e. ultimately in differences between the enzyme systems (Tétényi 1992). All other (morphological, anatomical) differences are only the consequences of these.

The secondary metabolites of MAPs, the end products of metabolic processes, if accumulated, can be directly observed by sensing (through color, taste, odor) and can be revealed by chemical analysis. Frequently, however, these chemical characters are hidden. Sometimes, they are accompanied by morphological divergence (e.g. cyanogenic glycosides in *Trifolium repens* and the presence or absence of a white spot on leaflets).

Differences in plant chemistry, i.e. in the special chemical features of MAPs, are attributed to **dissimilarities in the metabolism**. Since they are manifestations of the genetic background, they should be determined in a possibly most comprehensive way, when characterizing this special group of plants. This chemical fingerprint, i.e. the complexity of chemical traits, is called ***chemosyndrome***. It should be noted that the conclusions made on the basis of the chemosyndrome are not necessarily verifiable, since the accumulation of identical materials does not imply a relationship in chemism (e.g. the occurrence of the alkaloid bufotedine, in both the flowering plant *Piptadenia falcata* Benth. and toads) and it is also known that both rare (e.g. thebaine in certain *Papaver* species) and ubiquitous substances (e.g. chlorophyll) may also have homologous biosynthetic pathways. Therefore, their frequency of occurrence cannot be regarded as proof of relationship.

Recently, it is the metabolite fingerprint that is used with increasing popularity. **Metabolite profiling** may yield characteristic metabolic fingerprints that can be used to identify novel potential taxonomic markers, like it has been the case with *Glycyrrhiza glabra* (Farag et al. 2012).

It has also been found that chemical changes – e.g. infra-specific chemical modifications – can be caused by ecological and geographical conditions. These chemical differences are known as ***polychemism***. According to Tétényi polychemism is the materialized result of all chemical processes of the plant. It results from differences between the chemism and taxonomic units, i.e. chemotaxa can be established during chemical differentiation. Polychemism is known to be frequent in autogamous species (where a sudden chemical change can easily be inherited) and has been frequently described in cross-fertilized species, provided they are isolated (Baser et al. 1996).

In view of the abovementioned, investigators of MAPs are frequently faced with the question where are the limits of inherited or ecological factor triggered changes (This is frequently valid for the domestication process). Therefore, in the followings, we would like to briefly outline the major sources of ecology related variability.

## 8 Productivity of MAPs Under the Influence of Environment

Characteristically MAP productivity denotes the quantity of active principles synthesized or accumulated by the plant. It is composed of **biomass yield** and the ratio of **active principles accumulated within unit quantities of the biomass** (g, %).

There are several concepts to demonstrate these correlations (e.g. Máthé 1988; Bernáth and Hornok 1992). The scheme in Fig. 2.1 summarizes the interrelatedness among environmental factors and components of productivity according to Máthé (1994). In general, however, it should be noted that the variability of MAPs can be traced back to their genetic make-up, their geographic origin and the time of their study (as related to their phenophase and also in a diurnal way, during the day).

As a rule, plant growth and development of MAPs as well as the nature of secondary metabolites are affected by the **physical environment**, including light, temperature, rainfall, and soil properties. The impact of these has been studied by an increasing number of researchers growing various species under different climatic conditions, at different geographic locations and occasionally in a controlled environment (phytotron), which could form the basis of plant factories (Máthé 2014).

Variations have been also established according to the geographic origin of species (e.g. variations in the essential oil content of *Chamomilla recutita* on an

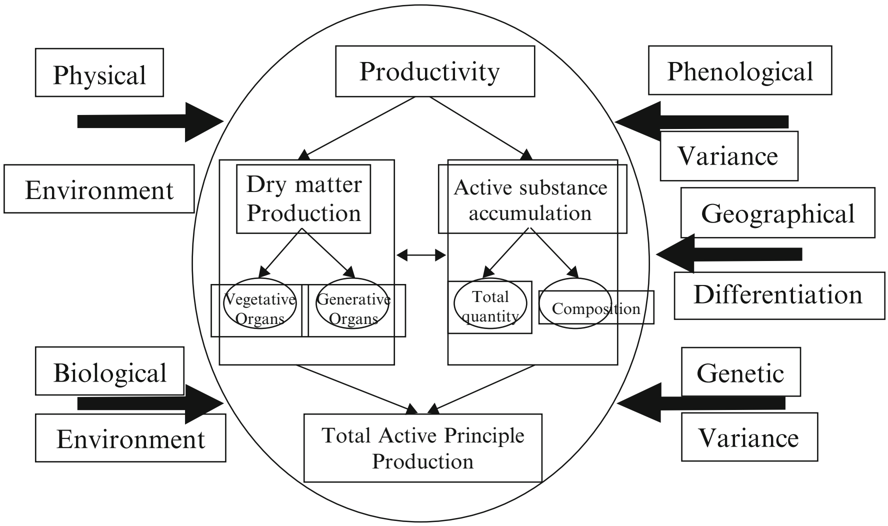


**Fig. 2.1** Major factors influencing biomass, yield and active substance production in medicinal and aromatic plants (Máthé 1994)

Hungarian as well as European scale Máthé 1962; Franz and Novak 2009; Massoud and Franz 1990), as related to differences in ecological factors.

It should also be noted that the synthesis, accumulation or translocation of secondary metabolites can undergo changes in the course of the **plant life cycle**. Consequently, their presence and/or optimal concentrations must be determined specifically. These aspects are taken into consideration when determining the harvest and collection dates of the relevant species.

In certain cases of **diurnal variations,** the changes in the amount and quality of active principles occur in the course of even one single day. Due to their character and rate, they can be relatively substantial. They are generally caused by the translocation of metabolites between various organs, occasionally even between above- and under-ground organs. To avoid false conclusions, the effect of these factors must be investigated in the course of breeding.

Breeders of MAPs use well established traditional and biotechnological methods of plant breeding. Selection breeding is generally important to retain fitness while inbreeding is used mostly in increasing uniformity. The latter is frequently accompanied by the deterioration of certain traits, e.g. vitality in *Digitalis* sp.

Selection assisted by genetic markers seems to be an extension of traditional crop breeding, mostly used with food crops. This is a means to recognize genotypes at an early stage, so that the speeding up of selection process becomes possible (Canter et al. 2005). It is also foreseen that the so called "**omics**" revolution will take its due place in MAP breeding, similarly to the spread of genetic manipulations systems (e.g. to produce active principles, and improve basic agronomic characters, or/and crops resistance to stress factors). Pathway engineering, i.e. regulating key enzymatic processes, like in the case of *Ocimum basilicum,* where by way of metabolic engineering it has been possible to enhance the levels of aroma and flavor compounds (Lewinsohn et al. 2001) is also promising.

## 9 Botanical Sciences and Quality Control in MAPs

Quality control has always been a focal issue in the production and utilization of medicinal and aromatic plants. Plant materials are used as home remedies, over-the-counter drug products (OTC) and raw materials for the pharmaceutical industry, and thus represent a substantial proportion of the global drug market (WHO 1998). The World Health Assembly – in resolutions WHA31.33 (1978), WHA40.33 (1987) and WHA42.43 (1989) – has emphasized the need to ensure the quality of medicinal plant products by using modern control techniques and applying suitable standards.

Quality control requirements and methods of quality control assurance are determined by various international, national and regional pharmacopoeia, where botanical sciences have an established basic role.

The last decades have seen a new upsurge in the improvement of the **traceability and safety of natural products**. The increasing reliability in the production/collection practices of these species has greatly contributed to the increasing acceptance of these commodities. Automated, specialized quality-control systems that can spot erroneous data that might obscure important biological effects are needed urgently.

The introduction of modern control techniques and the use of modern standards have already yielded success. Based on the already available modern sample preparation techniques, like Solid-Phase Micro-extraction (SPME), Supercritical Fluid Extraction (SFE), Pressurized –Liquid Extraction (PLE), Microwave Assisted Extraction (MAE) and Solvent Micro-Extraction (SME) etc., the study of the plant metabolome is already is gaining on popularity (Dunn and Ellis 2005; Huie 2002). Advances in plant genomics and metabolite profiling (Oksman-Caldentey and Inzé. 2004) also seem to offer unprecedented possibilities in exploring the extraordinary complexity of plant biochemical capacity. State-of the art genomics tools can be used to enhance the production of known target metabolites and/or to synthesize entire novel compounds in cultivated plant cells by the so-called combinatorial biochemistry.

The application of **rapid analytical methods** has several relevant advantages, among them the most important being rapidity, the ability to select high-quality single plants from populations, progenies (e.g.: crossing experiments), as well as industrial uses for quality checks and supervision.

## 10 Conclusions

Botany, the science of plants, is linked with medicinal and aromatic plants in many different ways. The ca. 40,000 plant species used for ethnomedicinal purposes, since the beginning of recorded history, have traditionally been collected and gathered from the wild. Botanical sciences (like plant systematics, morphology and physiology) have been assisting the study and utilization of MAPs in various ways.

The exact scientific study of medicinal plants should begin with the collection and correct identification of a voucher plant specimen. Formerly identification was done mainly on the basis of morphological characters. Later on, with the progress in scientific and technical development, the chemical traits assisted this process. Research trends provide new opportunities for revealing the reality of DNA and biosynthetic causes of chemo-differentiation, and most recently, the information supplied by the plant metabolome. The latest scientific achievements are opening up promising perspectives for the breeding of new, highly powerful chemo-cultivars of medicinal and aromatic taxa.

The inheritance and variability of important traits in medicinal plants are governed by the same rules as in other crops, though in the case of medicinal and aromatic plants the interrelatedness of these traits is more complex. Reason for this is that the immense variability of traits complemented by the ecological plasticity of plants that are not easy to distinguish from the inheritable characteristics, thus making MAP-breeding quite a challenge.

The efficiency of cultivation of these species is fundamentally dependent on the productivity of the plant material (biomass) within which the active principles are synthesized and frequently accumulated.

Floristics or Vegetation Science is a domain of botany that deals with plants in geographic dimensions. The knowledge and economic mapping of MAP resources is an important contribution to the sustainable utilization of these species.

In the wake of the Chiang Mai Declaration (1988), appropriate policies and legal frameworks to guide the protection, Fair Trade, and applications of medicinal and aromatic plant materials have been elaborated (GAP, GCP, GMP, etc.). These and also other guidelines (standards) mean substantial contribution to the survival and sustainable utilization of our medicinal and aromatic plant resources.

## References

Akerele O (1992) WHO guidelines for the assessment of herbal medicines. Fitoterapia LXIII (2):99–110

Baser KHC, Kirimer N, Ermin N, Kürkçüoglu M, Tümen G (1996) Essential oils from four chemotypes of Thymus zygioides Griseb. var. lycaonicus (Celak) Ronniger. J Essent Oil Res 8(6):615–618

Bennett BC, Balick MJ (2008) Phytomedicine 101: plant taxonomy for preclinical and clinical medicinal plant researchers. J Soc Integr Oncol 6(4):150

Bennett RN, Wallsgrove RM (1994) Secondary metabolites in plant defence mechanisms. New Phytol 127(4):617–633

Bernáth J, Hornok L (1992) Environmental factors. In: Hornok L (ed) Cultivation and processing of medicinal plants. Akadémiai Kiadó, Budapest, pp 56–68

Bernáth J, Németh É (eds) (2008) Gyógy- és fűszernövények gyűjtése, termesztése és felhasználása. (Collection, cultivation and use of medicinal and aromatic plants (in: Hungarian). Mezőgazda Kiadó, Budapest, p 256

Berry Ph et al (1937) J Chem Soc 1443

Bojor O (1991) Methodology of economic mapping of medicinal plants in the spontaneous flora. The medicinal plant industry. CRC Press, Boca Raton, pp 19–32

Canter PH, Thomas H, Ernst E (2005) Bringing medicinal plants into cultivation: opportunities and challenges for biotechnology. TRENDS Biotechnol 23(4):180–185

Cronquist A (1981) An integrated system of classification of flowering plants. Columbia Univ Press, Mew York

Cunningham AB (1993) African medicinal plants: setting priorities at the interface between conservation and primary health care. People and plants working paper 1. UNESCO, Paris, p 53

Daniel M (2006) Medicinal plants: chemistry and properties. IBH Publishing, Oxford

Dunn WB, Ellis DI (2005) Metabolomics: current analytical platforms and methodologies. TrAC Trends Anal Chem 24(4):285–294

Ehrendorfer F, Heywood VH (1968) Geographical and ecological aspects of infraspecific differentiation. In: Haywood VH (ed) Modern methods in plant taxonomy. Academic Press, New York, pp 261–296

Eliašová A, Repčák M, Pastirova A (2004) Quantitative changes of secondary metabolites of Matricaria chamomilla by abiotic stress. Z Naturforsch C 59:543–548

EUROPAM (The European Herb Growers Association): GAP/GWP – subcommittee Guidelines for Good Agricultural Practice (GAP) of medicinal and aromatic plants, Brussels, 3 Apr 2006. (EUROPAM GAP working copy no. 7.3)

Evans, WCh (ed) (2002) Trease and Evans Pharmacognosy, 15th edn. W.B. Saunders, Edinburgh. pp xiii + 585; ISBN 0-7020-2617-4; 59.95 GBP

FairTrade. http://www.fairtrade.net/

FAO (1995) Non-wood forest products for rural income and sustainable development. Rome (Non-wood forest products 7)

Farag MA, Porzel A, Wessjohann LA (2012) Comparative metabolite profiling and fingerprinting of medicinal licorice roots using a multiplex approach of GC–MS, LC–MS and 1D NMR techniques. Phytochemistry 76:60–72

Franz C, Novak J (2009) 3 Sources of essential oils. Handbook of essential oils: science, technology, and applications, 39

Gershenzon J, Mary TJ (1983) Secondary metabolites and the higher classification of angiosperms. Nord J Bot 3(1):5–34

Graham LE, Graham JM, Wilcox LW (2006) Plant biology. Pearson/Prentice Hall, Upper Saddle River, p 670

Hegenauer R (1986) Phytochemistry and plant taxonomy, an essay on the chemotaxonomy of higher plants. Phytochemistry 25(7):1519–1535

Hegnauer R (1962–1986) Chemotaxonomie der Pflanzen. Band 1-7. Birkhäuser Verlag, Basel/ Stuttgart

Huie CW (2002) A review of modern sample-preparation techniques for the extraction and analysis of medicinal plants. Anal Bioanal Chem 373(1–2):23–30

Jaleel CA, Sankar B, Murali PV, Gomathinayagam M, Lakshmanan GMA, Panneerselvam R (2008) Water deficit stress effects on reactive oxygen metabolism in *Catharanthus roseus* impacts on ajmalicine accumulation. Colloids Surf B Biointerfaces 62(1):105–111

Kathe W (2006) Revision of the 'Guidelines on the conservation of medicinal plants' by WHO, IUCN, WWF and TRAFFIC: process and scope. Frontis 17:109–120
Lange D (2004) Medicinal and aromatic plants: Trade, production, and management of botanical resources. Acta Hort (ISHS) 629:177–197
Leaman DJ, Salvador S (2005) International standard for sustainable wild collection of medicinal and aromatic plants (ISSC-MAP), draft 2. Steering group for the development of practice standards and performance criteria for the sustainable wild collection. http://www.floraweb.de/proxy/floraweb/map-pro/draft_2.pdf
Leaman DJ, Schippmann U, Glowka L (1997) Environmental protection concerns of prospecting and producing plant-based drugs. In: International symposium on herbal medicine. A holistic approach. Documents, proceedings and recommendations, pp 1–4
Lewinsohn E, Schalechet F, Wilkinson J, Matsui K, Tadmor Y, Nam KH, Pichersky E (2001) Enhanced levels of the aroma and flavor compound S-linalool by metabolic engineering of the terpenoid pathway in tomato fruits. Plant Physiol 127(3):1256–1265
Maltry W, Pötke E, Schneider B (1975) Landwirtschaftliche Trocknungstechnik, 2nd edn. VEB Verlag Technik, Berlin
Massoud H, Franz C (1990) Quantitative genetical aspects of Chamomilla recutita (L.) Rauschert. J Essent Oil Res 2(1):15–20
Máthé I (1962) A kamilla évjáratonkénti és tájankénti fejlődési és hatóanyagváltozásai. (Annual and geographical variations in the development and active principle content of chamomile.) Bot. Közlem 49(3–4):280–288
Máthé Á (1994) Utilization of biodiversity in horticultural crops. Scientific Theses. Degree Doctor of the Hungarian Academy of Sciences, Budapest
Máthé Á (2010) A new look at medicinal and aromatic plants. In: XXVIII International Horticultural Congress on science and horticulture for people (IHC2010): a new look at medicinal and 925, pp 13–20
Máthé I Jr (1988) Növények biológiai szkrínelése (Biological screening of plants) Összehasonlító vizsgálatok a növényi szekunder anyagcsere-termékek hasznosítási célú értékelésére. Doctor's Theses, Hungarian Academy of Sciences, Budapest
Máthé Á, Franz C (1999) Good agricultural practice and the quality of phytomedicines. J Herbs Spices Med Plants 6(3):101–113
Máthé Á, Máthé I (2008) Quality assurance of cultivated and gathered medicinal plants. Acta Horticult 765:67–76
Minelli A (1993) Biological systematics: the state of the art. Chapman & Hall, New York
Mothes K, Schütte HR, Luckner M (1985) Biochemistry of alkaloids. VEB Berlin 18(37):107
Narula A, Kumar S, Srivastava PS (2005) Abiotic metal stress enhances diosgenin yield in Dioscorea bulbifera L. cultures. Plant Cell Rep 24(4):250–254
Nilov VI (1934) Soc Plant 11:21
Nowacki EK, Waller GR (1973) Alkaloid transport in plants. Zeitschrift für Pflanzenphysiologie 69(3):228–241
Oksman-Caldentey KM, Inzé D (2004) Plant cell factories in the post-genomic era: new ways to produce designer secondary metabolites. Trends Plant Sci 9(9):433–440. doi:10.1016/j.tplants.2004.07.006
Prescott-Allen R, Prescott-Allen C (eds) (1996) Assessing the sustainability of uses of wild species: case studies and initial assessment procedure (vol 12). IUCN
Robbins WW, Weier TE, Stocking CR (1957) Botany; an introduction to plant science. Botany; an introduction to plant science, 2nd edn. Wiley, New York, p 578
Schippmann U (1997) Plant uses and species risk. From horticultural to medicinal plant trade, pp 161–165. In: Newton J (ed) Planta Europea. Proceedings of the first European conference on the conservation of wild plants. Hyeres, 2–8 Sept 1995, London, Plantlife
Schippmann U, Lange D (2007) Annotated bibliography on plant resource assessment methods for non-timber forest products with a focus on medicinal and aromatic plants. Floraweb.de,. (2014). Retrieved 13 Oct 2014, from http://www.floraweb.de/map-pro/Bib_Vilm.pdf

Schippmann U, Leaman DJ, Cunningham AB (2002) Impact of cultivation and gathering of medicinal plants on biodiversity: global trends and issues. In: FAO. 2002. Biodiversity and the ecosystem approach in agriculture, forestry and fisheries. 9th regular session of the commission on genetic resources for food and agriculture. Rome, 12–13 Oct 2002. Inter-Departmental Working Group on Biological Diversity for Food and Agriculture. Rome

Shankar D, Majumdar B (1995) Beyond the biodiversity convention: the challenges facing the biocultural heritage of India's medicinal plants. In: Bodeker G, Bhat KKS, Burley J, Vantomme P (eds) Medicinal plants for conservation and health care, FAO, Rome. Non-Wood Forest Products, vol 11. pp 87–99.

Singh G (2004) Plant systematics. An integrated approach. Science Publishers, Enfield-Plymouth

Stace CA (1991) Plant taxonomy and biosystematics. Cambridge University Press, Cambridge, UK, p 561

Sumner J (2000) The natural history of medicinal plants. Timber Press, New York

Swain PM (1976) Chemical plant taxonomy. Academic, London/New York

Takhtajan A (1997) Diversity and classification of flowering plants. Columbia Univ Press, New York

Terpó A (1992) Taxonomy of medicinal plants. In: Hornok L (ed) Cultivation and processing of medicinal plants. Akadémiai Kiadó, Budapest, pp 42–55

Tétényi P (1970) Infraspecific chemical taxa of medicinal plants. Akadémiai Kiadó, Budapest

Tétényi P (1987) Botany of medicinal plants. Acta Horticult 208:15–28

Tétényi P (1992) Heredity and variability of medicinal plants. In: Hornok L (ed) Cultivation and processing of medicinal plants. Akadémiai Kiadó, Budapest, pp 10–18

Thompson AE (1990) Breeding new industrial crops. In: Janick J, Simon JE (eds) Advances in new crops. Timber Press, Portland, pp 100–103

Uggla M, Gustavsson K-E, Olsson ME, Nybom H (2005) Changes in colour and sugar content in rose hips (*Rosa dumalis* L. and *R. rubiginosa* L.) during ripening. J Hortic Sci Biotechnol 80 (2):204–208

Vágujfalvi D (1992) Active substances in medicinal plants. In: Hornok L (ed) Cultivation and processing of medicinal plants. Akadémiai Kiadó, Budapest, pp 19–41

WHO/IUCN/WWF (1988) Saving lives by saving plants. The Chiang Mai Declaration 1988. In

WHO (1991) Guidelines for the assessment of herbal medicines

WHO (1998) General guidelines for methodologies on research and evaluation of traditional medicine. WHO/EDM/TRM/2000.1, Geneva, pp 128

WHO (2002) Traditional medicine strategy 2014–2023. http://apps.who.int/iris/bitstream/10665/92455/1/9789241506090_eng.pdf?ua=1

http://www.springer.com/978-94-017-9809-9

Medicinal and Aromatic Plants of the World
Scientific, Production, Commercial and Utilization Aspects
Máthé, A. (Ed.)
2015, VIII, 460 p., Hardcover
ISBN: 978-94-017-9809-9