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The content of oils in umbelliferous crops and its formation

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Abstract. The aim of this study is to give an overview about content and constituents of oils found in umbelliferous crops and the conditions influencing oil content in those crops. The large family *Umbelliferae* is rich in essential oils. Oils play the phytosanitary role by preventing parasites and diseases from developing or by acting like selective weed-killers in order to keep the ground clean around the plant. Factors influencing oil content in umbelliferous crops are: the latitude of cultivation, the climatic and weather conditions, diurnal and annual rhythm, salinity, fertilization, irrigation, growth retardants, plant development, the plant part used, variety, harvesting and storage.

Key words: Umbelliferous crops, content of oils, constituents of oils, factors influencing oil content

INTRODUCTION

The *Umbelliferae* are mostly temperate herbs almost always with umbellate inflorescences comprising about 300 genera and 3000 species. The family has a cosmopolitan distribution, but most of its members are confined to northern temperate regions and high altitudes in the tropics. The species are commonly further distinguished by the presence of hollow stems and sheathing petioles. The leaves are nearly always alternate and pinnately or palmately compound or more than once compound; stipules are generally absent. The flowers are typically small, mostly bisexual (Judd et al., 2007).

The family *Umbelliferae* is one of the most numerous families within vegetable crops. This family is rich in secondary metabolites and embodies numerous genera of high economic and medicinal value (including essential oils) (Margaris et al., 1982). The large family *Umbelliferae* is rich in essential oils (Margaris et al., 1982). Therefore this family has been chosen to give an overview about the content and constituents of oils. Essential oils are internal secretions, more or less fluid, which can be found in more than thirty botanical families, included *Umbelliferae*. By reviewing literature it was found that about 760 different constituents have been isolated from essential oils of umbelliferous crops, belonging to different chemical classes (Margaris et al., 1982).

The aim of this study is to give an overview about content and constituents of oils found in umbelliferous crops and the conditions influencing oil content in those crops.

Short description of essential oils. From studies in plant physiology it is known that an essential oil is a concentrated, hydrophobic liquid containing volatile aroma compounds from plants. Essential oils are also known as volatile or ethereal oils, or simply as the "oil of" the plant from which they were extracted, such as *oil of clove*. Oil is "essential" in the sense that it carries a distinctive scent, or essence, of the plant. Essential oils do not as a group needs to have any specific chemical properties in common, beyond conveying characteristic fragrances (Sellar, 2001).

The essential oils of *Umbelliferae* family are present under the form of tiny vesicles located between the cells, where they act as hormones, regulators and catalysts in the vegetable metabolism. They seem to help the plant to adapt to its environment and are consequently produced in higher quantities when plants meet extreme conditions. They play a phytosanitary role by preventing parasites and diseases from developing or by acting like selective weed-killers in order to keep the ground clean around the plant. The essential oils of *Umbelliferae* family can also have antimicrobial activity (Mohamed & Abdu, 2004). The essential oils of the seeds of *Seseli libanotis, Ligusticum stewartii* and *Pycnocycla aucheriana* have been tested against the pathogenic bacteria of *Staphylococcus aureus, Escherichia coli, Shigella dysentry* and *Vibrio cholera* (Syed et al., 1989). They are different from vegetable fatty oils in being highly volatile.

Generally these components of essential oils are divided into two main groups:

* hydrocarbons, which are made up almost exclusively of terpenes,
* oxygenated compounds, mainly aldehydes, ketones, alcohol, phenols, oxides and esters (Özoan & Chalchat, 2007).

PLANT SOURCES

Carrot. Fresh carrots contain 0.59% of essential oil (Alabran et al., 1975). The main components identified in carrot oil are isoprene (84%), caryophyllene (47%), linalool (38%), acetaldehyde (22%), cymene (22%), terpinolene (21%) and dipentene (15%). Carrot seeds contain (mostly) different components comparing to the fresh carrot (Seifert et al., 1968). Several scientists have found that main component of carrot seed oil is carotol (Seifert et al., 1968; Özoan & Chalchat, 2007).

Parsley. Parsley fruit or seeds contain volatile oil in larger proportion than the root (2.6%); it consists of terpenes and apiol (Calambosi, 1994). Other components are fixed oil, resin, apiin, mucilage and ash. Apiol is an oily non-nitrogenous allyl compound, insoluble in water, soluble in alcohol and crystallizable when pure into white needles. Parsley leaves contain 0.1–0.7% of essential oil (Melchior & Kastner, 1974). The terpene content is much higher in oil from leaves than in fruit oil. In leaf oil the main component is myristicin, followed by apiol. Parsley root contain 0.6% of essential oil (Galambosi, 1994). He also found that the content of apiol is nearly the same in roots and seeds, but ca 3 times less in leaves.

Celery. Celery contains 2.5–3% of essential oil. The main part of essential oil is limonene (60%) (Rao et al., 2000). We can find also selinene, pentyl benzene, phthalide, pinene, myrcene etc. Celery leaves contain about 0.1% of essential oil. Celery aroma is due to phthalides (Herrmann, 1992), and also apiin, bitter substances etc. (Melchior & Kastner, 1974).

Coriander. Coriander fruit contains about 0.2–1.5% of volatile oil and some other results indicate that some new cultivars contain it up to 2.7% (Purseglove et al., 1981).

The volatile oil is the active ingredient. The characteristic aroma is due to linalool (60–70%) (Galambosi, 1994; Ravi et al., 2007). The oil also contains geraniol, geranyl acetate, decyl acetate, decanal and thymol (Melchior & Kastner, 1974). Essential oil contains ca 20% of terpenes. The fruit contains 13–20% of fat oil. The fatty oil is characterized by very high content of octadecenoic acids.

Fennel. The best varieties from fennel yield from 4 to 5% of volatile seed oil, the principal constituents of which are anethol (50–60%) and fenchone (18–22%). Leaves of fennel contain 1–1.5% of oil (Galambosi, 1994). The oil of fennel also contains: d-pinene, phellandrine, anisic acid and anisic aldehyde. Fenchone gives a bitter taste. The fruit contain ca 12–18% of fat oil. There are differences between varieties vulgare and dulce (Melchior & Kastner, 1974). Vulgare contains ca. 12–22% of fenchone, as compared to 0,4–0,8% in dulce. However dulce contains about 3 times more limonene than vulgare (Melchior & Kastner, 1974).

Caraway. Caraway contains 2.5–4.5% of essential oil, which consists of 52% carvone and 45% limonene. Carvone, the principal constituent of caraway oil, can be produced synthetically (Melchior & Kastner, 1974). This has lowered demand for caraway oil in recent years. The oil also contains carveol, dihydrocarveol and perillylalcohol. The fruit contain ca 12% fat oil (Melchior & Kastner, 1974).

Anise. Anise fruit contains 2–3% of essential oil. Essential oil contains mainly anethol (80–90%), which gives to anise oil its characteristic aroma. Anise oil also contains p-methoxyphenylacetone, anisic alcohol and anisaldehyde (Lawrence, 1983). Other components can be found at levels less than 1%. The fruit contain 10–30% of fat oil (Melchior & Kastner, 1974).

Dill. Dill fruit contains 2.5–4% of essential oil (Bailer et al., 2001). Essential oil contains mainly carvone (40–55%) (Arora & Srinivas, 2002). Carvone, limonene and phellandrene made up close to 90% of the oil (Embong et al., 1977). Other components are dillapiol, dihydrocarvone and myristicin. The leaves of dill contained 0.05–0.35% of essential oil. During wilting oil content increases (Melchior & Kastner, 1974). Essential oil contain mostly the same things as fruit oil, but it was shown that main part is phellandrene (46%), then limonene and anethofuran at levels of 21 and 24% respectively (Strunz et al., 1992). The carvone content is insignificant compared to fruit oil content. The leaves also contain terpinene.

Chervil. Chervil leaves contain 0.03% of essential oil. The oil contained pinene, phellandrene, methyl chavicol (75.1%) and 1-allyl-2,4-dimethoxybenzene or osmorhizole (22.3%) (Lawrence, 1983).

CONDITIONS INFLUECING THE OIL CONTENT

Latitude of cultivation. Higher volatile oil contents (in coriander) were obtained when grown in Lithuania as compared to southern Russia (Purseglove et al., 1981). *Johreniopsis seseloides* from Teheran and Kurdistan were collected (Fouladi et al., 2006). The essential oil of *Johreniopsis seseloides* from Teheran province contained monoterpens (24.05%) and sesquiterpenes (43.19%). The essential oil of *Johreniopsis seseloides* collected from Kurdistan province contained high amount of monoterpens (69.67%) and lower sesquiterpenes (26.69%). Essential oil composition of coriander changed significantly among the two studied growing regions (Msaada et al., 2009a).

Climatic and weather conditions. The best oil yields of coriander are obtainable in cool, rather wet summers (Purseglove et al., 1981). Climate conditions had a significant effect on the essential oil composition of parsley by altering the ratio of the followed substances: β-phellandrene, 1,3,8-p-menthatriene, α-,p-dimethylstyrene, myristicin, β-myrcene and apiole (Petropoulos et al., 2004).

Date of sowing. Parsley sowing date had a significant effect on the essential oil composition by altering the ratio of the followed substances: β-phellandrene, 1,3,8-p-menthatriene, α-,p-dimethylstyrene, myristicin, β-myrcene and apiole (Petropoulos et al., 2004). For higher essential oil production anise must be sown early in the spring (Zehtab-salmasi et al., 2001).

Fertilization. N fertilization: Increasing the amount of nitrogen from different sources increased oil content (Hussien, 1995). Carrots with lower nitrogen application had higher amounts of essential oils (Schaller & Schnitzler, 2000). Ammonium nitrate gave the highest value of oil yield in coriander while urea was more effective for dill. Essential oil concentration in leaves of dill increased with lower nutrient concentrations (1.2, 2.4 and 3.6 mS/cm) (Udagawa, 1995). The concentration of essential oils in the roots and leaves of plain leaf parsley and turnip-rooted parsley was not affected by N application, but decreased with increasing N rate (3.2, 16.2, 32.4 and 48.6 g m^{-2}) in curl leaf parsley (Petropoulos et al., 2009). Fertilization with N affected not only the quantity, but also the composition of the essential oils (Schaller et al., 1998).

P fertilization: Four phosphorus levels (0, 20, 40, 60 kg ha^{-1}) effect on essential oil content of cumin plant and essential oil yield were investigated (Tunctürk & Tunctürk, 2006). The results of this research suggested that highest oil content and essential oil yield were obtained from 40 kg ha^{-1} P_2O_5 application.

Ni fertilization: Parsley plants were soil supplemented with 0, 25, 50, or 100 mg Ni per kg soil using $NiSO_4$ solution of different concentrations. In this experiment the results showed that low levels of Ni fertilization, particularly 50 mg kg^{-1} in clay soil, strongly improved parsley oil yield (Atta-Aly, 1999).

Organic fertilizers: Organic fertilizers (2.5 kg m^{-2}) considerably increased oil yield of fennel (Mohamed & Abdu, 2004).

Salinity. Oil content in the seeds of sweet fennel decreased progressively with increase in salinity (Ashraf & Akhtar, 2004). The essential oil yield of coriander was 0.06% in the control, on the basis of dry matter weight, and did not change at low concentration (25 mM), while it increased significantly with increasing NaCl concentrations to reach 0.12 and 0.21% at 50 and 75 mM NaCl, respectively (Neffati & Marzouk, 2009). Irrigation of fennel plant with saline water (3355 ppm) resulted in reduction of oil yield per plant and reduction of anethole content in oil reached 23.2% (El-Wahab, 2006). The essential oil yield of coriander increased significantly up to 18 and 43% with 25 and 50 mM Na Cl, respectively and decreased significantly under high salinity (Neffatti & Marzouk, 2008).

Irrigation. Water stress imposed by restricting the number of irrigations increased the percentages of volatile oils in parsley and fennel (Mohamed & Abdu, 2004; Petropoulos et al., 2008). At the same time volatile oil yield in fennel increased with irrigation (Mohamed & Abdu, 2004). Irrigation increased the essential oil content of coriander seeds, but decreased percent of linalool in the essential oil (Arganosa et al., 1998). Water deficit during stem elongation and umbel appearance reduced anise oil production (Zehtab-salmasi et al., 2001).

Growth retardants. Spraying the growth retardant (B-9) ranging from 500 to 4000 ppm on caraway and fennel plants resulted in increase of volatile oil content in the seeds, and by spraying plants with 4000 ppm B-9 maximum oil yield was obtained (Abou-Zied, 1974).

Plant development. Coriander (Purseglove et al., 1981) and turnip-rooted chervil (Mamedova & Akhmedova, 1991) content of volatile oil in vegetative organs increases progressively with plant development and reaches a maximum in the overground parts at the flowering stage. During the fruit-ripening phase, the vegetative organs progressively dehydrate and their volatile oil content diminishes as the oil canals flatten. The oil content in the various organs peaks at different stages of plant development: early on in the roots, at the flowering stage with the stems, and at plant maturity with the leaves. The total content of oils in caraway, carrot and coriander was lower in the samples, which were collected before full ripeness, than in samples, which were collected in full ripeness (Gonny et al., 2003; Msaada et al., 2009b; Sedlakova et al., 2001). Parsley growth stage had a significant effect on the essential oil composition by altering the ratio of the followed substances: β-phellandrene, 1,3,8-p-menthatriene, α-,p-dimethylstyrene, myristicin, β-myrcene and apiole (Petropoulos et al., 2004). A rapid oil accumulation started at newly formed fruits and continued until their full maturity (Msaada et al., 2009b). Essential oil composition of coriander changed significantly among the different stages of maturity (Msaada et al., 2009a). Geranyl acetate (46.27%), linalool (10.96%), nerol (1.53%) and neral (1.42%) were the main compounds at the first stage of maturity (immature fruits). At the middle stage, linalool (76.33%), *cis*-dihydrocarvone (3.21%) and geranyl acetate (2.85%) were reported as the main constituents. Essential oils at the final stage of maturity (mature fruits) consist mainly of linalool (87.54%) and *cis*-dihydrocarvone (2.36%) (Msaada et al., 2007a). Essential oil content of sweet fennel was measured during four different maturation stages (immature, premature, mature and full mature). Results showed that essential oil content declined with fruit maturity (Telci et al., 2009). In the case of *Carum carvi* and *Foeniculum vulgare*, the accumulation tendency of essential oils can be characterized by parallel optimum curves in vegetative and generative organs, with maximum points at different times and different levels (Nemeth, 2005).

Diurnal and annual rhythm. The seasonal changes in the content of essential oils of lovage leaves were less considerable than in the stems (Bylait et al., 1998). Diurnal changes in essential oil content of coriander were studied (Ramezani et al., 2009). Results of this experiment indicated that essential oil content changed according to the hour of day and night. Essential oils in content at noon was higher than in other hours so that yields of essential oil (w/w^{-1}%) at different times were in order of 6 (0.432%), 12 (0.436%), 18 (0.404%) and 24 (0.319%) treatments.

Part of plant used (root, leaf, stalk, flower, seeds). The highest content of volatile oils in dill plants were found in leaf blade and the smallest in the petiole compared to whole leaf and stem (Liziewska et al., 2007). Young carrot leaves contained more propenylbenzenes, methylisoeugenol, and alpha-asarone than old leaves. They found also significant differences in essential oil composition between leaflets and petioles (Kainulainen et al., 1998). Carrot leaves had significantly higher essential oil content compared with the roots (Habegger & Schnitzler, 2000). Oils obtained from different parts of wild carrot plants consisted mainly of monoterpene hydrocarbons (72–84%) (Staniszewska et al., 2005). Multivariate analysis revealed a high similarity in the essential oils composition of coriander between upper leaves and flowers in one hand and basal leaves, roots and stems on the other hand (Msaada et al., 2007b). The leaf oil of *Laserpitium gallicum* L. had a composition similar to the fruit oil (Chizzola, 2007). Nazdemiyeh et al. (2009) analyzed the volatile oils components of stems, umbels, fruits and roots of *Astrodaucus orientalis* (L.). The main components from the stem were sabinene (23.1%), α-pinene (16,4%), fenchyl-acetate (7.5%). Sabinene (25.6%), β-pinene (22.3%) and α-copaene (16.1%) were the main constituents of the volatile oils of the fruits. While α-copaene (26.1%), β-pinene (15.3%) and sabinene (13.7%) were the major components of the volatile oils of the umbels (flowers) and that of the roots were mainly composed of anisole (37.9%), bornyl acetate (36.9%) and geranyl tilgate (11.4%). According to the results the highest value of trans anethole (78.25%) can be found during summer in fennel dry seeds, limonene (42.30%) in spring stems/leaves and fenchone (16.98%) in green seeds in autumn (Stefanini et al., 2006a). The essential oil from the different parts (inflorescences, stems + leaves and roots) of *Eryngium glaciale* was analyzed (Pala-Paul et al., 2005). The results indicate that inflorescences oil contained phyllocladene (43.5%), (*E*)-caryophyllene (15.2%) and valencene (11.5%), while the oil from the stems and leaves only showed phylloclaene isomer (41.3%) as main one. The oil from the roots presented phyllocladene isomer (49.4%) and linalool (19.1%) as major constituents.

Variety. The same variety can produce different essential oils depending on climatic, geographic and agronomic conditions. Roots of the carrot variety ‘Cubic’ had higher essential oil content than the roots of the variety ‘Nanco F_1’, while leaves of the variety ‘Nanco F_1’ had higher essential oils content than the leaves of the variety ‘Cubic’ (Habegger & Schnitzler, 2000). The essential oil composition of carrot leaves was significantly different between the varieties (Kainulainen et al., 1998). The content of caraway essential oils decreased from ‘Rekord’ over ‘Prochan’ and ‘Kepron’ down to ‘Konczewicki’ variety (Sedlakova et al., 2001). They found also that different varieties of caraway contained 1–9% (m/m) of essential oil that produces typical caraway taste and fragrance. Results of investigations indicated that the sweet fennel variety ‘Zefa Fino’ recorded the highest values of essential oil content of leaves and bulbs compared with the varieties ‘Dulce’ and ‘Selma’ (Zaki et al., 2009). Essential oil content in fennel was the lowest in the variety ‘Sweet Fennel’ and the highest in the variety ‘Shumen’ (Bowes & Zheljakov, 2004). Variety had a significant effect on the essential oil composition of parsley by altering the ratio of the followed substances: β-phellandrene, 1,3,8-p-menthatriene, α-p-dimethylstyrene, myristicin, β-myrcene and apiole (Petropoulos et al., 2004). The oil composition differed significantly between leaves from different carrot varieties (‘Flakker 2’, ‘Nantura’, ‘Parano’, ‘Napoli’, ‘Panther’, ‘Splendid’, ‘Nantes 3 Express’) (Kainulainen et al., 2002). The coriander varieties ‘Jantar’ and ‘Alekseevski’ had dissimilar oil content and oil yield (Zheljakov et al., 2008).

Harvesting. Anise plants were harvested at 10 different growth stages (Özel, 2009). Results showed that the fourth harvesting stage gave highest yield of essential oil. The first and second harvesting stages provided the best quality of essential oils with a high (E)-anethole content. Three fenological stadiums of fennel harvest were tested: green seeds (green color), mature seeds (yellow color), dry seeds (straw yellow color)

(Stefanini et al., 2006 b). Results showed that seeds should be picked when they are still green, in this way it is possible to get a greater amount of essential oil. Seeds of anise harvested in waxy stage had higher oil content than those harvested at earlier or later stages (Zehtab-salmasi et al., 2001). Sweet fennel seeds were harvested at the stages of full bloom, waxy seed and seed ripening. The highest oil yields were found in plants harvested at waxy seed maturity stage (Marotti et al., 1993). The data showed that harvesting parsley or dill for one or two times to obtain fresh herb caused reduction in plant weight at flowering stage, consequently less umbels, seed and oil yield/plant comparing to non harvested plants (Osman & El-Wahab, 2009).

Storage. Dried coriander fruit stored in heaps or cotton bags over two-year period, storage losses of essential oils were only 3–5% (Purseglove et al., 1981). The content of essential oils decreases with increasing of storage period (Sedlakova et al., 2001).

CONCLUSIONS

The large family *Umbelliferae* is rich in essential oils. Oils play a phytosanitary role by preventing parasites and diseases from developing or by acting like selective weed-killers in order to keep the ground clean around the plant. Present investigation gives overview about oil contents and names of oil constituents of different umbelliferous crops. Factors influencing oil content in umbelliferous crops are: the latitude of cultivation, the climatic and weather conditions, fertilization, salinity, irrigation, growth retardants, plant development, diurnal and annual rhythm, the plant part used, variety, harvesting and storage.

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