International Journal of Multidisciplinary Research and Growth Evaluation.

Factors influencing yield, chemical composition and efficacy of essential oils

Lydia Mugao
Department of Agricultural Resource Management, University of Embu, P.O. Box 6 – 60100, Embu, Kenya

* Corresponding Author: **Lydia Mugao**

Article Info

ISSN (online): 2582-7138
Volume: 05
Issue: 04
July-August 2024
Received: 01-05-2024;
Accepted: 02-06-2024
Page No: 169-178

Abstract
Essential oils are secondary metabolites that are produced by plants for the purpose of protection from pests, predators, attraction of pollinators and seed dispersal. The oil is produced in different parts of the plants and contains various chemical compounds that give plants a characteristic odour and flavor. These compounds vary between different plant species and also within plants of the same species. The yield and the efficacy of essential oils also vary between and within species. The variations in the essential oil compounds, the yield and the efficacy is influenced by both exogenous and endogenous factors. Endogenous factors such as plant age, plant density, plant genotype, part of the plant where the oil is extracted brings about variability in yield, chemical composition and the efficacy of essential oils. Similarly, exogenous factors such as light intensity and temperature, water availability, altitude and latitude, soil type and composition, preparation of the plant material before the essential oil extraction, method of extraction of the essential oil and the storage conditions after extraction also have a great influence on the chemical composition, yield and efficacy of essential oils. The factors then need to be moderated in order to ensure that the essential oil produced is of the quality required. Once extraction is done, proper storage conditions to avoid oxidation is necessary as the essential oils await to be used. They should be stored in dark cool conditions in tightly closed dark glass containers to ensure long term quality. Knowledge on the growth requirements of the individual plants that produce oils is necessary so as to produce quality oil.

DOI: https://doi.org/10.54660/.IJMRGE.2024.5.4.169-178

Keywords: chemical, essential oils, Yield

1. Introduction

Essential oils are secondary metabolites that are produced by plants for protection from pests, predators, attraction of pollinators and seed dispersal [1]. The oils are made up of a mixture of compounds that give a characteristic flavor and odour to the plants. They are located in different parts of the plant such as buds, leaves, stems, bark, flowers, roots, fruits and seeds depending on plant species [2]. Almost every part of a plant can produce essential oil which can be extracted from the plant part and put to various uses [3]. The essential oils are accumulated in the cells, secretory cavities, canals, or glandular hairs of the plant parts [4]. They are soluble in organic solvents with generally lower density than water such as toluene, ethanol, benzene, acetone and methanol [5].

Essential oils constituents are lipophilic, transparent and highly volatile secondary plant metabolites, reaching a mass below a molecular weight of 300 and can be physically separated from other plant components [5]. The aroma and flavor of plants are influenced by the type and amount of compounds present in the essential oils [6, 7]. For example, Oxygenated monoterpenes are the major contributor to the taste and aroma of essential oils [8]. Other chemical compounds bring about variation in colour of essential oils from plants species [3].

Essential oils have portrayed various biological properties such as insecticidal, antibacterial, antioxidant, anti-inflamamtory, larvicidal and allelopathic due to the many different chemical compound present in them [9, 10].

The chemical composition of essential oils differs not only in the number and the type of molecules but also in their chemical structures. For example, most essential oils contain natural monoterpenes and sequiterpenes with a variety of functional groups that contribute to antibacterial and antifungal properties [11]. These differences may be as a result of different method of extraction, climate, soil composition of the environment where the plant is growing, plant organ where the essential oil was extracted, age of the plant and vegetative cycle stage [12]. Similary, Sohani *et al*. [13] reported that essential oils of similar plant species have differences in chemical composition depending on the geographical region where the plant is growing. For example, Raina *et al*. [14] reported that the essential oil from ginger varied in chemical composition depending on the geographical location where the ginger plant was growing. According to Franz [15], the chemical variation of essential oils is also determined by genetic variability of individual plants, the different parts of the plant such as roots, leaves, stems, or flowers, different stages of the growth of the plant and the environmental factors. These factors also influence the quality, the yield and the effectiveness of essential oils.

Essential oil extraction is done using various methods such as low temperature distillation, hydro-distillation, steam distillation and extraction with organic solvents. The method of extraction can influence the chemical composition and yield of essential oil. Inappropriate extraction procedures can result to damage or change of the chemical nature of the essential oils [3]. Bioactive compounds present in essential oils have been used locally as biopesticides but they are not adequately used by commercial industries because there are factors that influence the availability of these compounds in the essential oils. On the other hand, plants that produce essential oils have been widely used in herbal medicine without the knowledge on the quality or chemical composition though with lesser side effects [16].

The factors influencing the chemical variability and efficacy of essential oils can be grouped into exogenous and endogenous factors. The endogenous factors are factors related to the anatomical and physiological characteristics of the plants such as variation in chemical composition in different parts of the plant and the developmental stages. On the other hand, exogenous factors are factors related to the environment such as light, rainfall and soil. These factors influence the chemical composition, yield and effectiveness of the essential oils.

2. Factors influencing chemical variability and efficacy of essential oils

2.1. Endogenous Factors

These are factors related to the plant such as part of the plant where the essential oils are produced and accumulated, the age of the plant at the time of oil extraction and the genetic characteristics that regulate the essential oil secretion in plants.

2.1.1. Age of the plant and the tissues generating the essential oil

The synthesis of essential oil from the plants varies as the plant and the tissue ages. Same plant organs but at different growth stages produce essential oils with different chemical compounds [17]. Several studies have reported the influence of plant age on the chemical composition of essential oils and their efficacy in pest and disease control. In respect to this, the reports of Hudaib *et al*. [18] showed that the essential oil obtained from a two-year-old *Thymus vulgaris* contained more thymol (51.15) than the one obtained from a five-year-old plant (19.38) in the same vegetative cycle. Similarly, chemical variability of essential oils obtained from four-year-old and eleven-year-old *Eucalyptus camaldulensis* was also reported [19].

In peppermint leaves the level of monoterpenes content rapidly increased between twelve and twenty days of age after which it leveled off as the leaves got fully grown [20]. It was also reported that essential oil of *Thymus pulegoides* contained phenol content when the plant was harvested at the beginning of the flowering stage [21]. Linalool compound in *Artemesia pallens* essential oil decreased significantly from the beginning of the flowering stage to the end of it [22]. However, according to Tiwari *et al*. [23] the quantity of *Targetes minuta* essential oil increased as the plant aged. The oil extracted from the *Targetes minuta* at flower initiation, full flowering, late flowering and seed setting stages increased as the plant aged and the chemical composition that dominated were monoterpenes and their content increased as the plant aged. This could be due to the plant structures synthesizing the compounds increasing in size and thus increasing their activity. According to Croteau and Martinkus [24], the monoterpenes content in peppermint essential oil increased as the leaf aged. However, the findings of Gholamreza *et al*. [25] contradicted the previous reports by reporting that the proportions of monoterpenes in peppermint essential oil decreased as the plant aged. The evaluation of the components of the *Tagetes minuta* essential oil at different growth stages revealed a variation in various chemical compounds at different growth stages [26]. For example, dihydrotageton was high (54.3%) at vegetative stage but decreased to 21.9% at budding stage but increased again (30.3%) at full flower stage and slightly decreased to 29% at seed stage. The opposite happened to tagetenone compound which was low (0.9%)at vegetative stage, then increased to 9.9% at budding stage, decreased to 7.0% at full flower stage and once again declined to 5.3% at seed stage.

Some findings partially corroborates earlier reports from other studies and at the same time contradicts other reported findings. It has been reported that the quantity of some compounds of essential oils increase while others decrease as the plant age. According to Gholamreza *et al*. [25] the proportions of limonene, methofuran and pulegone compounds in peppermint oil decreased while menthol, cineole and neomenthol constituents increased as the plant aged. Such fluctuations in chemical composition of the essential oils due to variation in age influences the efficacy of the essential oil. It was also reported that essential oil extracted from a ten months old ginger rhizome lacked zingiberene while older ones produced oil with zingiberene [27]. These findings verify that the chemical composition and yield of essential oil is dependent on the different stages of growth as the plant ages and this may be as a result of modifications of secondary metabolism as the growth of the plant progresses. The variation in chemical composition as the plant ages influences the efficacy of the essential oils.

2.1.2. Part of the Plant Producing and Storing the Oil

Plant essential oils can be extracted from either the roots, stems, flowers, leaves or seeds. Different plant species store their essential oils in different parts. For example, plants of Lamiaceae family store their essential oils in the aerial parts while Citrus family store their oils in fruit peels and leaves [28]. The plant parts store oils with different chemical composition depending on the part of the plant. For example, the essential oil extracted from the flowers of *Salvia officinalis* had the highest quantity of β- pinene while the oil extracted from the leaves of the same plant had more α and β thujones [29]. There were also significant differences noted in the quantities of the essential oils produced from the different parts of the plant. The differences in chemical composition brings about variability in the essential oil efficacy [29].

Reports of Cheng *et al*. [30] showed significant differences in the chemical composition of essential oils obtained from four different tissues. Similarly, essential oils obtained from the leaves and flowers of *Lavandula stoechas* showed significant chemical variability especially with myrtenyl acetate and 1,8-cineole [31]. Some of the chemicals present in the essential oils are more effective on certain pest and pathogens and less effective on others. Analysis of *Lantana camara* essential oil extracted from the leaves and flowers revealed that the oil from the leaves had 36 compound that were not in the essential oil from the flowers with *cis*-3-hexen-l-ol compound taking the lead. This compound is said to have high efficacy against diseases caused by Fusarium. On the other hand, the oil from the flowers had 29 compounds that were only present in it but were absent in the oil from the leaves with caryophyllene oxide taking the lead [32]. The essential oil from the leaves recorded a higher number of the chemical compounds with the oxygenated sesquiterpenes dominating than the oil from the flowers. The amount of linalool and phytol was significantly higher in oil from the leaves than the oil from the flowers [32].

Monoterpenes and sesquiterpenes are known to contribute to the antifungal and antibacterial properties of essential oils and so their presence makes the essential oil more effective [11]. In addition, *Tagetes minuta* leaf essential oil compounds differed significantly with those in the oil extracted from the seeds. In the leaf essential oil dihydrotagetone took the lead (54.2%) while the oil from the seed was dominated by (Z)-β-ocimene [33]. According to the report of Zhao *et al*. [34] the roots of *Kadsura coccinea* essential oil had more compounds (47) as compared to the leaves (46) and the stem (44). However, the essential oil from the roots showed a higher antioxidant activity followed by the oil from the stem and the least antioxidant activity was from the leaf oil [34]. The antimicrobial properties of the root essential oil was higher compared to leaf and stem essential oils due to high level of oxygenated monoterpenes in the root essential oil which is said to have high antibacterial activity. Essential oil from leaves of *Siparuna muricata* had more chemical compounds than the oil from the fruits of the same plant. Hydrocarbon monoterpenes were significantly higher in the essential oil from the leaves than the oil from the fruits [35].

2.1.3. Variation in genotypes within plant species

The chemical variability in essential oils of similar plant species may be genetically influenced as evidenced in some plant species. Three different *Salvia fruticosa* populations were studied using Random Amplified Polymorphic DNA (RAPD) markers and essential oil profiles in order to determine their genetic variability [31]. The significant variation in the composition of essential oils allowed three clusters to be distinguished from the canonical discriminate analysis, corresponding to the three selected populations from diverse geographical locations. The results of genetic characterization and hierarchical cluster analysis revealed an extensive level of polymorphism confirming that there is also genetic variability within each population [31].

Similar results of the research conducted by Echeverrigaray *et al*. [36] on six cultivars of *Thymus vulgaris* using RAPD technique grouped the plants into two chemical and genetic groups. Analysis of essential oils of *Ocimum gratissimum* using RAPD showed a high correlation between genetic results and the essential oil constituents [37]. According to the results some groups of oils contained eugenol, others geraniol and others had thymol compounds indicating variability in their chemical composition. Similarly, a rapid analysis of *Artemisia annua* essential oil using RAPD showed a high degree of genetic variability in chemical composition [38]. Results of Nan *et al*. [39] revealed existence of three chemotypes of *Primula ovalifolia* based on genetic variations.

Plants such as *Thymus vulgaris* have seven different chemotypes depending on the chemical compound that is dominant in the essential oil. These dominant compounds were either thymol, α-terpineol, carvacrol, eucalyptol, linalool, sabinene hydrate or geraniol [40]. These dominant compounds influence the efficacy of the essential oils. According to Yaqub *et al*. [41], ten populations of *Stachys lavandulifolia* were investigated for their essential oil composition and it was revealed that some contained pulegone and α-zingiberene as the major essential oil constituents while another group had germacrene D and limonene as the main essential oil compounds. This may be attributed to the genetic factors.

2.1.4. Plant Density

Some studies have revealed that plant density influenced the content and composition of essential oils. It has been reported that low plant density resulted to high content of essential oil. This is because low plant density will reduce competition for resources like light, water and nutrients enabling the plants to be able to synthesis of various compounds within them. For example, in sweet basil low plant density yielded more essential oil than high plant density [42]. Similarly, thyme and parsley essential oils were found to decrease as the plant density increased [43]. However, these finds contradicts the reports of other researchers like Callan *et al*. [44] who reported that the plant density had no effects on the essential oils of parsley. Hyssop plant also showed no response to plant density [45].

2.2. The Exogenous Factors

These are environmental factors that influence plant growth, essential oil composition, yield and the essential oil efficacy. These factors include light, rainfall (precipitation), geographical location (altitude and latitude), the soil (pH and soil components).

2.2.1. Light intensity and temperature

Research has pointed out that light is responsible for variation in chemical compounds of essential oils of similar plant species growing in environments with different light intensity. This is because light intensity influences plant metabolic activities that results to synthesis of the chemical compounds. For example, it was noted that high light intensity was responsible for increased concentrations of phenyl propanes and monoterpenes in *Ocimum basilicum* and *Satureja douglasii* [46, 47]. These components increase the efficacy of essential oils. Temperature also influenced the synthesis of essential oil both positively and negatively in different plants. Temperature influences enzyme controlled reactions that results to the synthesis of various chemical compounds. It was reported that *Feoniculum vulgare* essential oil yield correlated negatively with high temperature [48] but positively correlated in Eucalyptus essential oil yield [49]. Moreover, findings have also reported the influence of temperature on the *Ocimum basilicum* with the highest essential oil yield when temperatures were low [50].

2.2.2. Water availability

Water availability influences chemical composition of essential oils by influencing the secondary metabolism since biosynthetic reactions occur in an aqueous medium. In relation to this, research has shown that increase in water availability increased monoterpenes production in essential oils [51, 52]. However, these results did not agree with those of Boira and Blanquer [53] who reported that moneterpenes increased in *Thymus piperella* essential oil when the water availability was low. Nowak *et al.* [54] also reported increase in concentration of moneterpenes during drought periods. Monoterpenes exhibit potential antimicrobial activity and strongly inhibit microbial pathogens. The more the monoterpenes in an essential oil the more effective it is in controlling microbial pathogens.

It has also been reported that water deficit resulted to increase in essential oil compounds such as α- and β- thujone, 1,8-cineol and camphor [55]. However, a decrease in p-cymene compound in *Thymus vulgaris* essential oil under water deficit was noted [56]. Studies carried on essential oil extracted from *Origanum vulgare* [57] and *Satureja Hortensis* [58] showed that the essential oil constituents and yield was influenced by water. Results revealed that the quantity and chemical content of essential oil increased with decrease in water availability. Under water stress conditions more essential oil was produced [59]. Similar results were reported by El-Zaeddi *et al*. [43] who reported increase in the quantity of essential oil from the leaves of curley-leafed and plain-leafed parsley under drought conditions. Several other researchers have also reported similar results stating that essential oil increase with decrease in water availability [45, 58, 60].

In addition, the report of Yaqub *et al*. [41] revealed that the chemical composition of *Stachys lavandulifolia* essential oil varied significantly with annual precipitation. More chemical compounds were identified from oils extracted when the plants were growing under low precipitation. It is believed that water stress reduces the leaf area of the plant resulting to a higher density of the grandular trichomes that produce essential oils on the leaf tissue, thus the quantity of essential oil per unit of the leaf tissue increases [24]. However, according to Corell *et al.* [61] lack of water reduced the quantity of oil produced in *S. officinalis.* Similar results were also reported in *Mexican oregano* [62] and parsley [63]. Report of Gholamreza *et al*. [25] showed that drought stress can lower the yield and content of essential oils in medicinal plants which does not conform to the previous reports. A study carried on *Artemisia annua* revealed that water deficit stress lowered the density of grandular trichomes on both surfaces of the leaves and resulted to decrease in the quantity of the essential oil [64] which is contrary to the previous reports. Reports of Clark and Menary [65], revealed that increase in the level of irrigation increased the yield of essential oil and other dry matter. These reports contradict that of Baghalian *et al.* [66] who reported that water stress had no significant effect on German chamomile essential oil content.

2.2.3. Altitude and Latitude

The altitude of the region where the plant is growing has an influence on the quality and efficacy of the essential oil of the same plant species growing in different altitude. According to the report of Satta *et al.* [67] the chemical composition of *Helichrysum italicum* essential oil varied significantly with the altitude. The chemical composition of essential oil from plants growing at an altitude range of 200-900 m above sea level varied significantly with those from plants growing at an altitude range of 0-100 m above sea level. This was noted in monoterpenes content in thymus essential oil [53]. According to Neucirio *et al*. [68] sesquiterpenes were significantly higher in oils extracted from *Hyptis suaveolens* growing in low altitudes while monoterpenes were significantly higher in essential oils extracted from those growing in high altitude. According to Vokou *et al.* [59] the chemical composition and quantity of essential oil increased with decrease in altitude. The essential oil quantity of *Thymus migrus* was found to be low in higher attitude of 1900 m above sea level [69]. According to Patel *et al.* [70] Ocimum essential oils were different in composition in different altitudes. Torras *et al*. [71] reported that high altitude caused a significant decrease in the *Tymus vulgaris* essential oil.

According to Di Giacomo and Mincione [72], *Citrus bergamia* grown in different latitudes produced essential oils that were varying significantly in their chemical composition. Similarly, a study carried out by Neucirio *et al.* [68] on the chemical composition of essential extracted from *Hyptis suaveolens* growing in different latitudes showed that the oil from plants growing in low latitudes were richer in sesquiterpenes. Sesqiterpenes in essential oils exhibit high anti-microbial activity and so the more they are in the essential oil the more the efficacy as a bio-pesticide. Slavkovska *et al.* [73] also obtained similar results after studying on the *Satureja montana* essential oil extracted from plants growing in different latitudes.

Reports of Mugao *et al.* [74] revealed that zingiberene, a compound found in ginger essential oil varied significantly with the geographical location of ginger plant. For example, in India zingiberene amount in essential oil was 46.2%, China (38.12), Nigeria (29.0%) Australia (20-28%), Mauritius (9.5%), Central African Republic (3.6%) and Srilanka (1.5%). These countries are in different altitudes and latitudes. It was also reported that the essential oil extracted from leaves and flowers of tick berry in Madagascar and Cameroon contained curcumene compound [75] while the one extracted in Kenya lacked curcumene [74]. Studies on the chemical compounds of *Tagetes patula* essential oil derived from different countries (India, Egypt and South Africa) revealed different chemical composition [76]. In this study the oil from South Africa had the highest (E)-β-ocimene (69.8%) while the oil from India had the lowest (35.3%). According to Marzieh and Iraji [77] high latitude increased the essential yield of *Achillea eriophora*.

2.2.4. Soil Type and Composition

The soil type, pH and soil constituents influences the yield, efficacy and chemical composition of the essential oils because the plants depend on the soil for nutrients and the pH influences the nutrient absorption from the soil by the plants. In connection to this, a research carried by Barra [28] showed that *Rosmarinus officinalis* essential oil chemical composition varied significantly in different pH of the soil in the same altitude. Similarly, Pala *et al*. [51] reported that *Erygium campestre* plants grown in separate soil pH (alkaline and acidic) conditions produced essential oils that varied significantly in the chemical composition. The population grown in acidic soil produced essential oil that had significantly higher amount of myrcene and lower amount of β-curcumene than the population grown in alkaline soils. According to De Feo *et al*. [78], *Thymus spinulosus* grown in calcareous soil produced essential oil with high monoterpenes content while those grown in siliceous soil produced essential oil with high sesquiterpenes.

Similar results were obtained by Robles and Garzino [79], after analyzing the chemical composition of essential oils of *Cistus monspeliensis* grown in calcareous soils and in siliceous soil. Elsewhere, it was reported that the content of phosphorus in the soil influenced the chemical composition of *Salvia officinalis* essential oil [80]. According to Smith and Read [81], phosphorus is required by plants since it forms a constituent of nucleic acids or biomembranes. Phosphorus is also involved in energy metabolism of cells and therefore necessary in biosynthesis of primary and secondary metabolites such as terpenoids in plants. That means then that plants growing is soils with high phosphorus will have more terpenoids in their essential oils. Similarly, reports of Dordas [82] showed that *Origanum vulgare* essential oil yield increased with increase in calcium concentration in the soil. Low levels of calcium depress plant growth and reduce the essential oil yield [83].

Nitrogen, potassium and phosphorus influenced the synthesis of essential oil in aromatic plants by influencing the levels of enzymes necessary for biosynthesis of terpenoids [84]. Indeed, nitrogen plays a big role in synthesis of enzymes and amino acids which facilitate the biosynthesis of many compounds that are found in essential oils [85]. For example, findings of Rioba *et al*. [86] revealed that nitrogen levels influenced the quantity of the monoterpene β-pinene in the *Salvia officinalis* essential oil while increased phosphorus increased the level of α-bisabolol compound in *Chamomilla recutia* essential oil. However, fluctuations of linalool and limonene was experienced with application of potassium in caraway essential oil [87].

A research on purple basil revealed differences in essential oil quantity depending on the type of soil. Basil growing in loamy sand soil produced significantly higher amount of essential oil than basil growing in sandy-clay loam and clay soil types. Increase in the amount of sand in the soil composition increased essential oil yield while increase in the amount of clay decreased essential oil yield in basil [88]. It was also reported that basil grown in clay soil produced essential oil with significantly higher chemical compounds (72 compounds) as compared with sandy-clay soil while those grown in loamy sandy soil produced essential oil with the lowest number of chemical compounds. Increased amount of sand content in the soil resulted to increased number of chemical compounds in the basil essential oil.

The opposite happened when the ratio of clay was increased in the soil [88]. In terms of individual groups of compounds monoterpenes were significantly high in the essential oils from the basil grown in sandy-clay soils while the basil grown in loamy-sandy soil recorded the lowest monoterpene compounds. Decreased amount of clay ratio in the soil increased the number of aromatic compounds and linalool [88]. It is believed that plants grown in sandy soil are likely to be exposed to more stress factors such as water shortage, and low nutrient content and these stressors results to plants producing more essential oils [89]. In contrary to these findings Ahmed *et al*. [90] reported that the soil parameters had no significant influence on the essential oils of *Artemisia monosperma*.

2.2.5. Seasonal Variations

The yield and chemical composition of essential oils from the same plants may vary from season to season and this is influenced by variation in precipitation during the dry and the rainy season and temperature changes within seasons. It was reported that in *Salvia officinallis* essential oil, monoterpene hydrocarbons significantly increased while the oxygenated monoterpenes decreased significantly in winter [91]. This brings about variability in efficacy between essential oils from plants grown in winter and those grown in summer. The essential oil of *Salvia libanotica* produced during winter time was reported to have more camphor, thujones and camphene than the oil produced during spring time [92]. It has been reported that oxygenated monoterpenes in the essential oils destroy cells of micro-organisms, inhibit cell respiration and ion transport processes resulting death of the microorganisms [93]. That means essential oils with more oxygenated monoterpenes have a higher antimicrobial activity.

Results of the analysis of *Tagetes minuta* essential oil from India revealed that plants harvested in winter (December-January) had their essential oil having more quantities of ocimenes while those that were harvested in autumn (October-Novemeber) had their oil dominated by dihydrotagetone. However, the plants harvested in summer (June) had their oil dominated by tagetone compounds [94]. Similarly, *Ocimum basilicum* essential oil was found to have high concentration of oxygenated sesquiterpenes and oxygenated monoterpenes (80%) during winter but the concentration was a bit lower (74%) during summer [50]. These findings are also supported by the report of Ahmed *et al*. [90] who revealed that the yield of essential oil significantly varied with seasons. *Artemisia monsperma* produced more oil during the spring season and less during autumn. These results also corroborates with those of El-Sherei *et al*. [95] who reported that *Solidago canadensis* essential oil significantly increased in summer as compared to other seasons. Summer being the hottest season creates a stressful condition that makes plants secrete more oil. It was also reported that the antioxidant activity of *Artemisia monosperma* essential oil varied with seasons where samples collected during autumn and summer seasons showed significantly higher antioxidant activity as compared to winter and spring seasons [90].

2.2.6. Treatment of the plant material before oil extraction

Research has revealed that the treatment process that the plant material undergo through before oil extraction influences the chemical composition, yield and efficacy of the essential oil. Some researchers freeze-dry the plant materials before oil extraction while others air-dry them. Some also use the fresh material directly for oil extraction. According to Kelly and

Valtcho [96], essential oil from air-dried basil lacked carene while the essential oil from freeze-dried basil had carene compound. On the other hand, freeze-drying was seen to significantly lower the concentration of both linalool and methyl chavicol in basil essential oil [96].

A study conducted by Moshafi *et al.* [97] reported high quantities of zingiberene compound in essential oil extracted from fresh ginger while the essential oil extracted from dried ginger had high citral content. The essential oil from the dried ginger was reported to have lower amounts of the chemical compounds as compared to those that were present in the essential oil extracted from fresh ginger. The variation in the chemical composition brings about variation in their efficacy. Studies have also revealed that essential oil extracted from fresh garlic contains high terpene content [74] while dried garlic lacked terpenes in their essential oil [98]. A different study revealed that that the chemical compounds of lemon verbena essential oil increased with increase in temperature and air-flow rate [99].

2.2.7. The method of oil extraction

There are various methods of essential oil extraction. These include, low temperature distillation for compounds that require low temperatures and steam distillation for those that require high temperatures [2], Extraction with solvents and hydro-distillation [100], microwave assisted distillation, expression, supercritical carbon dioxide extraction, enfleurage, phytonic process and ultrasonic extraction [101, 102]. The method of essential oil extraction determines the chemical composition hence the quality of essential oils. For example, essential oil from rosemary extracted using microwave-assisted extraction and Clevenger hydrodistillation method showed significance differences in chemical concentration α-Pinene concentration was higher (42.3) in the essential oil extracted using microwave-assisted extraction while the same compound was low (26.20) in the essential oil extracted through Clevenger hydrodistillation method (103). On the other hand, 1,8 Cineole concentration was low (31.73) in microwave assisted extraction but more (40.72) in clevenger hydrostillation method (103). Inappropriate extraction procedures can result to change or damage of the chemical nature of the essential oil [3]. Most of the natural products are thermally unstable and can be damaged easily during thermal extraction and this lowers the quality and efficacy of the essential oil [74]. For example, when the essential oil is required in large scale steam distillation is commonly used because large quantities can be extracted but the water used and high temperatures can cause chemical modifications [74].

The compounds soluble in water are easily lost in water when hydro-distillation is used and the volatile compounds get lost because of high temperatures under steam distillation [104, 105]. Monoterpenes are susceptible to chemical changes under steam distillation [106]. On the other hand, essential oil extracted through solvent extraction are mostly contaminated by the solvent used for extraction and these solvents can pollute food and fragrances [104]. In order to avoid chemical compounds' damage, the method of essential oil extraction should be dependent on the kind of the chemical compounds suspected to be in the oil and the location of the oils within the vegetative structure of the plant species [100]. Therefore, knowledge about characteristics of various chemical compounds of the essential oils is necessary in order to get a suitable method of essential oil extraction which does not cause damage on them.

2.2.8. Essential oil storage conditions

The chemical composition and the efficacy of the essential oils is also affected by the storage conditions. When the essential oil is exposed to air it easily loses its smell thus lowering the repellant activity. Exposure to sunlight may result to oxidation thus lowering the chemical composition [107]. The UV rays from the light brings about breakdown of molecules resulting to free radicles that influence the efficacy of essential oils. Additionally, when the essential oils are exposed to light some substances in the essential oil significantly increase while others significantly decrease and this affect the microbial activity and the chemical composition [108, 109].

After one-month storage of *Homalomena occulta* essential under direct light, the concentration of Linalool compound increased slightly in the first month but decreased in the second month of the experimental setup. In contrast, Terpenen-4-ol in the same essential continued to decrease throughout the experimental period [110]. Linalool exhibits strong antibiotic activity and therefore its reduction results in low antibiotic activity [111]. Research has also indicated that chemical reactions in essential oil increase with increase in temperature. Temperature between 4 °C and 45 °C causes denaturation of the essential oil content. It was reported that there was a great decline in the chemical composition of *Homalomena occulta* essential oil due to degradation as the temperature increased [110]. Exposure of essential oil to air in the storage containers increases the rate of oxidation under the influence of oxygen which distorts the chemical composition and thus should be stored in air-tight containers to maintain its quality. According to Nguyen, [112] factors such as temperature, light and oxygen influence colour changes, aroma, viscosity and chemical composition of essential oils.

3. Conclusion

Essential oils even from same plant species vary significantly in their yield, chemical composition and their efficacy. These variations are influenced by factors within the plant such as genotypes, age, plant density, part of the plant from which the oil is being extracted from among others. Environmental factors such as light intensity and temperature, essential oil storage after extraction, soil type and composition, methods of essential oil extraction, altitude and latitude also influence the yield chemical composition of essential oils. The environmental factors influence genetic diversity of plants as plants try to adjust to the prevailing conditions for survival resulting to variation in yield and chemical composition of their essential oils. A balance in these conditions is necessary to obtain quality essential oils. Essential oils need proper storage conditions to avoid oxidation after extraction as they await to be used. They should be stored in dark cool conditions in a tightly closed dark glass containers to ensure long term quality. Knowledge on the growth requirements of the individual plants that produce oils, their chemical composition of the plants and methods of extraction is necessary so as to produce quality oil.

4. Conflicts of Interest

The authors declare that they have no conflicts of interest.

5. References

1. Wink M. Plant secondary metabolites modulate insect behavior-steps towards addiction. Frontiers in Physiology. 2018;9:364.
2. Baser KH. Handbook of Essential Oils: Science, Technology and Applications. University of Wien, Austria; 2010. ISBN 978-1-4200-6315-8.
3. Adorjan B, Buchbauer G. Biological properties of essential oils: An updated review. Flavour and Fragrance Journal. 2010;25(6):407–426.
4. Rehman R, Hanif MA, Mushtaq Z, Mochona B, Qi X. Biosynthetic factories of essential oils: the aromatic plants. Natural Products Chemistry and Research. 2016;4(4):227.
5. Sell C. Chemistry of essential oils. In: Baser KH, Buchbauer G, editors. Handbook of Essential Oils Science, Technology, and Applications. Boca Raton, FL: CRC Press; 2010;121-150.
6. Shakeel R, Masood R, Iram A. Aromatherapy-Scope through selected essential oil-bearing plants in Jammu and Kashmir (India). EC Pharmacology and Toxicology. 2018;6(1):5-12.
7. Tongnuanchan P, Benjakul S. Essential oils: extraction, bioactives and their uses for food preservation. Journal of Food Science. 2014;79(7):1231-1249.
8. Parthasarathy VA, Chempakam B, Zachariah TJ. Chemistry of spices. London: CAB International; 2008;21-40.
9. Benites J, Moiteiro C, Miguel G, Rojo L, Lopez J, Venancio F, *et al*. Composition and biological activity of the essential oil of Peruvian Lantana camara. Journal of the Chilean Chemical Society. 2009;54:379-384.
10. Sousa EO, Rocha JBT, Barros ARC, Costa JGM. Phytochemical characterization and in-vitro antioxidant properties of *Lantana camara* L. and *Lantana montevidensis* Briq. Industrial Crops and Products. 2013;43:517-522.
11. Sridhar SR, Rajagopal RV, Rajavel R, Masilamani S, Narasimhan S. Antifungal activity of some essential oils. Journal of Agricultural and Food Chemistry. 2003;51(26):7596-7599.
12. Angioni A, Barra A, Coroneo V, Dessi S, Cabras P. Chemical composition, seasonal variability, and antifungal activity of *Lavandula stoechas* L. ssp. *stoechas* essential oils from stem/leaves and flowers. Journal of Agricultural and Food Chemistry. 2006;54(12):4364-4370.
13. Sohani NZ, Hojjati M, Barrachina AA. Bioactivity of *Lantana camara* L. essential oil against *Callosobruchus maculatus* (Fabricius). Chilean Journal of Agricultural Research. 2012;72(4):502-507.
14. Raina VK, Ajai K, Aggarwal KK. Essential oil composition of ginger (*Zingiber officinale* Roscoe) rhizomes from different places in India. Journal of Essential Oil Bearing Plants. 2005;8(2):187-191.
15. Franz CH. Genetics. In: Hay RKM, Waterman PG, editors. Volatile Oil Crops: Their Biology, Biochemistry, and Production. Harlow, UK: Longman; 1993;93-66.
16. Mariajancyrani J, Chandramohan G, Brindha P, Saravanan P. GC-MS analysis of terpenes from hexane extract of *Lantana camara* leaves. International Journal of Advances in Pharmacy, Biology, and Chemistry. 2014;3(1):2277-4688.
17. Shokrpour M, Abdi G, Salami SA. Essential oil composition at different plant growth development of peppermint (*Mentha* × *piperita* L.) under water deficit stress. Journal of Essential Oil Bearing Plants. 2019;22(2):431-440.
18. Hudaib M, Speroni E, Di Pietra AM, Cavrini V. GC/MS evaluation of thyme (*Thymus vulgaris* L.) oil composition and variation during the vegetative cycle. Journal of Pharmaceutical and Biomedical Analysis. 2002;29:691-700.
19. Pagoula F, Baser KH, Kurkcuoglu M. Essential oil composition of *Eucalyptus camaldulensis* Dehnh from Mozambique. Journal of Essential Oil Research. 2000;12:333-335.
20. McConkey ME, Gershenzon J, Croteau RB. Developmental regulation of monoterpene biosynthesis in the glandular trichomes of peppermint. Plant Physiology. 2000;122:215-224.
21. Senatore F. Oli essenziali, provenienza estrazione ed analisi chimica. Roma, Italy: EMSI; 2000.
22. Mallavarapu GR, Kulkarni RN, Baskaran K, Rao L, Ramesh S. Influence of plant growth stage on the essential oil content and composition in Davana (*Artemisia pallens* Wall.). Journal of Agricultural and Food Chemistry. 1999;47:254-258.
23. Tiwari A, Goswami P, Bisht BS, Chauhan A, Verma RS, Padalia RC. Essential oil composition of African marigold (*Tagetes minuta* L.) harvested at different growth stages in foothill agroclimatic conditions of North India. American Journal of Essential Oils and Natural Products. 2016;4(3):4-7.
24. Croteau R, Martinkus C. Metabolism of monoterpenes: demonstration of (1)-neomenthyl-b-D-glucoside as a major metabolite of (2)-menthone in peppermint (*Mentha piperita*). Plant Physiology. 1979;64:169-175.
25. Gholamreza A, Majid S, Seyed AS. Essential oil composition at different plant growth development of peppermint (*Mentha* × *piperita* L) under water deficit stress. Journal of Essential Oil Bearing Plants. 2019;12:1-12.
26. Prakasa Rao EVS, Puttanna K, Ramesh S. Effect of nitrogen and harvest stage on the yield and oil quality of *Tagetes minuta* L. in tropical India. Journal of Herbs, Spices, and Medicinal Plants. 2000;7:19-24.
27. Sharma RK, Sarma TC, Leclereq PA. Essential oils of *Zingiber officinale* Roscoe from North East India. Journal of Essential Oil Bearing Plants. 2002;5(2):71-76.
28. Barra A. Factors affecting chemical variability of essential oils: a review of recent developments. Natural Product Communications. 2009;4(8):1147-1154.
29. Perry NB, Andreson RE, Brennan NJ, Douglas MH, Heaney AJ, McGimpsey JA, *et al*. Essential oils from Dalmatian sage (*Salvia officinalis* L.): variations among individuals, plant parts season and sites. Journal of Agricultural and Food Chemistry. 1999;47:2048-2054.
30. Cheng SS, Lin HY, Chang ST. Chemical composition and antifungal activity of essential oils from different tissues of Japanese cedar (*Cryptomeria japonica*). Journal of Agricultural and Food Chemistry. 2005;53:614-619.
31. Skoula M, El Hilali I, Makris AM. Evaluation of the genetic diversity of *Salvia fruticosa* Mill. using RAPD markers and comparison with the essential oil profiles. Biochemical Systematics and Ecology. 1999;27:559-568.

32. Meajiddin K, Adeem M, Hamad ZA. Characterization of leaves and flowers volatile constituents of *Lantana camara* growing in central region of Saudi Arabia. Arabian Journal of Chemistry. 2015;9:764-774.
33. Gupta P, Vasudeva N. Marigold: a potential ornamental plant drug. Hamdard Medicus. 2012;55:45–59.
34. Zhao T, Ma C, Zhu G. Chemical composition and biological activities of essential oils from the leaves, stems and roots of *Kadsura coccinea*. *Molecules*. 2021;26(20):6002.
35. Morocho V, Hidalgo-Tapia M, Delgado-Loyola I, Cartuche L, Cumbicus N, Valarezo E. Chemical composition and biological activity of essential oil from leaves and fruits of limoncillo (*Siparuna muricata* (Ruiz & Pav.). Antibiotics. 2023;12:180.
36. Echeverrigaray S, Agostini G, Atti-Serfini L, Paroul G, Pauletti GF, Atti dos Santos AC. Correlation between the chemical and genetic relationships among commercial thyme cultivars. Journal of Agricultural and Food Chemistry. 2001;49:4220-4223.
37. Hosni K, Jemli M, Dziri S, Msallem M, Dhibi M, Casabianca H. Seasonal variations in essential oils composition of *Salvia officinalis* leaves from different wild populations. Food Chemistry. 2013;15:354-361.
38. Soares MC, Lahti RA, Ruddick JA, Willey RB, Goldberg SR. The antinociceptive effect of linalool in rats: interactions with the central nervous system. International Journal of Experimental and Clinical Pharmacology. 1997;31:484-488.
39. Tene A, Tantaoui-Elaraki A. Effect of pH on the antifungal activity of cinnamon oils against food spoilage yeasts. Journal of Essential Oil Research. 1997;9:289-295.
40. Cimanga K, Apers S, De Bruyne T, Hermans N, Totte J, Pieters L, *et al*. Chemical composition and antifungal activity of essential oils of different *Ocimum* species. Phytochemistry. 2002;59:101-107.
41. Mohammadi L, Delazar A, Bahadori MB, Farimani MM, Maham M. Chemical composition and antioxidant activity of essential oils and methanol extracts of *Lantana camara* L. Natural Product Research. 2016;30:236-239.
42. Ozioma EO, Chinwe OA. Herbal medicines in African traditional medicine. In: Watson RR, Preedy VR, editors. Bioactive Foods in Promoting Health. 1st ed. Academic Press; c2010;551-563.
43. Rajput SB, Karuppayil SM. Activity of phytochemical compounds against human fungal pathogens: a review of methods and mechanisms of action of antifungal resistance. Fungal Biology Reviews. 2013;27(4):152-160.
44. Sher H, Aldosari AA. A Review on the potential therapeutic uses of essential oils and their chemical components: focus on *Lantana camara*. Journal of Essential Oil Bearing Plants. 2020;23(4):791-808.
45. Vanisree M, Lee CY, Lo SF, Nalawade SM, Lin CY, Tsay HS. Studies on the production of some important secondary metabolites from medicinal plants by plant tissue cultures. Botanical Bulletin of Academia Sinica. 2004;45:1-22.
46. Singh B, Sharma RA. Plant terpenes: defense responses, phylogenetic analysis, regulation and clinical applications. 3 Biotech. 2015;5:129-151.
47. Machado DG, Cunha MP, Neis VB, Balen GO, Colla A, Bettio LE, *et al*. Antidepressant-like effects of the sesquiterpene *beta*-caryophyllene in a mouse model of depression. Physiology & Behavior. 2015;138:60-67.
48. Setzer WN, Duke SO, Craker LE. Handbook of Essential Oils: Science, Technology and Applications. 2nd ed. CRC Press; c2016;163-197.
49. Raut JS, Karuppayil SM. A status review on the medicinal properties of essential oils. Industrial Crops and Products. 2014;62:250-264.
50. Verma RS, Rahman L, Verma RK, Chauhan A, Yadav AK, Singh A, *et al*. Essential oil composition of *Lantana camara* L. during the year from lower region of Himalayas. Natural Product Research. 2014;28:725-732.
51. Palà-Paùl J, Perèz-Alonso MJ, Velasco-Neguerela A, Palà-Paùl R, Sanz J, Conejero FC. Seasonal variation in chemical constituents of *Santolina rosmarinifolia* L. ssp. Rosmarinifolia. Biochemical Systematics and Ecology. 2001;29:663-72.
52. Taveira FSN, de Lima WN, Andrade EHA, Maia JGS. Seasonal essential oil variation of *Aniba canelilla*. *Biochemical Systematics and Ecology*. 2003;31:69-75.
53. Boira H, Blanquer A. Environmental factors affecting chemical variability of essential oils in *Thymus piperella* L. Biochemical Systematics and Ecology. 1998;26:811-22.
54. Nowak M, Kleinwächter M, Manderscheid R, Weigel HJ, Selmar D. Drought stress increases the accumulation of monoterpenes in sage (*Salvia officinalis*), an effect that is compensated by elevated carbon dioxide concentration. Journal of Applied Botany and Food Quality. 2012;83(2):133-6.
55. Manukyan A. Effect of growing factors on productivity and quality of lemon catmint, lemon balm and sage under soilless greenhouse production and drought stress. Medicine and Aromatic Plant Science and Biotechnology. 2011;5:119-25.
56. Azizi K, Kahrizi D. Effect of nitrogen levels, plant density and climate on yield quantity and quality in cumin (*Cuminum cyminum* L.) under the conditions of Iran. Asian Journal of Plant Science; 2008.
57. Azizi A, Yan F, Honermeier B. Herbage yield, essential oil content and composition of three oregano (*Origanum vulgare* L.) populations as affected by soil moisture regimes and nitrogen supply. Industrial Crop Production. 2009;29:554-61.
58. Baher ZF, Mirza M, Ghorbanli M, Bagher Rezaii M. The influence of water stress on plant height, herbal and essential oil yield and composition in *Satureja hortensis* L. Flavour Fragrance Journal. 2002;17(4):275-7.
59. Vokou D, Kokkini S, Bessiere JM. Geographic location of Greek oregano (*Origanum vulgare* ssp. *Hirtum*) essential oils. Biochemical Systematics and Ecology. 1993;21(2):287-95.
60. Karamzadeh S. Drought and production of secondary metabolites in medicinal and aromatic plants. Drought Journal. 2003;7:90-5.
61. Corell M, Castillo García M, Cermeño P. Effect of the deficit watering in the production and quality of the essential oil, in the cultivation of *Salvia officinalis* L. Acta Horticulture. 2007;826:281-8.
62. Dunford NT, Vazquez RS. Effect of water stress on plant growth and thymol and carvacrol concentrations in Mexican oregano grown under controlled conditions. Journal Applied and Horticulture. 2005;7(1):20-2.

63. Petropoulos S, Daferera D, Polissiou M, Passam H. The effect of water deficit stress on the growth, yield and composition of essential oils of parsley. Science and Horticulture. 2008;115(4):393-7.
64. Yadav RK, Sangwan RS, Sabir F, Srivastava AK, Sangwan NS. Effect of prolonged water stress on specialized secondary metabolites, peltate glandular trichomes, and pathway gene expression in *Artemisia annua* L. Plant Physiology and Biochemistry. 2014;74:70-83.
65. Clark RJ, Menary RC. The effect of two harvests per year on the yield and composition of Tasmanian peppermint oil (*Mentha piperita* L.). Journal of the Science of Food and Agriculture. 2006;35:1191-5.
66. Baghalian K, Abdoshah S, Khalighi-Sigaroodi F, Paknejad F. Physiological and phytochemical response to drought stress of German chamomile (*Matricaria recutita* L.). Plant Physiology and Biochemistry. 2011;49(2):201-7.
67. Satta M, Tuberoso CI, Angioni A, Pirisi FM, Cabras P. Analysis of the essential oil of *Helichrysum italicum* G.Don. ssp. *Microphyllum* (Willd.). Journal of Essential Oil Research. 1999;11:711-5.
68. Neucirio RA, Irani FP, Heleno DF, Tomas AP, Sizana CS, Jose RP, *et al*. Chemical variability in the essential oil of *Hyptis suaveolens*. Phytochemistry Journal. 2001;57:733-6.
69. Yavari A, Nazeri V, Sefidkon F, Hassan MH. Influence of some environmental factors on the essential oil variability of *Thymus migricus*. Journal of Natural Products and Communications. 2010;5(6):943-8.
70. Patel RP, Singh R, Rao BR, Singh R, Srivastava A, Lal R. Differential response of genotype × environment on phenology, essential oil yield and quality of natural aroma chemicals of five *Ocimum* species. Industrial Crop Production. 2016;87:210-7.
71. Torras J, Grau MD, López JF, de las Heras FXC. Analysis of essential oils from chemotypes of *Thymus vulgaris* in Catalonia. Journal of the Science of Food and Agriculture. 2007;87:2327-33.
72. Di Giacomo A, Mincione B. *Olio essenziale di bergamotto*. Laruffa: Reggio Calabria, Italy; 1995.
73. Slavkovska V, Jancic R, Bojovic S, Milosavljevic S, Djokovic D. Variability of essential oils of *Satureja montana* L. and *Satureja kitaibelii* Wierzb. ex Heuff from the central part of the Balkan Peninsula. Phytochemistry. 2001;57:71-6.
74. Mugao LG, Gichimu BM, Muturi PW, Mukono ST. Characterization of the volatile compounds of essential oils of selected plants in Kenya. Biochemistry Research International; 2020;2020 ID 8861798.
75. Ngassoum MB, Yonkeu S, Jirovetz L, Buchbauer G, Schmaus G, Hammerschmidt FJ. Chemical composition of essential oils of *Lantana camara* leaves and flowers from Cameroon and Madagascar. Flavour Fragrance Journal. 1999;14:245-50.
76. Tisserand R, Young R. Essential Oil Safety: A Guide for Health Care Professionals. 2nd ed. London, UK: Churchill Livingstone Elsevier; c2014.
77. Marzieh E, Iraj T. Ecological factors regulate essential oil yield, percent and compositions of endemic yarrow (*Achillea eriophora*) in Southeast Iran. International Journal of Horticultural Science and Technology. 2019;6(2):201-15.
78. De Feo V, Bruno M, Tahiri B, Napolitano F, Senatore F. Chemical composition and antibacterial activity of essential oils from *Thymus spinulosus* Ten. (*Laminaceae*). Journal of Agricultural and Food Chemistry. 2003;51:3849-53.
79. Robles C, Garzino S. Infraspecific variability in the essential oil composition of *Cistus monspeliensis* leaves. Phytochemistry. 1999;53:71-5.
80. Nell M, Vötsch M, Vierheilig H, Steinkellner S, Zitterl-Eglseer K, Franz C, Novak J. Effects of soil composition on *Salvia officinalis* essential oil. Journal of Science, Food and Agriculture. 2009;89:1090-8.
81. Smith SE, Read DJ. Mycorrhizal Symbiosis. 3rd ed. London: Academic Press and Elsevier; 2008.
82. Dordas C. Foliar application of calcium and magnesium improves growth, yield, and essential oil yield of oregano (*Origanum vulgare* ssp. *hirtum*). Industrial Crops and Products. 2009;29:599–608.
83. Figueiredo AC, Barroso JG, Pedro LG, Scheffer JJ. Factors affecting secondary metabolite production in plants: volatile components and essential oils. Flavour and Fragrance Journal. 2008;23:213–226.
84. Sell C. A fragrant introduction to terpenoid chemistry. Royal Society of Chemistry; 2003.
85. Koeduka T, Fridman E, Gang DR, Vassão DG, Jackson BL, Kish CM, *et al*. Eugenol and isoeugenol, characteristic aromatic constituents of spices, are biosynthesized via reduction of a coniferyl alcohol ester. Proceedings of the National Academy of Sciences USA. 2006;103(26):10128–10133.
86. Rioba NB, Itulya FM, Saidi M, Dudai N, Bernstein N. Effects of nitrogen, phosphorus and irrigation frequency on essential oil content and composition of sage (*Salvia officinalis* L.). Journal of Applied Research on Medicinal and Aromatic Plants. 2015;2(1):21-29.
87. El-Din AAE, Hendawy S, Aziz EE, Omer E. Enhancing growth, yield and essential oil of caraway plants by nitrogen and potassium fertilizers. International Journal of Academic Research. 2010;2(3):192-197.
88. Ayse OT. Impact of soil types on chemical composition of essential oil of purple basil. Saudi Journal of Biological Sciences. 2022;29:103314.
89. Khalid KA, Ahmed AMA. Effect of soil type on grapefruit and shaddock essential oils. Journal of Soil Science and Plant Nutrition. 2021;21(3):2048-2056.
90. Ahmed M, Abdulaziz MA, Saudi A, Mohamed SA, Giuliano B, Abdelsamed IE. Influence of season and habitat on the essential oils composition, allelopathy and antioxidant activities of *Artemisia monosperma* Delile. Journal of Separations. 2023;10(4).
91. Santos-Gomes PC, Fernandes-Ferreira M. Organ and season-dependent variation in the essential oil composition of Salvia officinalis cultivated at two different sites. Journal of Agricultural and Food Chemistry. 2001;49:2908-2916.
92. Farhat GN, Affara NL, Gali-Muhtasib HU. Seasonal changes in the composition of the essential oil extract of East Mediterranean sage (*Salvia libanotica*) and its toxicity in mice. Toxicology. 2001;39:1601-1605.
93. Deba F, Xuan TD, Yasuda M, Tawata S. Chemical composition and antioxidant, antibacterial and antifungal activities of the essential oils from *Bidens pilosa* Linn. var. Radiata. Food Control. 2008;19(4):346-352.

94. Singh V, Singh B, Kaul VK. Domestication of wild marigold (*Tagetes minuta* L.) as a potential economic crop in western Himalaya and north Indian plains. Economic Botany. 2003;57:535-544.
95. El-Sherei M, Khaleel A, Motaal AA, Abd-Elbaki P. Effect of seasonal variation on the composition of the essential oil of *Solidago canadensis* cultivated in Egypt. Journal of Essential Oil Bearing Plants. 2014;17:891-898.
96. Kelly MB, Valtcho DZ. Factors affecting yields and essential oil quality of *Ocimum sanctum* L. and Ocimum basilicum L. cultivars. Journal of the American Society for Horticultural Science. 2004;129(6):789-794.
97. Moshafi MH, Fariba S, Dehghan RG, Ameri Ali EH. Bioassay screening of the essential oil and various extracts of fruits of Heracleum persicum Desf. and rhizomes of *Zingiber officinale* Rocs using brine shrimp cytotoxicity assay. Iranian Journal of Pharmaceutical Research. 2009;8(1):59-63.
98. Rao PP, Nagender A, Rao LJ, Rao DG. Studies on the effects of microwave drying and cabinet tray drying on the chemical composition of volatile oils of garlic powder. European Food Research and Technology. 2007;224:791-795.
99. Shahhoseini R, Ghorbani H, Karimi SR, Estaj A, Moghaddam M. Qualitative and quantitative changes in the essential oil of lemon verbena (*Lippia citriodora*) as affected by drying condition. Drying Technology. 2013;31(9):1020-1028.
100. Singh G, Kapoor IPS, Singh P, Heluani GDS, Lampasona MPD. Chemistry, antioxidant and antimicrobial investigations on essential oil and oleoresins of *Zingiber officinale*. Journal of Food and Chemical Toxicology. 2008;46(10):3295-3302.
101. Okoh O, Sadimenko A, Afolayan A. Comparative evaluation of the antibacterial activities of the essential oils of *Rosmarinus officinalis* L. obtained by hydrodistillation and solvent-free microwave extraction methods. Food Chemistry. 2010;120(1):308-312.
102. Farhat A, Fabiano-Tixier AS, Visinoni F, Romdhane M, Chemat F. A surprising method for green extraction of essential oil from dry spices: microwave dry-diffusion and gravity. Journal of Chromatography A. 2010;1217(47):7345-7350.
103. El Hassan S, Zeroual A, Kasrati A, Gharby S. Combined effects of domestication and extraction technique on essential oil yield, chemical profiling and antioxidant and antimicrobial activities of rosemary (*Rosmarinus officinalis* L.). Journal of Food Biochemistry. 2023;13.
104. Guan W, Li S, Yan R, Tang S, Quan C. Comparison of essential oils of clove buds extracted with supercritical carbon dioxide and other three traditional extraction methods. Food Chemistry. 2007;101(4):1558-1564.
105. Khajeh M, Yamini Y, Shariati S. Comparison of essential oils compositions of Nepeta persica obtained by supercritical carbon dioxide extraction and steam distillation methods. Food and Bioproducts Processing. 2010;88(2):227-232.
106. Lo Presti M, Ragusa S, Trozzi A, Dugo P, Visinoni F, Fazio A, et al. A comparison between different techniques for the isolation of rosemary essential oil. Journal of Separation Science. 2005;28(3):273-280.
107. Tran TK, Tran TH, Le XT, Tran QT, Le NTT, Anh HL, Mai HC. Effect of storage conditions on the chemical composition of Vietnamese clove (*Syzygium aromaticum*) essential oil. Journal of Global Pharma Technology. 2020;12:447-454.
108. Turek C, Stintzing FC. Impact of different storage conditions on the quality of selected essential oils. Food Research International. 2012;46:341-353.
109. Turek C, Stintzing FC. Stability of essential oils: A review. Comprehensive Reviews in Food Science and Food Safety. 2013;12:40-53.
110. Tran NT, Tran TH, Le XT, Tran QT. Chemical compositions and stability of Vietnamese Homalomena occulta essential oil under the influence of storage conditions. Egyptian Journal of Chemistry. 2022;65(7):23-31.
111. Park SN, Lim YK, Freire MO, Cho E, Jin D, Kook JK. Antimicrobial effect of linalool and α-terpineol against periodontopathic and cariogenic bacteria. Anaerobe. 2012;18:369-372.
112. Nguyen H, Campi EM, Jackson M, Roy W, Patti AF. Effect of oxidative deterioration on flavour and aroma components of lemon oil. Food Chemistry. 2009;112:388-393.