Plants, as factories of natural substances and edible oils

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Abstract

Plant biodiversity is a source of natural substances produced in many forms and compositions. Under the influence of ecological factors, green plants, as factories, are capable of converting captured solar energy into a multiplicity of versatile organic substances and frequently specialized metabolites. We already exploit these as nutrients, edible oils, medicines, colors, scents and flavors.

Photosynthesis, as the basic "manufacturing process" of the primary metabolism takes place under varied conditions, indicating the tolerance and adaptability of plants. Products of the secondary metabolism have important ecological functions, like adaptive significance in protection, as attractants, repellents e.g.: for pollinators and pests, respectively. Allelochemicals can influence the competition among plant species.

Exploring the scientific basis of these processes starts with the study of general, scientific aspects of "plant factories". Botany, biochemistry, genetics, physiology and plant-breeding are the sciences that assist to improve crop productivity, quality. As a result of successful research, MAP production can be optimized to resemble industrial production.

Biotechnological production of natural products - an attractive alternative - has had only limited success. Recent advances in plant genomics and metabolite profiling seem to offer unprecedented possibilities.

Qualitative and quantitative analysis of all metabolites by new analytical techniques combined with powerful tools of functional genomics can be used to elucidate the biosynthetic pathways of natural products and to assist quality control of plant materials. As such they can efficiently contribute to the safety and efficacy of plant medicines.

INTRODUCTION

Most frequently, **medicinal plants** are defined as feral and/or cultivated plants that based on their traditions and literature records are directly or indirectly used for medical purposes.

Healing with plants dates back probably to the evolution of *Homo sapiens.* Nature has served as a source of medicinal agents for thousands of years. To date, *ca.* 80% of the world's population rely mainly on traditional medicines for their primary health care (Akerele, 1995), while medicinal plants continue to play an important role in the health care systems of the remaining 20%. Partly based on their use in traditional medicine, an impressive number of modern drugs have also been isolated from natural plant sources.

According to WHO, around 21,000 plant species have the potential for use as a medicinal plants. Remarkably, however, even today there is quite a significant number of plant derived drugs for which no synthetic one is available Table 1 lists major plant drugs of known structure, among which, remarkably, none is currently produced through synthetic means (Table 1). (Kumar et al., 1997.

Exploiting Natural Biodiversity

With regards to their botanical characteristics, medicinal plants are rather diverse. They belong to various plant families. Frequently, the plant families comprize characteristic and similar active ingredients (as a result of similarities in the biosystentitic routs of metabolism). As an example, the Family Labiateae (Lamiaceae) comprizes a large number of essential oil containing species (lavandula, 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.). Plant families with more than 100 species that contain pharmacologically active principles are comprised in Table 2.

THE PLANT FACTORY

Plant factory is a closed growing system which utilizes **energy flow and nutrient cycling in an optimal/efficient form** thus enabling a farmer (agrotechnician) to achieve a constant production of plants, herbs, vegetables, all year around (Wikipedia, 2014).

These facilities utilize artificial control of light, temperature, moisture, and carbon dioxide concentrations and have two main types: hydroponics and vertical farming.

Green plants are like factories that make natural substances, in a metaphoric sense. A factory takes raw materials and turns them into new products. In the plant factory anorganic nutrients dissolved in water are taken up by the green plant, and carbon dioxide absorbed from the ambient air. Plants use the light energy of the sun to synthesize raw materials to make their own food in the process of **photosynthesis**.

Plants use about ninety percent of the food they make to grow and reproduce, whereas about ten percent is stored in the plant's tissues.

Primary and secondary metabolism

In a simplified form, the compounds produced by plants are divided into two major groups: primary metabolites and secondary metabolites. The **primary metabolites** are produced in the basic metabolic process (primary metabolism), such as photosynthesis and respiration and are considered essential, functional, operating components of all living organisms.

Secondary metabolism

Secondary metabolites are mostly derived from the precursors produced by the primary metabolic processes. *They* have no generally recognized, direct roles in the processes of photosynthesis, respiration and other major metabolic processes of the plants. Secondary metabolites also differ from primary metabolites (amino acids, nucleotides, sugars, acyl lipids) in having a restricted distribution in the plant kingdom. (Taiz and Ziegler, 2006). With other words, particular secondary metabolites are often found in only one plant species or related group of species, whereas primary metabolites are often found throughout the plant kingdom.

Many secondary metabolites have been suggested to have important **ecological functions** in plants, 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.

Biomass vs. active principle production by plant factories

Under the controlled environmental conditions of plant factories it is expected that both biomass production, and within that the production of pharmacologically useful secondary metabolites take place in an optimal form. The Plant factory supervises and governs the factors (biotic and abiotic) normally controlled by the environment (Figure 1). As a result, it is expected that species with a lower competition ability (e.g. *Chamomilla recutita*) can be secured optimal conditions for growth and development (Figure 2).

Under the influence of environmental factors, biomass productivity is very much dependent on the size of leaf surface, the length of vegetation period, as well as the intensity of photosynthesis. In certain species the biomass losses caused by (photo)respiration can be relatively significant. Exceptions are the C4 and CAM species that are mostly species of the Families Euphorbiaceae and Poaceae, as well as Agaveacea, Euphorbiaceae and Liliaceae, respectively (Marchese et al., 2006).

In MAPs the biomass produced by plants (Net-photosynthesis) and within this the content of active principles can be located in various plant organs e.g. roots, stems, herba, leaves, flowers, fruits/berries that are ultimately utilized as crude drugs. As a specific feature of MAPs, their secondary metabolites are synthesized through frequently complex and branched biosynthetic pathways, so that even to date, a relatively modest number of ca. 200 000 naturally occurring secondary metabolites have been isolated and identified.

Are MAPs suitable to produce active principles, like real plant factories?

Examples of Natural substances of crude drug origin produced by plant factories of intact plants are rather few, as are also few the known MAPs species grown under controlled environmental conditions. The reason for this lies mainly in the low feasibility, i.e. limited extractable active principle production of these species per unit area vs. the relatively high production and extraction costs. **In principle, however, plant factories are capable of producing natural products**.

Plant factory like production is, however, popular and profitable with aromatic species (herbs and spices like basil, chives, dill - Anonyme, 2014). Hydroponically grown aromatic species, especially fresh cut herbs seem to be good examples for plant factories (although they are grown for their organoleptic properties and not for the extraction of their active principles).

According to De Kock et al. (2010) the main benefits of using hydroponics are: growing time is decreased by over fifty percent, the amount of nutrients and land used is decreased by over 75 percent, and the total water used is decreased by almost ninety percent. Advantages of Plant Factories over traditional farming and greenhouses also include that cultivation is allowed to go **three-dimensional**," i.e. Instead of being planted in the ground, crops are grown in trays in multilayer cultivation shelves, with artificial lights installed above and nutrient solutions supplied directly to their roots. **Resources** that fuel plant growth **can be utilized more efficiently**, e.g. condensed water is eventually captured in air conditioners and reused on plants," and finally the amount of **irrigation water required is only about 2 %** of that needed in open-field farming. Despite of these there are some obvious disadvantages, e.g.: higher initial equipment investment and higher energy costs, inadequately developed cultivation technologies. Furthermore, this technology is available for only a limited range of crops and most importantly the organoleptic qualities (active substances) of plants produced are inferior to those grown by the more traditional methods.

Future resources of natural substances

Plant secondary metabolism remains to be an important source of many fine chemicals such as drugs, dyes, flavors, and fragrances.

Presently, especially in view of the production of natural substances in plant factories (industry-like production), it is the plant cell culture systems that seem represent a potential renewable source for valuable medicinals, flavors, essences and colorants that cannot be produced by microbial cells or chemical syntheses. However, also in this respect, only a few cultures produce these compounds in commercially useful amounts (DiCosmo and Misawa, 1995). It is thus of interest to be able to engineer secondary metabolite production in plant cell factories, e.g. to produce more of a fine chemical, to produce less of a toxic compound, or even to make new compounds (Verporte et al., 2000).

Conclusions

The low productivities of natural substances in plant factories are associated with our poor understanding of the biochemistry of these systems. Plant breeding, i.e. the engineering of plant secondary metabolism is becoming increasingly important and feasible nowadays, though they require the knowledge of the biosynthetic pathways involved.

Recent advances in molecular biology, enzymology, physiology and fermentation technology of plant cell cultures seem to suggest that these systems could become viable sources of important natural products. **Exploring the scientific basis** of these processes starts with the study of general, scientific aspects of "plant factories". Botany, biochemistry, genetics, physiology and plant-breeding are the sciences that assist to improve crop productivity, quality.

Qualitative and quantitative analysis of all metabolites by new analytical techniques (Figure 1) combined with powerful tools of functional genomics can be used to elucidate the biosynthetic pathways of natural products and to assist quality control of plant materials (Oksman-Caldentey and Inzé, 2004). As such they can efficiently contribute to the safety and efficacy of plant medicines.

Ultimately, these researches are likely to create the basis for the understanding of the metabolism of intact MAP species that could be grown either in large scale field cultures or under controlled environmental conditions (in plant factories).

Presently, however, natural substances obtained from either wild-crafted plants or from plants grown in large-scale cultures remain to be the main resources. We must rely on our natural resources that should be exploited in a sustainable way (Schippman et al., 2006) and in harmony with relevant international standards: Good Agricultural and Collection Practice (World Health Organization. (2003), Fairwild (Meinshausen, 2006), Fairtrade (Krier,2005), etc. Domestication of MAPs, to serve as good quality, reliable raw material sources should be encouraged. Rural Industries Programs in Australia (http://www.rirdc.gov.au/) boosting the efficient production and utilization of essential oil crops can serve as good examples for plant industries (plant factories).

Literature cited

Akerele, O. (1995). Medicinal Plants and Protected Areas. *Expanding partnerships in conservation*, 75.

Anonymous, 2014. http://www.hydroponics-simplified.com/

Brian DeKock, Brenton Eelkema, Jacqueline Kirkman, Nathan Meyer, Brandon Vonk 2010. Hydro tower. Gardening solutions. 2010-2011 Team 02 Project Proposal and Feasibility Study. http://www.calvin.edu/academic/engineering/2010-11-team2/files/Team02_PPFS.pdf

DiCosmo, F., and Misawa, M. (1995). Plant cell and tissue culture: alternatives for metabolite production. *Biotechnology advances*, *13*(3), 425-453.

Jiaxiang, S. 1997. Introduction to the Chinese Materia Medica. In UNDP, 1997.

Franz, Ch. (2013): Domestication of wild medicinal plant species, a challenge and Chance for small scale farming. in: Medicinal Crops - Challenges and Prospectives for Sustainable Development, p. 19-28. I.A.S. Publishing Athens 2013

Jiaxiang, S. (1997). Introduction to the Chinese Materia Medica. UNDP.

Krier, J. M. (2005). Fair trade in Europe 2005: Facts and figures on fair trade in 25 European countries

Marchese, J. A., Ming, L. C., Ducatti, C., Broetto, F., Da Silva, E. T., & Leonardo, M. (2006). Carbon isotope composition as a tool to control the quality of herbs and medicinal plants. *Photosynthetica*, *44*(1), 155-159.

Meinshausen, F. (2006). FairWild Standards. Version 1. Zurich, Weinfelden and Munich, Swiss Import Promotion Programme (SIPPO), Forum Essenzia. Institute for Marketecology (IMO).

Oksman-Caldentey, K. M. and Inzé, D. (2004). Plant cell factories in the post-genomic era: new ways to produce designer secondary metabolites. *Trends in plant science*, *9*(9), 433-440.

Rural Industries Research and Development Corporation: http://www.rirdc.gov.au/

Schippmann, U. W. E., Leaman, D., & Cunningham, A. B. (2006). A comparison of cultivation and wild collection of medicinal and aromatic plants under sustainability aspects. *Frontis*, *17*, 75-95.

Taiz, L., and Zeiger, E. (2010). Plant physiology. *Sunderland, MA: Sinauer Associates*.

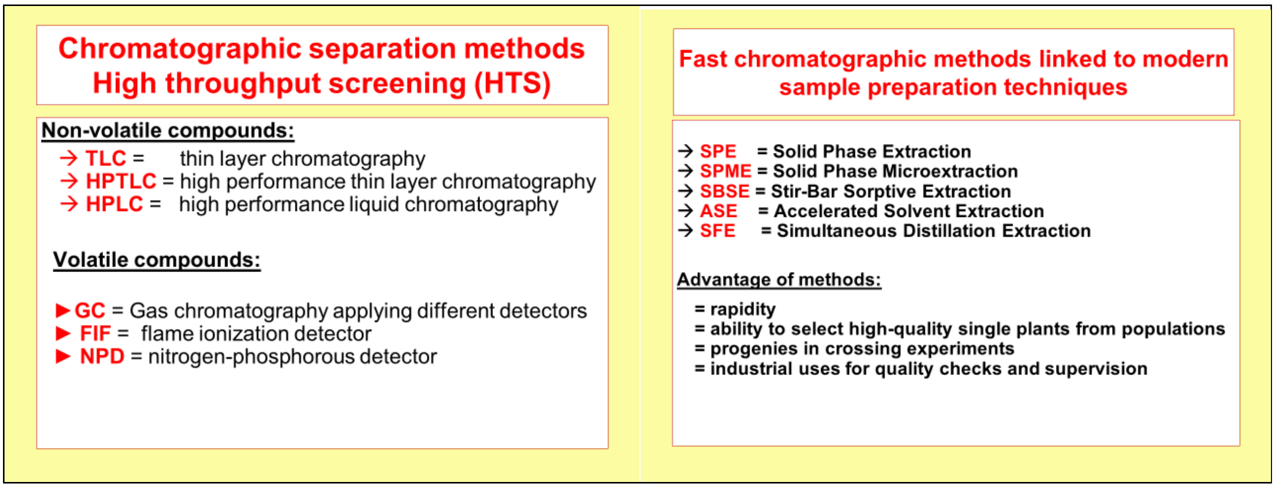
Verpoorte, R., van der Heijden, R., and Memelink, J. (2000). Engineering the plant cell factory for secondary metabolite production. *Transgenic research*, *9*(4-5), 323-343.

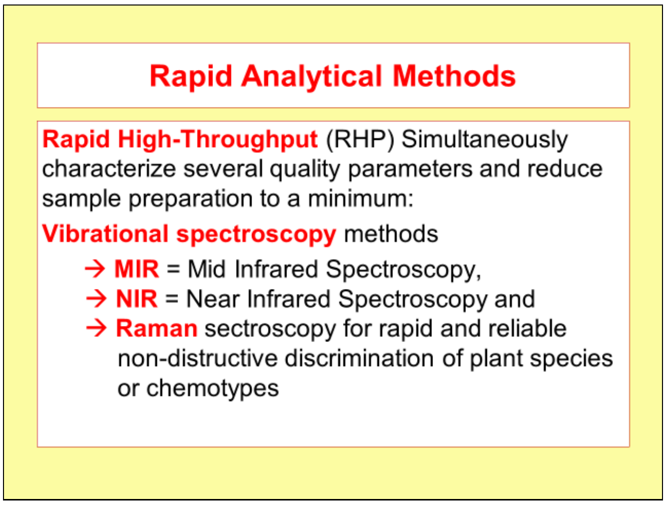
Wikipedia (2014). http://en.wikipedia.org/wiki/Plant_factory

World Health Organization. (2003). *WHO guidelines on good agricultural and collection practices (GACP) for medicinal plants*. Geneva: World Health Organization.

Figures

Figure 1 Some quantitative and qualitive analytical techniques used with MAPs





Tables

Table 1. Major plant drugs for which no synthetic one is currently available (Kumar et al, 1997).

Drug	**Plant species**	**Use**
Vinblastine	*Catharanthus roseus*	Anticancer
Vinblastine	*Catharanthus roseus*	Anticancer
Ajmalacine	*Catharanthus roseus*	Anticancer, hypotensive
Rescinnamine	*Rauvolfia serpentina*	Tranquilizer
Reserpine	*Rauvolfia serpentina*	Tranquilizer
Quinine	*Cinchona sp.*	Antimalarial, amoebic dysentery
Pilocarpine	*Pilocarpus jaborandi*	Antiglucoma
Cocaine	*Erythroxylum coca*	Topical anaesthetic
Morphine	*Papaver somniferum*	Painkiller
Codeine	*Papaver somniferum*	Anticough
Atropine	*Atropa belladonna*	Spasmolytic, cold
Atropine	*Hyoscyamus niger*	pasmolytic, cold
Cardiac glycosides	*Digitalis sp.*	For congestive heart failure
Artemisinin	*Artemesia annua*	Antimalarial,
Taxol	*Taxus baccata* *T. brevifolia,*	Breast and ovary cancer, antitumour
Berberine	*Berberis*	For leishmaniasis
Pristimerin	*Celastrus paniculata*	Antimalarial
Quassinoids	*Ailanthus*	Antiprotozoal
Plumbagin	*Plumbago indica*	Antibacterial, antifungal
Diospyrin	*Diospyros montana*	
Gossypol	*Gossypium sp.*	Antispermatogenic
Allicin	*Allium sativum*	Antifungal, amoebiasis
Ricin	*Ricinus communis*	Emetine
	Cephaelis ipecacuanha	Amoebiasis
Glycyrrhizin	*Glycyrrhizia glabra*	Antiulcer
Nimbidin	*Azadirachta indica*	Antiulcer
Catechin	*Acacia catechu*	Antiulcer
Sophoradin	*Sophora subprostrata*	Antiulcer
Magnolol	*Magnolia bark*	Peptic ulcer
Forskolin	*Coleus forskohlii*	Hypotensive, cardiotonic

Table 2 Plant families containing over 100 species with therapeutic value (Jiaxiang, 1997).

Family	Genera	Species
I. Monocots		
Liliaceae	45	165
Orchidaceae	45	135
II. Dicots		
Compositae	89	331
Leguminosae	91	313
Ranuculaceae	31	208
Laminaceae	46	189
Rosaceae	28	146
Umbelliferae	34	123
Rubiaceae	35	118
Euphorbiaceae	30	104
Asclepiadaceae	29	101

Table 3 Pros (+) and Cons (-) of large scale production (After: Franz, 2013)

Pros (+)

- Support nature protection (Convention on Biological Diversity)
- Quantities produced are easier to estimate / predict
- Quality (incl Adulterations) is easier to control

Cons (-)

- Costly investments are needed
- large cultivated acreages needed
- Reduce the income for wild-crafting livelihoods