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Review Article

Cultivation of Medicinal and Spice Plants in Germany – A Review

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Abstract

Medicinal and spice plants are a diverse group of crops cultivated mostly on small areas and in specialized farms. Successful production of these crops requires special knowledge about the plant properties, availability of adapted machines and suitable processing technology. The producers and traders have to meet high quality demands according to national or European law regulations. Further extensive investigations in plant breeding, agronomy and technology research are necessary to establish and develop the production of medicinal and spice plants in future. This review attempts to give an overview about the use and research of medicinal and spice plants in Germany with special regard to own experience and research. Information about the characteristics and cultivation of essential oil containing crops such as German chamomile, lemon balm, anise and oregano as well as about artichoke and glucosinolates containing crops such as garden cress are given.

Keywords: Medicinal plants; Spice plants; Cultivation; Secondary metabolites; Essential oil; Phenolic acids

Introduction

Plants used particularly for their medicinal or aromatic properties are defined as medicinal and aromatic plants (MAPs) in the EU (EUROPAM, 2010; Lubbe and Verpoorte, 2011). From these plants, specialty materials like essential oils, pharmaceuticals and herbal health products can be obtained (Lubbe and Verpoorte, 2011). Some plants defined as MAPs can also be used for the production of dyes, colorants, cosmetics and crop protection products. From a biological view, MAPs are a very large and diverse group of crops belonging to different groups (families) of taxonomic classification. The use of MAPs depends on the content and composition of their active compounds, particularly located in roots, stems, leaves, flowers or seeds. Most of these compounds can be characterized as so-called secondary metabolites, like terpenes, carotenoids, phenolic acids, flavonoids, coumarins, glucosinolates and alkaloids, which are naturally occuring in plants and acting as a protective mechanism against predators, pathogens and competitors. In addition, secondary metabolites may also serve as metal transporting agents in the plants, as agents of symbiosis between plants and microbes, nematodes, insects and higher animals, as sexual hormones, and as differentiation effectors (Demain and Fang, 2000).

Some of these compounds, like phenolic acids, flavonoids and diterpenes are known due to their potential benefits for human health. It was published that antioxidant and radical scavenging activities are the main properties of polyphenols as well as phenolic diterpenes and triterpenes (Jordán *et al*., 2012). Because of genetic and environmental influences on the synthesis of these metabolites, detailed investigations are necessary to understand how the quality of spice plants can be improved by breeding and by cultivation methods.

The most important medicinal and spice crops cultivated in Germany are essential oil producing plants like chamomile (*Matricaria chamomilla* L.), lemon balm (*Melissa officinalis* L.), peppermint (*Mentha x piperita* L.), common oregano (*Origanum vulgare* L.), and garden parsley (*Petroselinum crispum* L.) characterized by different active compounds and therapeutic uses (Table 1).

In addition, several other crops containing different active compounds are used as medicinal plants in Germany. Examples for some important crops cultivated for several years are: (1) flavonoids containing crops: buckwheat (*Fagopyrum esculentum*) and marine thistle (*Silybum marianum*), (2) naphthodianthrones and phloroglucinols containing plants: St. John's wort (*Hypericum perforatum*), (3) alkaloids containing plants: foxglove (*Digitalis lanata*, *Digitalis purpurea*), (4) mucilaginous plants: flax seed (*Linum usitatissimum*), (5) phenolic acids containing plants:

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artichoke (*Cynara cardunculus),* echinacea (*Echinacea* sp.) and common sage (*Salvia officinalis*) and (6) iridoid glucosides containing plants: gentian (*Gentiana lutea*), common wormwood (*Artemisia absinthium*) and valerian (*Valeriana officinalis*) (Figs. 2–12). However, also primary compounds like polysaccharides and lipids (unsaturated fatty acids), for example from evening primrose (*Oenothera biennis*) and borage (*Borago officinalis*), are used for therapeutic applications (Ghasemnezhad and Honermeier, 2007). Beside these crops, some new crops have been investigated and introduced in the last years, for example Chinese sage (red sage, *Salvia miltiorrhiza*), whose red-colored rhizomes and roots (containing diterpenes, called tanshinones) are used (Sung and Honermeier, 2012).

In this review functional properties and cultivation of medicinal plants used in Germany and investigated in our lab are discussed. The review will focus mostly on the situation in Germany under consideration of relevant results from other countries and research groups. The review provides the information needed by specialists and researchers about medicinal and spice plants in Germany.

German Chamomile

Two different plant species named as chamomile, namely Roman chamomile (*Anthemis nobilis* L.) and German chamomile (*Matricaria recutita* L.), are used worldwide as medicinal plants. Both plants, which are belonging to the Asteraceae family synthesize relevant amounts of essential oil in their flower heads. In Germany, only *Matricaria recutita* L., an indigenous plant in Europe, is cultivated on a comparably large growing area of about 1000 ha (Fig. 2B). German chamomile contains around 0.5 to 1.0% essential oil, characterized by a high percentage of the sesquiterpenes matricin and α-bisabolol accumulated in glandular trichomes of the flower (ESCOP, 2003). Within the active compounds, also monoterpenes (e.g., myrcene, geraniol), coumarins (e.g., herniarin, umbelliferone), flavonoids (e.g., apigenin, apigenin-7-glucoside) and *cis*- and *trans*-spiroethers can be found in chamomile flowers (McKay and Blumberg, 2000; ESCOP, 2003). Polysaccharides with high molecular weight composed of D-galacturonic acid, xylose, arabinose or rhamnose, are also involved in medicinal effects of chamomile products, particularly on stomach disorders (McKay and Blumberg, 2000; Kroll and Cordes, 2006).

In Europe, several diploid and tetraploid chamomile cultivars are available with different plant characteristics and quality parameters. The cultivars can be classified in different chemotypes: (I) high matricin content, (II) low matricin content, (III) high matricin and bisabolol content, (IV) high matricin and bisabolol oxide content (Franke and Hanning, 2012). The current chamomile breeding in Germany is focussed on improving the homogeneity of flower insertion and flower development, increasing the flower yield (size of flower heads, flower number per plant and flower head weight) as well as on increasing the content and yield of essential oil with high concentrations of matricin and α-bisabolol. Presently, an inter-disciplinary research project supported by the Federal Government is running to investigate the genetics of German chamomile and to establish hybrid breeding for improving the chamomile yields by the use of heterosis.

Two cultivation methods are used in chamomile: (I) sowing in autumn (September) with following overwintering in 6 to 8 leaf stage and harvest of chamomile (2 or 3 times) after the beginning of flowering in summer of the second year, (II) sowing in spring (from March to April) and harvest in July (Franke and Hanning, 2012). It seems that chamomile needs to be sown as early as possible in spring to ensure adequate growth as well as sufficient formation of side branches to get high number of flowers per plant (Mohammad *et al*., 2010). Yield and quality improvement of chamomile can be achieved by adapting the growing system such as sowing time, plant density, harvest time and technology to the local soil and climate conditions. Not only morphological characters and flower yields are affected by environmental conditions and growing system but also the essential oil and its qualitative profile could be modified by growing conditions. In field experiments with German chamomile carried out in Belgium, it was observed that the planting date had a more pronounced effect on growth, yield, essential oil content and main essential oil compounds as compared to the age of seedling at transplanting (Mohammad *et al*., 2010). It was concluded that the essential oil profile is genetically determined but the quantity depends on external factors. Further on it was found that chamazulene the main essential oil compound of German chamomile was relatively stable different under field conditions but oxygenated compounds (bisaboloids) were more influenced by delayed planting and ecological conditions (high temperature, long day period during flowering) (Mohammad *et al.*, 2010).

In several countries, chamomile flower heads are harvested manually by the use of small picking combs. In contrast to this in Germany, the harvest of chamomile flower heads is carried out by machine-based combs, combined with a rotating drum in special picking machines (Ehlert *et al*., 2011). Generally, some other picking principles like rotating virtual combs and cutting bars can be used. Due to the strong influence on picking quality and flower head losses in chamomile, the comb parameters have to be optimized. Extensive investigations about the harvest technology in chamomile were carried out in the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim in Germany in the last years (Ehlert *et al*., 2011). It was found that the picking quality of the test blades involved was partially influenced by the thickness of the blade, the shape of the gap between the teeth and substantially by the strength of the individual chamomile stalks (Ehlert *et al*., 2011).

Table 1: Selected number of important medicinal plants cultivated in Germany

Plant	Scientific name	Active compounds	Therapeutic use
German chamomile (Fig. 2B)	*Matricaria recutita* L. (Asteraceae)	Essential oil (matricin, bisabolol)	Inflammation of skin, spasmolytic effects
Lemon balm (Fig. 4A, B)	*Melissa officinalis* L. (Labiaceae)	Essential oil (geranial, neral, citronellal), phenolic acids	Antiviral activity, aromatherapy, relieving depression
Peppermint (Fig. 5A, B)	*Mentha x piperita* L. (Labiaceae)	Essential oil (menthol, menthone), phenolic acids	Common cold, irritable bowel syndrome
Common oregano (Fig. 7A, B)	*Origanum vulgare* L. (Labiaceae)	Essential oil (thymol, carvacrol), phenolic acids	Antimicrobial activity, antioxidant activity
Garden parsley (Fig. 10A)	*Petroselinum crispum* Mill. (Apiaceae)	Essential oil (myristicin, apiol, phellandrene), flavonoids, furanocoumarins	Antioxidant activity, anti-inflammatory
Garden valerian (Fig. 8A, B)	*Valeriana officinalis* L. (Valerianaceae)	Iridoid glycosides, valerianic acids	Sleep and anxiety disorders
St. John's wort (Fig. 3A, B)	*Hypericum perforatum* L. (Clusiaceae)	Hyperforins	Mild depression
Linseed (Common flax) (Fig. 6A, B)	*Linum usitatissimum* L. (Linaceae)	Seed oil (α-linolenic acid), lignans, arabinoxylans	Atherosclerosis, irritable bowel syndrome, constipation
Echinacea (Fig. 10B)	*Echinacea pallida, E. purpurea, E. angustifolia* (L.) Moench (Asteraceae)	Phenolic acids, polysaccharides, alkamids	Respiratory tract infection, regulation of immune system
Artichoke (Cardoon) (Fig. 9A, B)	*Cynara cardunculus* L. (Asteraceae)	Phenolic acids, flavonoids, sesquiterpene lactones	Dyspeptic disorders, hepatobiliary excretion
Grecian foxglove (Fig. 2A)	*Digitalis lanata* Ehrh. (Scrophulariaceae)	Steroidal glycosides (digitoxin)	Heart disorders, antiarrhythmic agent

Source: ESCOP (2003), Azizi *et al.* (2009), Krüger *et al.* (2011), Franke and Hanning (2012), Ali and Honermeier (2012)

Aniseed

Compared with Mediterranean regions, the climate conditions in Germany are not well suited for the production of essential oil containing plants. Nevertheless, some spice plants originated from subtropical regions are cultivated. An example for that is aniseed (*Pimpinella anisum* L.), cultivated as a grain (fruit) crop characterized by 2 to 6% essential oil accumulated in trichomes located in ribs and intercostal spaces of the seeds (Fig. 11A, B). In field experiments carried out in Germany, around 2.5 to 4.0% essential oil could be found (Ullah, 2012). The main compound of anise oil is the phenylpropene *trans*-anethole (content: 90 – 97%), inducing the typical flavour of the crop. Depending on the cultivar, additional 12 to 18 minor compounds including γ-himachalene (5 – 7%) and methylchavicol (estragole) (< 1%) could be detected by GC-MS. Due to the short growth cycle of anise crop and its flexible photoperiodic reaction, the anise plant seems to be well adapted to climate conditions of central Europe. Successful cultivation of anise plants in Central Europe requires sowing in April, a plant density of around 200 – 300 plants/m^2, depending on soil conditions low doses of nitrogen application (30 – 60 kg N ha^{-1}) and an effective weed control (Yan *et al.*, 2011). High grain yield losses can occur in anise plant stands caused by the fungal pathogens *Puccinia pimpinellae* (anise rust) and *Passalora malkoffi* (Passalora blight). In own field experiments (Fig. 11A, B), it was found that Passalora blight infection can be reduced clearly by the application of the fungicides Mancozep+Metalaxyl-M and Azoxystrobin+Difenoconazol (Ulla *et al*., 2013). This was consistent over two vegetation periods with different levels of the disease in each year. Furthermore, it was observed that fungicides can modify the essential oil content in anise seeds and its main compounds.

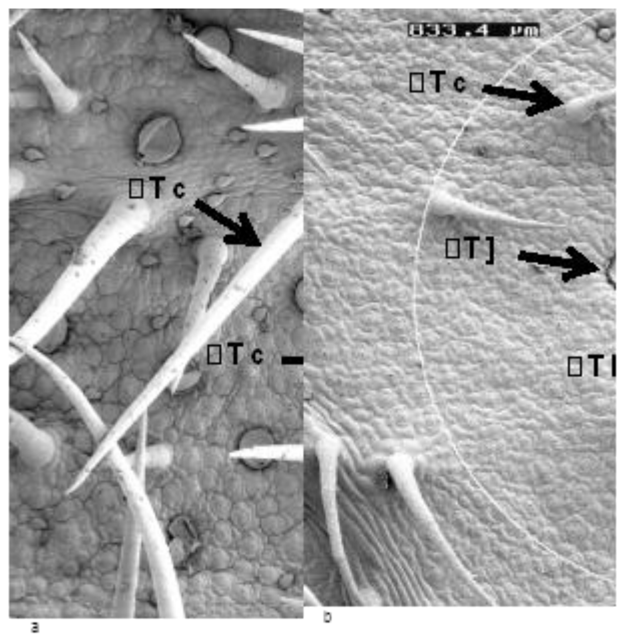

Fig. 1. Morphology and distribution of trichomes on the abaxial side of leaf surface of two oregano subspecies (SEM × 100), a) *Origanum vulgare* L. ssp. *viride* (Boiss.) Hayek, b) *Origanum vulgare* L. ssp. *vulgare*, NGT: non glandular trichomes, PGT: peltate glandular trichomes, CGT: capitate glandular trichomes (Photos: Marzieh Shafiee-Haijabad)

This was the case after the application of Fosetyl-Al, a systemic fungicide, which caused higher content of trans-anethole in the essential oil of anise fruits in both experimental years. It seems that this fungicide improved the host defense mechanism of the anise plants, which

Fig. 2: A: Foxglove (*Digitalis lanata* L.), B: German chamomile (*Matricaria recutita* L.) (Photos: Bernd Honermeier)

Fig. 3: St. John`s wort (*Hypericum perforatum* ssp. *perforatum* L.), A: Flowering stage, B: Early (left) and late (right) flowering cultivars (Photos: Bernd Honermeier)

Fig. 4: Lemon balm (*Melissa officinalis* L.), A: Juvenile plants on a field, B: Leaves at the end of stem elongation (Photos: Bernd Honermeier)

Fig. 5: Pepper mint (*Mentha* x *piperita* L.), A: Beginning of flowering, B: End of flowering (Photos: Bernd Honermeier)

could be the reason for a higher level of trans-anethole in anise fruits (Ullah *et al*., 2013). Disease infection caused by anise rust and Passalora blight is the most important factor limiting the fruit yields in anise cultivation in Germany. In contrast to disease control other cultivation practices such as sowing time, sowing rate (plant density),

Fig. 6: Linseed (*Linum usitatissimum* L.), A: Plant stand in a field trial, B: View on the flowers (Photos: Bernd Honermeier)

Fig. 7: Common oregano (*Origanum vulgare* ssp. *vulgare* L.), A: Variety with red flowers, B: Variety with white flowers (Photos: Bernd Honermeier)

Fig. 8: Valerian (*Valeriana officinalis* L.), A: Juvenile plants in leaf stage, B: Plants after stem elongation with inflorescences (Photos: Bernd Honermeier)

Fig. 9: Artichoke (*Cynara cardunculus* L.), A: Leaf rosette stage, B: Flower stage (Photos: Bernd Honermeier)

weed control, fertilization and harvest technology are well investigated and established (Ullah, 2012; Ullah and Honermeier, 2013). It can be concluded that anise can be successfully cultivated in Central Europe with fruit yields of around 0.5 to 1.0 t ha^{-1}, essential oil contents of around 2 to 4% and essential oil yields of around 20 kg ha^{-1}.

Oregano

In contrast to anise, some other essential oil containing plants like peppermint (*Mentha* x *piperita* L.), lemon balm (*Melissa officinalis* L.), common sage (*Salvia officicnalis* L.) and common oregano (*Origanum vulgare* L.) are well adapted and have been cultivated in Germany for many years. These crops are well investigated regarding their essential oil compounds, morphological traits, growing properties and genetic relations (Ietswaart, 1980). In investigations with oregano (*Origanum vulgare* L.) (Fig. 7A, B), it was found that this species can be classified in different groups of chemotypes. Beside the carvacrol type accessions (> 70% carvacrol) also accessions with thymol (> 65% thymol) as main component or with sabinene (> 50% sabinene) as well as combinations of different compounds in essential oil (germacren, caryophyllene, thymol and carvacrol) could be identified (Azizi *et al*., 2009). However, in sweet marjoram (*Origanum majorana* L.), the compounds *cis*-sabinene hydrate and thymol were detected as the main components followed by terpinen-4-ol (Soliman *et al*., 2009), whereas in *Origanum vulgare* ssp. *vulgare* (L.) the sesquiterpenes ß-bisabolene, germacrene D, spathulenol and ß-caryophyllene and the monoterpenes terpinen-4-ol, 1,8-cineol and α-terpineol were found (Dambolena *et al*., 2010). *Origanum vulgare* ssp. *vulgare* (L.) is the only *Origanum* subspecies studied which is rich in γ-terpinene (Dambolena *et al*., 2010). Two of the most important oregano plant species used as spices in many countries are Greek oregano (*O. vulgare* ssp. *hirtum* L.) and Turkish oregano (*O. onitis* L.). Both crops originate from Mediterranean region and are adapted to warmer climate conditions. Nevertheless, both species can be cultivated not only under warmer conditions, but also in a cool temperate climate (Grevsen *et al*., 2009). In field experiments with Greek oregano carried out in Denmark it was found that the content of volatile terpenes reached a relatively high level ranging from 3.7 to 4.9% (first year) and 2.6 to 4.6% (second year) (Grevsen *et al*., 2009). In the same experiments, the highest content of phenolic acids was found at an earlier stage (10 – 20% open flowers) in comparison with the highest content of flavonoids obtained later near full flowering stage (50 – 60%). It can be concluded from these investigations that also under cool temperate climate conditions the development stage of Greek oregano has a significant impact on the content of volatile terpenes as well as on flavonoids and phenolic acids.

Fig. 10: A: Garden parsley (*Petroselinum crispum* ssp. *crispum* L.), B: Echinacea (*Echinacea purpurea* L.) (Photos: Bernd Honermeier)

Fig. 11: Anise (*Pimpinella anisum* L.) A: Plant stand during ripening stage, B: Flowering stage (Photos: Bernd Honermeier)

Fig. 12: Garden cress (*Lepidium sativum* L.), A: Beginning of ripening stage, B: Disease infected plants (Photos: Bernd Honermeier)

Crops belonging to the family of Labiatae, like oregano, lemon balm, thyme and sage, are characterized by high contents of phenolic acids, mainly rosmarinic acid, caffeic acid and protocatechuic acid. These compounds have significant antioxidative activities (Chen and Ho, 1997). In investigations with common oregano (*O. vulgare* ssp. *vulgare* L.), we found in our group a high variability of rosmarinic acid contents in herbs (ranging from minimal 7 to maximal 40 mg g^{-1} DM, detected by HPLC method), influenced by the genotype (accession, cultivar, subspecies) and growing conditions (light impact) of the plants (Zeller, 2011).

The volatile compounds of oregano plants are accumulated in glandular trichomes which can be classified in two types: peltate and capitate glands. Both types differ in their morphological structure and in their time and mode of secretion (Fig. 1). The density and size of the glandular trichomes are genetically determined (by subspecies, genotype or cultivar) and can be modified by nitrogen nutrition, water deficiency and micro climate (light and air temperature) of the plant stand. It seems that the environmental conditions can affect the concentration of essential oil by influencing the number and size of glandular trichomes which are formed on the leaf surface (Bosabalidis and Kokkini, 1997; Caliskan *et al.*, 2010).

Beside climate and growing conditions also the cultivation methods may have strong effects on the plant growth of oregano. Two of the most important agronomical factors, which can influence the essential oil quantity and quality are water supply and nitrogen fertilization (Azizi *et al*., 2009; Ozkan *et al.,* 2009; Sotiropoulou and Karamanos, 2010). It was found that nitrogen application could effectively change the number of stems, branches and inflorescences per plant, leaf area index, dry matter yield as well as essential oil yield of *Origanum vulgare* ssp. *hirtum* (Sotiropoulou and Karamanos, 2010). In those experiments the optimum level of nitrogen supply was 80 kg N ha^{-1}.

Further investigations with oregano carried out in our group have shown that the responses of genotypes to nitrogen and water treatments were different. Nitrogen application increased fresh and dry matters of three genotypes in both harvests whereas it could decrease the content of essential oil (Azizi *et al*., 2009). Also, the oil content varied from 2.2 to 4.5% under different soil moisture regime. The highest oil content was recorded with irrigation at optimal ratio (during seedling development and stem elongation) in combination with late water deficiency in the beginning of blooming (folded flowers). These results confirm that short-term water stress affected essential oil biosynthesis in volatile-oil plants, but with different responses in various species. For example, in mints and sweet basil, it caused a greater oil gland density, and increased the essential oil content (Sangwan *et al*., 2001). The study on oregano indicated a positive effect of a short-term water stress and a neutral effect of long-term water stress on the essential oil content.

Oregano is characterized by high genetic, morphological and chemical diversity resulting in high variation of herb and essential oil yields as well as in different composition of volatile and phenolic compounds. For that reason genetic investigations and breeding programs must be established in oregano to get homogenous cultivars in future. The establishment of more effective plant selection and targeted breeding program requires sufficient knowledge particularly about floral and reproduction biology as well as about the biosynthesis of the relevant chemical compounds. On the basis of more homogenous varieties or cultivars further experiments should be carried out to investigate the influences of abiotic stress factors (water deficiency, heat, ozone, CO_2 enrichment) und different nutrient supply on herb yield and quality of oregano.

Lemon Balm

Similar to oregano, lemon balm (*Melissa officinalis* L.), known for its lemon-like fragrance, is an important medicinal plant from the same family (Labiatae). *Melissa officinalis* can be classified in three subspecies: (I) ssp. *officinalis* (diploid, 2n = 32 chromosomes, no or only few hairs on the leaf blades, typical lemon-like fragrance caused by citronellal, geranial and neral), (II) ssp. *altissima* (tetraploid, 2n = 64 chromosomes, dense hairy leaf surface, high content of sesquiterpenes like ß-caryophyllene and germacrene D), (III) ssp. *inodora* (diploid, 2n = 32 chromosomes, hairy stems, contains particularly sesquiterpenes in combination with low contents of monoterpenes) (Davis, 1982; Pignatti, 2002). The pharmaceutically relevant lemon balm is *Melissa officinalis* ssp. *officinalis*. Typical contents of essential oil, which is accumulated particularly in trichomes of the leaves, varied between 0.06 and 0.33% (Adzet *et al.,* 1992; Carnat *et al.,* 1998; Patora *et al.,* 2003; Mimica-Dukic *et al.,* 2004).

The lemony flavour of the plants (leaves) is due largely to the compounds citral (geranial and neral) and citronellal, whereas other compounds also synthesized in lemon balm contribute to rose-scent (geraniol) and lavender-scent (linalool). In contrast, the compounds ß-caryophyllene oxide and germacrene D induce fruity or herbal scent. For alternative medical practises, chemo-types with a high content of geranial, neral and citronellal are preferred. Beside the essential oil, lemon balm synthesizes also phenolic acids (rosmarinic acid, caffeoylquinic acids, caffeic acid, protocatechuic acid) and flavonoids (luteolin, luteolin-3'-glucuronide, further luteolin-glycosides and delphinidin-3-arabinosid) in its leaves (Patora and Klimek, 2002; Hossain *et al*., 2009; Krüger *et al*., 2010; Barros *et al*., 2013). Rosmarinic acid is the main phenolic compound synthesized in lemon balm. According to the European Pharmacopoeia, a rosmarinic acid content of at least 1.0% in the dried plant material is required (Ph. Eur. 7, 2012). Phenolic acids generally, but rosmarinic acid particularly, may provide antioxidant activity. Content and composition of phenolic acids in lemon balm leaves depends on cultivar (genotype), growing conditions and development stage of the plant. In investigations of Krüger *et al*. (2010) it was found that leaves achieved from the first growth cycle (first harvest) had higher contents of hydroxyl-cinnamic acid derivates in comparison with the second growth cycle (second harvest) per vegetation year. It is suggested that genetically, physiologically and environmentally determined variations of phytochemicals apply also to flavonoids, terpenes and other phytochemicals. Therefore it is of interest to better understand, which parameters influence the content of the quality determining constituents in this important medicinal plant.

Lemon balm is a perennial plant which can be harvested two times (in first year) to three times (in second or third year) per vegetation year (Fig. 4A, B). Regarding the stem growth in first vegetation year, lemon balm cultivars can be classified into erect, horizontal and intermediate types. In the second vegetation year, however, all cultivars form more or less erect stems with several side branches.

Due to its origin, lemon balm prefers warm growth conditions. Optimum growth temperatures have been described as 20-30°C (Bomme *et al.,* 2013). Especially for the germination, high temperatures are needed, which restricts the possibility of direct seed in springtime under the local conditions in Germany. Therefore, lemon balm is mostly sown under greenhouse conditions, with later planting of the plants to the field.

Due to the biomass production - with yields varying between 6-15 t ha^{-1} (first harvest), 9-20 t ha^{-1} (second harvest) and 4-10 t ha^{-1} (third harvest) under the climate conditions in Germany (Bomme *et al.,* 2002; Bomme *et al.,* 2013) - a sufficient supply with nutrients, especially nitrogen, as well as with water is necessary. Although lemon balm is generally a perennial and over-wintering crop under Central Europe conditions, strong winters can lead to a massive loss of plants. In our field experiments, strong differences in winter hardiness between the different cultivars could be observed. Currently, research is going on to breed cultivars with improved winter hardiness under temperate climate conditions as well as with increased content of essential oil and rosmarinic acid. Further investigations are carried out to establish a method for direct seeding in summer time, to improve the economic efficiency by avoiding the labor- and cost-intensive planting.

Artichoke

Artichoke (*Cynara cardunculus* L.), belonging to the Asteraceae family, is a traditional vegetable of south European countries (Moglia *et al.*, 2008), which grows well in semi-arid environments (Bianco, 2005). *Cynara cardunculus* is the most spread and cultivated species within the genus *Cynara*. Due to morphological properties, the botanical species *C. cardunculus* can be classified in three groups: (I) var. *sylvestris* (wild cardoon), (II) var. *altilis* (cultivated cardoon) and (III) var. *scolymus* (globe artichoke) (Gil Ortega, 2007). Phenolic acids are the main chemical compounds in the leaves of artichoke, which are used for choleretic-bile increasing (Pittler *et al.*, 2002), antioxidative (Jimeanez-Escrig *et al.*, 2003) and hepatoprotective effects (Adzet *et al.*, 1987). The artichoke leaves consist of around 2–4% DM phenolic acids (chlorogenic acid, cynarin, caffeic acid), and in addition up to 4% DM sesquiterpene lactones and up to 1% DM flavonoids.

In contrast to Mediterranean regions, in Germany the artichoke is cultivated annually with a growth cycle from April (planting) to October (last leaf harvest) attributed to the climate conditions (Fig. 9 A, B). Nevertheless, due to the re-growth ability of the leaves, the artichoke can be harvested three to six times within one growing period (one vegetation year). In field experiments with artichoke for leaf use, it was found that plant density, harvest time and harvest frequency of the leaves may influence the phenolic acid contents of the artichoke leaves. It was found that maximal leaf yields were observed in most cases with first (early) harvest from total three harvests within one growth period of the artichoke plant (Honermeier and Goettmann, 2010). The concentration of caffeoylquinic acids and flavonoids in the leaves was significantly influenced by the harvest time resulting in higher concentrations of around 2-3% DM caffeoylquinic acids in early (June, July) harvested leaves in comparison with lower than 1% DM caffeoylquinic acids in later (September, October) harvested leaves.

The reasons for these relationships can be found in changes of developmental stages and in modifications of the leaf morphology (portion of leaf blades and leaf veins within the leaf) of artichoke plants (Ali and Honermeier, 2011). Harvest at earlier time of leaf development lead to comparatively larger leaf blades containing higher contents of phenolic acids and smaller veins containing lower contents of phenolic compounds leading to more phenolic compounds in the whole leaf.

In addition, abiotic stress like water deficiency and herbicide stress can contribute to the reduction of phenolic acids contents in the artichoke leaves. A field study conducted for the evaluation of the abiotic stress imposed by herbicides reported that the post emergence herbicides used imposed stress on the non-target crop, i.e. artichoke (Ali and Honermeier, 2008). This stress was measured in terms of chlorophyll fluorescence and electron transport rate under direct sunlight and dark adapted conditions on one hand and by the analysis of polyphenols on the other. This temporary stress imposed by the herbicides was recovered perhaps by the development of new leaves and decomposition of the chemicals in a period of around two weeks. The intensity of the stress varied with the prevailing environmental conditions.

The international agronomy research of artichoke is focussed particularly on globe artichoke (cardoon) which is cultivated as a bi-annual crop with over wintering growth cycle used as vegetable (esp. immature flower heads). There are many research activities on the fields of breeding, crop physiology, propagation, cultivation and product quality of that vegetable crop (Bianco, 2005; Gil Ortega, 2007; Moglia *et al*., 2008). An overview about the state of the art in artichoke cultivation, especially for the production of immature flower heads, was given on the 6th international symposium on artichoke, cardoon and their wild relatives held in Spain 2006. In contrast to this only few publications are available about artichoke used as a medicinal (leaf) plant. Therefore, there is a need to evaluate the agronomic behaviour of artichoke cultivars used as leaf or medicinal plant under different site conditions in future. Furthermore better understandig of the accumulation and remobilization of assimilates, phenolic acids and flavonoids within the artichoke plant and during the vegetation period of the artichoke is needed.

Glucosinolates Containing Plants

Further secondary compounds to be found in some vegetables as well as in medicinal and spice plants are glucosinolates (thioglucosides), known as sulphur-containing glycosides, present particularly in plants of the Brassicaceae (Asteraceae) family. Besides Brassicaceae, glucosinolates also occur in plants of Capparaceae, Moringaceae, Resedaceae, and Tovariaceae (Fenwick *et al*., 1983). After cell disruption during processing, chewing and digestion, these compounds are hydrolyzed by an endogenous enzyme called myrosinase (ß-thioglucosidase) which is located within the vacuoles of the plant matrix. Enzymic hydrolysis results in the products ß-D-glucose and an unstable aglycone intermediate (thiohydroxamate-o-sulfonate), converted to different breakdown products for example isothiocyanates, thiocyanates, nitriles or epithionitriles (Botti *et al.*, 1995). These products of enzymic hydrolysis are responsible for the distinctive flavour and aroma characteristics of vegetables and spices belonging to the Brassicaceae family (Mithen, 2001). There is evidence that breakdown products of glucosinolates hydrolysis may prevent and control diseases of the gastro-intestinal tracts, including cancer and inflammation (Mithen, 2001).

Most of the glucosinolates containing crops cultivated world-wide and also in Germany are vegetables like cabbage species (*Brassica oleracea* L.) including several subspecies and variations, turnip rape (*Brassica rapa* L.), radish (*Raphanus sativus* L.), arugula (salad rocket, *Eruca sativa* L.) or garden cress (*Lepidium sativum* L.). Garden cress is an example of a vegetable and spice plant from which the sprouts are consumed. The main breakdown product of glucosinolates in garden cress is the compound benzyl-isothiocyanate (glucotropaeolin) (Gil and Mc Leod, 1980). Several physiological effects of garden cress, like diuretic, aperient and hypoglycemic properties, could be found (Sharma and Agarwal, 2011).

A requirement for the production of garden cress sprouts used as a spice is the propagation of seeds, produced mainly in organic farming. Garden cress used for seed propagation is cultivated annually with sowing in April and seed harvest in August. Soft to medium heavy soil is appropriate for the growth of the plant. Depending on soil conditions, around 200-300 seeds per m^2 resulting in plant densities of 150-250 plants per m^2 are needed.

During the cultivation of garden cress, high plant damages and yield losses caused by fungal diseases could be observed in Germany over the last years. The pathogens frequently detected in garden cress plants under field conditions are downy mildew (*Hyaloperonospora parasitica*, *Perofascia lepidii*) and white rust (*Albugo lepidii*). The diseases, particularly downy mildew, can cause a complete failure of the harvest. It can be suggested that *Hyaloperonospora parasitica* persists as oospores in the soil over several years. In addition, we assume that *H. parasitica* is a seed-transmitted pathogen. For that reason, it is important to identify the hosts for downy mildew of garden cress and to consider the crop rotation management to avoid disease infestations. The control of downy mildew is difficult and includes probably both cultivation methods (crop rotation, suitable preceding crop, soil tillage, right sowing time, weeding of wild host plants) and treatments of the seeds (before sowing) and plants (during growth cycle) of garden cress. Possible seed treatments accepted under organic farming are water steam and electron beam application. However, until now only few is known about the development cycle of downy mildew (*Hyaloperonospora parasitica*, *Perofascia lepidii*) in garden cress. Therefore future investigations about possible wild host plants of that fungus are necessary.

Conclusion

Essential oil containing plants are the largest group of medicinal and aromatic plants (MAPs) used worldwide as well as cultivated in Germany. It seems that the demand for natural ingredients, particularly essential oils used for cosmetics and alternative medicine, is increasing. In spite of comparably wet and cool climate conditions, high productivity can be achieved with well adapted aromatic plants (e.g., chamomile and peppermint) in Central Europe. The constituents of most of the plants used for medical therapy are characterized by small concentrations and by a wide range of different compounds. Furthermore, medicinal plants are characterized by genetic and phenotypic variability as well as variability of the quality and instability of the extracts. These problems can be solved by domestic cultivation, which offers the opportunity to maximize yields and achieve uniform, high quality products. Domestic cultivation requires the breeding of cultivars by using conventional or biotechnological plant-breeding methods. For that reason it can be expected that the breeding activities of state and private organizations will increase in future.

The knowledge about the biological activity of secondary metabolites has increased over the last years, but in many cases the metabolism of these compounds in the human body is further on unclear and must be investigated in future. Because many secondary metabolites (e.g. phenolic acids, flavonoids, terpenes) are occuring also in plant foods this kind of research has generally an immense importance.

Successful production of MAPs has to consider the quality demands of the industry and of the national and European law regulations. In Europe, traceability and strict documentation are becoming more important. For that reason, only those MAPs products are accepted by the trade or by the industry which are produced according to the GAP (Good Agriculture Practice) and GMP (Good Manufacturing Practice) guidelines. To realize these demands, crop adapted growing systems must be developed for each medicinal and spice plant under the consideration of the local climate and soil conditions. These future activities include not only the development of optimized methods for crop rotations, planting, seeding, weed control, nutrient supply, disease and pest control as well as harvest technology, but also investigations to optimize the processing technology and storage conditions of MAPs. Suitable agrononomic investigations require basic physiological and biochemical knowledge about growing conditions on the one hand and the synthesis and expression of secondary metabolites (active compounds) in the plant on the other hand. On the field of medicinal plant and spice crop production (esp. fresh or dried herbs, leaves and seeds), there is an increasing trend for organic farming products in Germany. For that reason, alternativ (non-chemical) methods for the production of spice crops must be developed.

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