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DOES MINERAL FERTILIZATION MODIFY ESSENTIAL OIL CONTENT AND CHEMICAL COMPOSITION IN MEDICINAL PLANTS?

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Abstract. Essential oils are the main active components of many essential oil raw materials. This is the most numerous group of medicinal raw materials, which has a big tradition and still a wide application in therapeutics. Oil raw materials are obtained from natural stands and from crops. Cultivation method, fertilization, irrigation, date of harvest of plant material can significantly modify both the content and composition of essential oil. Nutrients applied in the form of mineral and organic fertilization are supplied to plants by root and foliar application. Foliar nitrogen application increases essential oil content in some plants and affects essential oil composition. Moreover, essential oil content and yield are modified by the rate of applied nitrogen. Higher nitrogen application increases methyl chavicol concentration and decreases the percentage of linalool in the volatile oil of some aromatic plant species. In the cultivation of some aromatic plants, a higher amount of potassium contributes to an increase in essential oil content and in the percentage of 1,8-cineole, linalool, eugenol, and γ-cadinene in the oil. Other nutrients available in the nutritional environment of plants are also capable of changing essential oil yield and composition. Likewise biofertilization, balanced mineral fertilization of aromatic plants is an important cultivation factor determining essential oil quantity and quality.

Key words: volatiles, biological activity, NPK form and dose, microelements

INTRODUCTION

Essential oils are synthesized by various plant species characteristic of temperate, Mediterranean, and tropical climate zones. 18 000 plant species that synthesize essential oils are known and they are described as essential oil-producing plants. Global annual production of volatile substances by plants, mainly terpenoids, is ca. $1.4 \cdot 10^9$ tonnes [Kopcewicz and Lewak 2002]. Among the oils that are mentioned, about 300 are important for industry, since they are used in therapeutics and also as natural food flavourings

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and cosmetic essences. Essential oils, likewise other secondary biologically active substances, are characteristic only for some smaller or larger systematic groups of plants: families, genera, and even species. The following can be included in the most know essential oil-producing groups: Pinaceae (genera: *Pinus, Abies, Picea, Larix*), Cupressaceae (genus *Juniperus*), Piperaceae, Lauraceae (genera: *Laurus*, *Cinnamomum*), Apiaceae (genera: *Carum, Pimpinella, Foeniculum, Coriandrum, Anethum, Angelica, Levisticum*), Myrtaceae (genera: *Eucalyptus, Eugenia*), Lamiaceae (genera: *Mentha, Salvia, Thymus, Rosmarinus, Ocimum, Lavandula, Origanum, Melissa, Hyssopus, Satureja*), Rutaceae (genera: *Citrus, Ruta*), Asteraceae (genera: *Artemisia, Matricaria, Anthemis, Tanacetum, Arnica, Achillea*), Zingiberaceae (genera: *Zingiber, Alpinia, Curcuma, Elettaria*), Araceae (genus: *Acorus*), Poaceae (genus: *Cymbopogon*).

Physico-chemical characteristics and biological activity of essential oils. Volatile oils are mixtures of volatile substances of different nature. The general features of these oils are as follows: solid consistency, lipophilicity, optical activity, and a unique smell. This last feature is of great importance in selecting the oil for the composition of perfumes and eau de toilettes as well as for pharmaceutical preparations or food agents. However, the activity of the compounds contained in the volatile aromatic mixture called the essential oil has the greatest importance. Essential oils are multi-component mixtures of monoterpene, sesquiterpene, diterpene compounds and phenylpropane derivatives. In the composition of different essential oils, more than 1500 compounds have been identified, such as hydrocarbons, alcohols, aldehydes, ketones, and esters; sulphur and nitrogen substances, acetylene derivatives, coumarins and organic acids are also encountered [Alizadeh et al. 2010, Baj et al. 2010, Tajuddin and Yusoff 2010, Nurzyńska-Wierdak 2012]. Essential oils are products of the exogenous or endogenous secretory tissue. Oil formation is preceded by intense changes in the secretory cell (autoploidization). Oil synthesis occurs mainly in very young cells [Ganjewala and Luthra 2007]. After the period of intense changes in the secretory cell, there is a gradual disappearance of its activity, and even its complete death. On the other hand, however, sucrose metabolism in the tissues of palmarosa flowers has been shown to be linked to essential oil biosynthesis [Dubey et al. 2003], which suggests the complexity of some control mechanisms in essential oil biosynthesis. In chemical terms, natural oils are very diverse chemical compounds, hence their synthesis in the plant probably occurs along different pathways. There are two hypotheses about the formation of these compounds: one links the process of formation of terpenes to the transformation of carbohydrates and makes it dependent on this transformation, while the other one links it to the transformation of proteins [Dubey et al. 2003, Lattoo et al. 2006].

Essential oils are the main active components of many pharmacognostic materials termed essential oil raw material. This is the most numerous group of medicinal raw materials that have a big tradition and still a wide application in therapeutics. Essential oils extracted from the raw material (through steam distillation) are also pharmacopoeial articles used in therapeutics. Different types of pharmacological properties are observed among essential oils, depending on the nature of their main constituents [Sahin et al. 2004, de Sousa et al. 2004, Chung et al. 2010]. In general, essential oils have an irritating effect on the skin and mucous membranes; besides, as generally aromatic products, they improve the taste and smell of many drugs. Among the main types of biological activity of essential oils, one should stress their antimicrobial properties which are important in therapeutics [Bozin et al. 2006, Zhang et al. 2009], plant protection [Oka et al. 2000, Calmasur et al. 2006], and food technology [Nour et al. 2009, Piyo et al. 2009, Budka and Khan 2010, Meftahizade et al. 2010, Rattanachaikunsopon and Phumkhachorn 2010]. Moreover, the antioxidant activity of some essential oils is extremely valuable [Bozin et al. 2006, Baj et al. 2010, Meftahizade et al. 2010, Hussain et al. 2011], since it is important for pharmaceutical, cosmetic, and food production.

Quantitative and qualitative variation of the essential oil. Plants synthesizing essential oils are grown as medicinal, spice, aromatic, and cosmetic plants. Growing conditions, which sometimes largely determine raw material yield, also determine raw material quality. Cultivation method, fertilization, irrigation, and date of harvest of plant material can significantly modify both the content and composition of essential oil. Essential oil biosynthesis, likewise other processes taking place in the plant, is dependent on a number of factors, among others, the presence of different input substances and enzymes, depending on the metabolic pathway in which a given group of compounds is formed [Dubey et al. 2003, Ganjewala and Luthra 2007, 2010, Woronuk et al. 2011]. For example, terpenes are produced from a small number of substrates, whereas terpene synthases are capable of forming numerous terpene skeletons [Novak et al. 2000, Novak et al. 2002]. A special feature of monoterpene cyclases is that several different products can be the effect of the action of some of them. For instance, in addition to limonene itself, the limonene synthase also produces small amounts of α- and β-pinene as well as myrcene [Kopcewicz and Lewak 2001]. The biochemical pathways of synthesis of some volatile compounds, which are essential oil components, have not been yet fully explained. Some earlier studies [Klischies et al. 1975, Gang et al. 2001] suggested that phenylpropanes are synthesized in plants from phenylpropanols, while later research [Koeduka et al. 2006] proved that an enzyme that can use coniferyl acetate and NADPH to form eugenol participates in this process. In addition, ontogenetic and genetic factors affect these processes. Lewinsohn et al. [2000] showed the combination of the effect of ontogenesis and chemotype on the activity of *O*-methyltransferase, the enzyme catalyzing the transfer of the methyl group from methionine to the acceptor. Furthermore, these authors demonstrated the presence of two types of activity of this enzyme in two basil chemotypes; one of them is highly specific for chavicol, while the other one can accept eugenol as a substrate. In the context of the above data, fertilization and feeding of herbal plants seem to be an important factor modifying their aromatic profile.

Macro- and microelements as nutrients affecting plant metabolism. Nutrition plays a key role in the growth and development of all crop plants. In the case of medicinal plants that synthesize essential oils, nutrients can effectively increase oil yield and quality [Aziz et al. 2010, Jabbari et al. 2011, Sharafzadeh et al. 2011a,b, Zheljazkov et al. 2010, 2011]. Nitrogen, one of essential minerals, is used by plants to build many organic compounds: amino acids, proteins, enzymes, and nucleic acids. Amino acids and enzymes play a key role in the biosynthesis of numerous compounds which are essential oil constituents [Koeduka et al. 2006]. Plants mainly use nitrate and ammonium nitrogen, and the nitrate ion moves from the soil solution to the roots by passive and active uptake. To undergo further transformations, the nitrate anion must be reduced to ammonia, which occurs in the cells of the roots and in the aerial parts ($NO_3 \rightarrow NO_2$) as well as in chloroplasts ($NO_2 \rightarrow NH_3$). Organic nitrogen compounds are formed by biosynthesis from nitrogen taken up in the cation form (NH_4^+) and plant species-specific amino acids are the main product of this synthesis [Nowacki 1980, Kopcewicz and Lewak 2002]. Nitrogen uptake and use by plants are dependent, among others, on the type of fertilizer (nitrogen form) and its amount (nitrogen rate). The response of plants to different nitrogen forms depends on the concentration of NH_4^+ and NO_3^- ions in the nutritional environment, whereas the excess uptake of NH_4^+ ions causes disturbances in plant metabolism leading even to poisoning [Chaillou et al. 1986, Lamb et al. 1993, Barker 1999]. A second important nutrient for plants is potassium, which usually occurs in the plant at quite a high concentration, in particular in the meristematic tissues and in the phloem. Disturbances in nitrogen metabolism, resulting from potassium deficiency, manifest themselves in changes in the proportions between nitrogen fractions as well as in the accumulation of harmful amino substances (agmatine, N-carbamoyl putrescine, putrescine) and ammonium ions [Nowacki 1980] in the plant. The accumulation of NH_4^+ ions occurs mainly when plants are supplied with ammonium salts or urea. These phenomena are induced by the impairment of protein biosynthesis, while their additional cause is the reduced photosynthetic rate resulting from potassium deficiency [Nowacki 1980, Kopcewicz and Lewak 2002]. In addition to the above-mentioned macronutrients, one should also notice the role of other minerals: phosphorus, calcium, magnesium, sulphur as well as micronutrients, including heavy metals, in the development of essential oil-producing plants and in essential oil biosynthesis [Zheljazkov et al. 2006, 2008, Dzida 2010, Prasad et al. 2011, Sharafzadeh et al. 2011a, b]. In addition to the direct effect of most of the above-mentioned elements on plant metabolism, their interaction, oftentimes stronger than their individual action, is also important. The concentration of germacrene D in basil essential oil is significantly dependent on the rate of applied nitrogen and on the interaction between N and K, but it is not influenced by the rate of potassium [Nurzyńska-Wierdak and Borowski 2011]. Moreover, basil essential oil yield is significantly dependent on the rate of nitrogen, rate of potassium and the interaction between N and K [Rao et al. 2007]. Similarly, rosemary oil yield is significantly dependent on N and K application [Puttanna et al. 2010]. The above relationships are significantly translated into quantitative and qualitative changes in volatile substances in essential oil plants.

Nitrogen. The type of nitrogen fertilizer (N form) is a significant factor that modifies essential oil content and yield in aromatic plants. In the case of lemon balm, essential oil yield is significantly higher in plants supplied with slow-release urea fertilizers compared to other ones [Aziz and El-Ashry 2009]. The application of ammonium sulphate at a rate of 60 kg $fed.^{-1}$ at two equal doses is recommended to achieve maximum essential oil yield in *Ocimum americanum* L. var. *pilosum* [Omer et al. 2008]. Compost, as an organic fertilizer, affects the essential oil composition in *Ocimum basilicum* L. in a similar way as inorganic fertilization (ammonium nitrate) [Kandil et al. 2009]. Compost application in growing basil contributes not only to an increase in essential oil content, but also increases the concentration of linalool and borneol in the oil, with a simultaneous decrease in the content of methyl chavicol and 1,8-cineole [Taie et al. 2010].

In horticultural production, nitrogen fertilizers are applied to roots, as the main source of supply of this nutrient to plants, and to foliage, additionally to primary application. Foliar feeding, done with full nitrogen supply to plants, is a very effective method to increase plant yield and health. Foliar applied nitrogen, most frequently in the form of urea, is much more quickly and effectively assimilated and used by plants. This relationship results from the greater permeability of the membranes of the leaf cuticle for urea than in the case of inorganic ions [Wójcik 2004]. Foliar application of nitrogen, in particular with its quick absorption from urea, causes at the same time enhanced nutrient uptake from the nutritional environment, thereby increasing the pool of macro- and micronutrients in the plant. This phenomenon is obviously associated with the dynamics of the biosynthesis of secondary metabolites, such as essential oils. Foliar nitrogen application increases essential oil content in thyme and affects its chemical composition [Jabbari et al. 2011] as well as it increases the accumulation of *β*-asarone in calamus oil [Meneghini et al. 1998]. Foliar feeding of nitrogen in the form of urea contributes to an increased concentration of linalool and *epi-α*-cadinol as well as a decreased content of 1,8-cineole, geraniol and eugenol in the oil of *Ocimum basilicum* L. [Nurzyńska-Wierdak 2012]. This correlation can be explained by the complicated pathways of biosynthesis of terpene and aromatic compounds present in volatile oils and by the effect of quickly absorbed nitrogen on the biosynthesis of particular oil components. In the cultivation of calamus, foliar applied urea affects the photosynthetic parameters of plants and essential oil content [Meneghini et al. 1998]. Changes in the chemical composition of plants take place under the influence of urea application: generally, the concentration of nitrogen, protein and nitrates increases, while other constituents undergo characteristic biochemical transformations to a greater or lesser degree [Wojciechowska et al. 2005, Borowski and Michałek 2010]. Moreover, foliar nitrogen application contributes to increased tolerance to thermal stress in fescue [Zhao et al. 2008], which can also be of importance in other plant species.

Essential oil content and yield in herbal plants are also modified by the rate of applied nitrogen [Arabaci and Bayram 2004, Daneshkhah et al. 2007, Mahfouz and Sharaf-Eldin 2007, Daneshian et al. 2009, Zheljazkov et al. 2010, Hendawy and Khalid 2011]. Furthermore, foliar or root applied nitrogen affects the chemical composition of essential oil [Hendawy and Khalid 2011, Nurzyńska-Wierdak and Borowski 2011, Nurzyńska-Wierdak 2012, Sharma and Kumar 2012]. Nitrogen, as the main yield-increasing nutrient, significantly contributes to an increase in height, weight and yield of essential oil plants, thereby to an increase in oil yield. The application of the highest nitrogen rate (1.2 g N·10 kg^{-1} of soil) produced the best effects with respect to herbage yield and essential oil production in *Origanum vulgare* L. [Said-Al Ahl et al. 2009b]. In turn, an increase in the rate of nitrogen in the form of ammonium nitrogen (33.5% N) contributed to higher essential oil content and yield in caraway fruits [Ezz El-Din et al. 2010]. Ehsanipour et al. [2012] proved an increase in essential oil concentration in fennel fruits under the influence of a higher rate of nitrogen. The above authors link this relationship to higher plant height and fruit yield as well as to a higher amount of nitrogen available in the nutritional environment of the plants. The increasing rates of fertilizer nitrogen significantly contributed to an increase in essential oil yield in sweet basil [Zheljazkov et al. 2008, Kandil et al. 2009, Nurzyńska-Wierdak and Borowski 2011], oregano [Azizi et al. 2009, Said-Al Ahl et al. 2009a], and chamomile [Letchamo 1993, Tamizkar and Khoshouei 2011]. Nitrogen applied at a higher rate (100 and 300 kg·ha^{-1}) increased volatile oil yield in sweet basil [Sifola and Barbieri 2006]. As explained by these authors, this relationship results from the increase in oil concentration in herbage and in leaf biomass. Similarly, Rao et al. [2007] showed that a higher rate of nitrogen causes an increase in basil oil yield from the main harvest and from other harvests.

Nitrogen applied at an increased rate can also modify the chemical composition of essential oil [Rao et al. 2007, Nurzyńska-Wierdak and Borowski 2011, Sharma and Kumar 2012]. Zheljazkov et al. [2008] report that maximum basil oil yield is obtained when 50–60 kg of nitrogen per hectare is applied; in addition, nitrogen significantly modifies the percentage of linalool, eugenol, bornyl acetate, and eucalyptol in basil essential oil. Higher nitrogen application increases the concentration of methyl chavicol and decreases the proportion of linalool in basil volatile oil [Rao et al. 2007, Nurzyńska-Wierdak and Borowski 2011]. The concentration of linalool and eugenol is the highest when the lowest rate of nitrogen is applied (0.2 g N·dm^{-3}), whereas the percentage of eucalyptol and bornyl acetate is the highest at the higher rate (0.6 g N·dm^{-3}) [Nurzyńska-Wierdak and Borowski 2011]. The above linkages result from the interrelationships between the above-mentioned compounds, which is evidenced by the negative correlation of methyl chavicol and linalool content [Rao et al. 2007] and the positive correlation of the percentage of eucalyptol and bornyl acetate [Zheljazkov et al. 2008]. Nitrogen rate also modifies the chemical composition of Clary sage essential oil [Sharma and Kumar 2012]. The oil of plants fed with the medium rate of nitrogen (3.0 g N per plant) was marked by the highest concentration of linalool, *trans*-geraniol and linalyl acetate [Sharma and Kumar 2012]. But the linalool content in the essential oil of *Artemisia pallens* Wall. was not significantly differentiated by the application of increased fertilization with nitrogen, phosphorus, and biofertilizers [Kumar et al. 2009]. Furthermore, the composition and yield of fennel essential oil was not modified by nitrogen rate [Chatzopoulou et al. 2006]. The above differences may arise from the genetic conditions of the biosynthesis of secondary metabolites as well as from environmental factors.

One of the methods to increase height, yield and availability of minerals in the soil, with the decreased use of inorganic fertilizers, is to apply biofertilization, which also affects the chemical composition of crop plants. The highest amount of anethole in the essential oil of *Foeniculum vulgare* Mill. was found in the case of application of a half rate of NPK and inoculation with *Bacillus megaterium* – microorganisms that increase phosphorus availability [Mahfouz and Sharaf-Eldin 2007]. In studying dill plants, Hellal et al. [2011] showed the highest oil content and yield when biofertilizers were applied in combination with 200 kg N·fed.$^{-1}$ in the form of ammonium sulphate. The above relationships resulted from the effect of inoculation of dill seeds with bacteria from the genera *Azotobacter*, *Bacillus,* and *Pseudomonas* as well as from the positive effect of nitrogen and the interaction between the investigated factors. Similarly, essential oil yield in *Artemisia pallens* Wall. was the highest when the medium rate of nitrogen (93.75 kg·ha^{-1}) and biofertilization with *Azospirillum* were applied [Kumar et al. 2009].

Potassium. In greenhouse cultivation, depending on the type of medium and cultivated plant species, the optimal potassium content is in the range of 0.3–0.8 g K·dm^{-3} of medium or root-zone solution. The amount of a single dose of potassium is of major importance due to the antagonistic effect of this nutrient on the uptake of other cations: sodium, calcium, and in particular magnesium, by plants. Increased potassium fertilization did not cause any significant changes in the content of essential oil in caraway, but it modified its chemical composition [Ezz El-Din et al. 2010]. In basil, the essential oil content in herbage is significantly higher in plants fertilized with the higher (0.8 g $K\cdot dm^{-3}$) rather than the lower rate (0.4 $g\cdot dm^{-3}$) [Nurzyńska-Wierdak and Borowski 2011]. Moreover, a higher amount of potassium contributes to an increase in the percentage of 1.8-cineole, linalool, eugenol, and γ-cadinene in basil oil [Nurzyńska-Wierdak and Borowski 2011]. Differently than in the study of Rao et al. [2007], basil oil yield was not significantly determined by potassium rate. In turn, in the case of *Rosa damascena* Mill. the application of the medium rate of potassium (30 $kg\cdot ha^{-1}$) contributed to maximum essential oil concentration [Daneshkhah et al. 2007]. An increase in NPK rate in chamomile cultivation contributed to an increase in essential oil content and yield as well as in germacrene D and α-bisabolol concentration in the oil, relative to the control [Hendawy and Khalid 2011]. Potassium applied in caraway cultivation contributed to increased carvone production [Valkovszki and Nemeth-Zambori 2011]. Spraying of oregano plants with potassium humate causes an increase in essential oil yield and also affects the concentration of carvacrol and other oil components [Said-Al Ahl et al. 2009b], but one should also take into account the role of humin substances themselves, as they are responsible for general improvement of soil fertility and productivity.

Other minerals. Nutrients available in the nutritional environment of plants are capable of changing essential oil yield and composition [Nurzyńska-Wierdak and Borowski 2011, Sharafzadeh et al. 2011a,b, Sakr et al. 2012]. The highest basil essential oil yield was found at the highest NPK rate [Sharafzadeh et al. 2011a]. Nitrogen and phosphorus application contributes to quantitative changes in the essential oil of *Artemisia pallens* Wall., but it does not modify its composition [Kumar et al. 2009]. The application of a higher NPK rate can increase essential oil content in *Tagetes patula* L., but only in some harvest periods [Stojanowa et al. 2000]. Increased fertilization of summer savoury plants with macro- and micronutrients increases oil yield but also modifies its chemical composition [Alizadeh et al. 2010]. Phosphorus application significantly increases basil essential oil content, but fresh and dry weight of herbage remains unaffected [Ramezani et al. 2009]. Phosphorus fertilization significantly increases oil yield in rose-scented geranium and also the content of citronellol and 10-*epi*-γ-eudesmol [Prasad et al. 2012]. A higher amount of sulphur in the cultivation of dragonhead plants increased essential oil yield and changed the level of other secondary metabolites [Aziz et al. 2010]. Similarly, an increased amount of sulphur causes a rise in production of essential oil and eucalyptol in basil oil [Zheljazkov et al. 2008]. In turn, iron application in growing thyme has a repressive effect on essential oil content and chemical composition [Jabbari et al. 2011]. Differently, in basil grown under salt stress conditions foliar application of zinc and iron increases the linalool content in the oil [Said-Al Ahl and Mahmoud 2010]. Moreover, the above-mentioned metals contribute to increased tolerance of plants to salt stress. Oregano essential oil yield is higher by 31% compared to the control under the influence of foliar application of calcium and magnesium [Dordas 2009]. At the same time, volatile oil content is not dependent on the application of Ca^{2+} and Mg^{2+}; these differences result primarily from a significant increase in dry matter yield under the influence of plant feeding [Dordas 2009]. A higher rate of calcium carbonate in basil cultivation contributes to a decrease in oil content and linalool concentration as well as to an increase in methyl chavicol content [Dzida 2010]. In summer savoury, the application of calcium carbonate positively affects essential oil content, while its higher rate contributes to an increase in carvacrol concentration in the oil; the interaction of nitrogen and calcium fertilization on oil content is also important [Mumivand et al. 2011].

Salt concentration (EC) in the nutritional environment and proper proportions between particular nutrients are extremely important for the proper uptake of water and nutrients dissolved in it by plants [Suh et al. 1999, Singh et al. 2004, Nurzyńska-Wierdak et al. 2011]. The value of EC is affected by all cations and anions, but to a greater extent by nitrates, potassium, and magnesium [Nurzyński 2003]. Salt concentration in the nutritional environment of essential oil plants modifies their growth and development; the highest essential oil content of peppermint and lemon verbena is characteristic of the moderate value of EC ($1.4\ dS \cdot m^{-1}$) [Tabatabaie and Nazari 2007]. Furthermore, the value of EC modifies the chemical composition of mint and lemon verbena essential oil: an increase in menthone concentration and a decrease in menthofuran content at $5.6_{Na}\ dS \cdot m^{-1}$ NaCl (45 mM) enhance the marketable quality of mint oil, while a higher value of EC slightly increases the percentage of geraniol and neral in lemon balm oil [Tabatabaie and Nazari 2007]. Increased soil salinity also contributes to higher basil oil content and yield [Said-Al Ahl and Mahmoud 2010, Said-Al. Ahl et al. 2010] as well as to an increase in the content of linalool, methyl chavicol, farnesol, geraniol and myrcene and a decrease in eugenol and methyl eugenol content [Said-Al. Ahl et al. 2010]. The above results show that an increase in essential oil content can be obtained without adverse changes in essential oil composition, through proper salt concentration in the nutritional environment.

The influence of heavy metals on oil yield in medicinal plants is interesting, in particular in the aspect of their cultivation in areas with contaminated soils. An increased concentration of metals in the nutritional environment of aromatic plants affects essential oil content and chemical composition, but only in some species [Zheljazkov and Nielsen 1996, Zheljazkov et al. 2006]. The linalool content in basil essential oil decreased, while the methyl chavicol content increased under the influence of chromium, cadmium and lead application [Prasad et al. 2011]. Furthermore, the percentage of linalool and methyl chavicol in basil oil decreased as a result of nickel addition [Prasad et al. 2011]. On the other hand, Scora and Chang [1997] did not find any changes in the concentration of peppermint essential oil components under the influence of different concentrations of heavy metals in the medium. Heavy metals: cadmium, lead, and copper, do not move from the tissues during steam distillation, which confirms the usefulness of aromatic plants as alternative crops on soils rich in the above-mentioned metals [Zheljazkov et al. 2006].

CONCLUSIONS

Essential oils, as substances with a complex chemical composition, are differently modified by the presence and availability of nutrients in the nutritional environment. The biosynthesis of volatile oil constituents, among others terpene compounds, occurs along different metabolic pathways, hence other compounds are substrates and enzymes in these processes. The participation of macro- and micronutrients in building basic organic compounds and in almost all plant life processes as well as the results of the presented agronomic studies show the significant role of these minerals in the modification of essential oil content and chemical composition. Nitrogen contributes to the greatest extent to an increase in the biosynthesis of essential oil and its composition in numerous aromatic plant species. A higher rate of nitrogen causes an increase in volatile oil content and yield in some plants as well as it increases the percentage of methyl chavicol and *β*-asarone and decreases linalool concentration in the oil. In the cultivation of some aromatic plants, a higher amount of potassium contributes to an increase in essential oil content and in the percentage of 1,8-cineole, linalool, eugenol, and *γ*-cadinene in the oil. Essential oil yield and chemical composition can be significantly dependent on the rate of nitrogen and rate of potassium as well as on the interaction between these minerals. Other nutrients, such as phosphorus, sulphur, calcium, magnesium and microelements, are also capable of changing essential oil yield and composition. Salt concentration in the nutritional environment of essential oil plants modifies their growth and development and also affects essential oil biosynthesis. Increased soil salinity may contribute to higher essential oil content and yield and cause certain changes in its composition. Similarly to biofertilization, optimal and balanced mineral fertilization of aromatic plants, adjusted to their nutritional requirements and growing conditions, is an important cultivation factor determining the quantity and quality of essential oil.

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CZY NAWOŻENIE MINERALNE MODYFIKUJE ZAWARTOŚĆ I SKŁAD CHEMICZNY OLEJKU ETERYCZNEGO U ROŚLIN LECZNICZYCH?

Streszczenie. Olejki eteryczne są głównymi składnikami czynnymi wielu surowców olejkowych. Jest to najliczniejsza grupa surowców leczniczych, o długiej tradycji i wciąż dużym zastosowaniu w lecznictwie. Surowce olejkowe pozyskiwane są ze stanowisk naturalnych oraz z uprawy. Metoda uprawy, nawożenie, nawadnianie oraz termin zbioru surowca w znacznym stopniu mogą modyfikować zarówno zawartość, jak i kompozycję olejku eterycznego. Składniki pokarmowe stosowane w uprawie w formie nawożenia mineralnego i organicznego dostarczane są roślinom dokorzeniowo i dolistnie. Aplikacja dolistna azotu zwiększa zawartość olejku eterycznego u niektórych roślin oraz wpływa na jego skład chemiczny. Zawartość i plon olejku eterycznego roślin zielarskich są ponadto modyfikowane dawką stosowanego azotu. Zwiększona aplikacja azotu podnosi koncentrację metylochawikolu oraz zmniejsza udział linalolu w olejku lotnym niektórych gatunków roślin aromatycznych. W uprawie niektórych roślin aromatycznych zwiększenie ilości potasu przyczynia się do zwiększenia zawartości olejku eterycznego oraz udziału 1,8-cyneolu, linalolu, eugenolu, γ-kadinenu w olejku. Pozostałe składniki pokarmowe dostępne w środowisku odżywczym roślin także są zdolne do zmian plonu i kompozycji olejku eterycznego. Zrównoważone nawożenie mineralne roślin aromatycznych, podobnie jak bionawożenie, jest istotnym czynnikiem uprawowym określającym ilość i jakość olejku eterycznego.

Słowa kluczowe: substancje lotne, aktywność biologiczna, forma i dawka NPK, mikroelementy

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